Mass Movement Processes in Metalline Creek, Southwest Yukon Territory

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ABSTRACT. In Metalline Creek, a small valley in the Kluane Range of the southwest Yukon Territory, the glacial deposits and the talus material have been affected by mass movement processes promoted by the occurrence of glacier ice and ice formed from avalanche snow. In addition, minor periglacial mass movement processes occur in the valley. Variations in the type of process are attributed to altitudinal changes, to aspect, and to change in the height of the regional snow line during the Neoglacial period.

RÉSUMÉ. *Processus de mouvements de masse près du ruisseau Metalline, dans le sud-ouest du territoire du Yukon.* Aux abords du ruisseau Metalline, dans une petite vallée de la chaîne de Kluane dans le sud-ouest du territoire du Yukon, les dépôts glaciaires et les matériaux de talus ont été affectés de mouvements de masse, eux-mêmes facilités par la présence de glace de glacier et de glace formée de neige d'avalanche. De plus, des processus mineurs de mouvements de masse périglaciaires agissent dans la vallée. Les variations dans les types de processus sont dues aux changements d'altitude, à l'orientation et aux changements de hauteur de la limite de la neige dans la région durant le Néoglaciaire.

РЕЗЮМЕ. *Процессы перемещения земляных масс в долине Металин-Крик, Юго-западный Юкон.* В Металин-Крик, небольшой долине горной системы Клуэйн, Юго-западный Юкон, ледниковые и делювиальные отложения подвержены массивному перемещению, вызванному распространением льда ледника и льда, образованного снегом лавин. В дополнение к этому процессу в долине происходит незначительное перигляциальное перемещение земляных масс. Различия в типах процессов связываются с высотными изменениями, обращением склонов и изменением уровня снеговой линии в новую ледниковую эпоху.

INTRODUCTION

In the St. Elias Mountains, situated in the southwest corner of the Yukon Territory (Fig. 1), there is an abundance of small valley environments within which are to be found large amounts of talus material and glacial deposits. These valleys have experienced periglacial conditions since deglaciation. There is widespread evidence for mass movement of the deposits, and the variety of morphological expressions of this mass movement is indicative of the operation of a wide range of processes. Detailed study of mass movement landforms in this area is particularly valuable in helping to clarify some of the problems which have arisen concerning the processes involved, and also in raising questions about some of the assumptions previously made during studies of mass movement.

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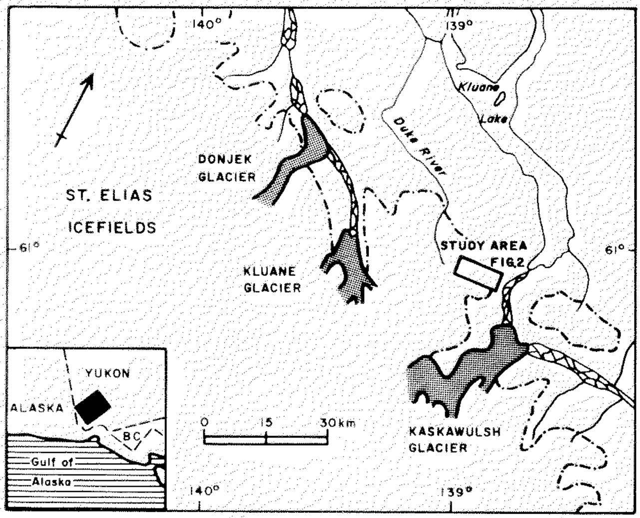

FIG. 1. Location of study area.

During the summer of 1973 a study was made of the valley of the Metalline Creek (Fig. 2) in the Kluane Range, 20 km to the west of the southern tip of Kluane Lake (see Fig. 1). This valley descends from an unnamed cirque glacier (to be referred to in this paper as the Metalline Glacier) at an elevation of 2,440 m to the point where it flows into Bullion Creek at 1,067 m. The valley is about 12 km long, and so it has an average gradient of 11.5%, which implies considerable changes in the climatic conditions down its length. There are two main tributaries

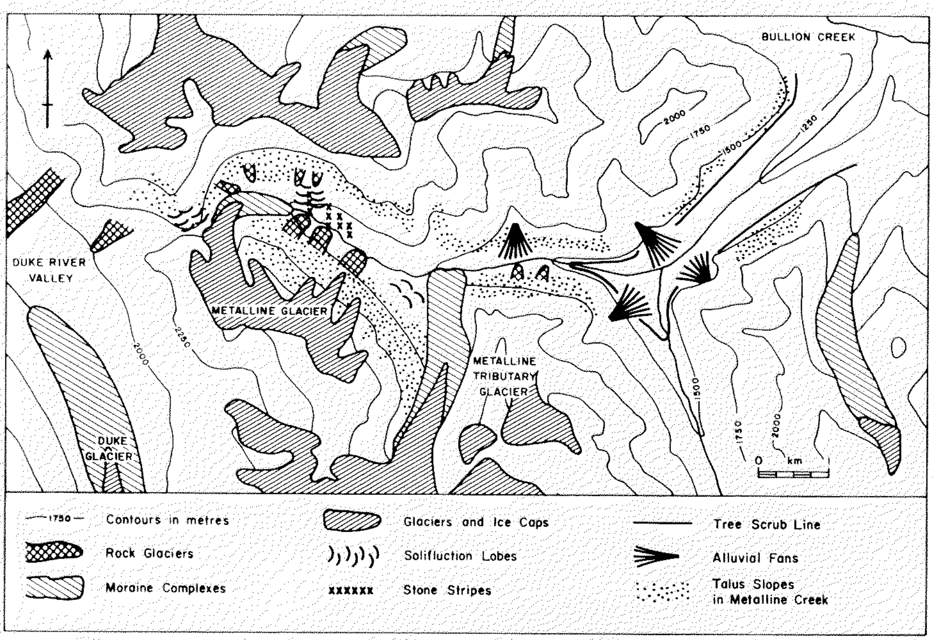

FIG. 2. Mass movement phenomena, Metalline Creek.

to the valley, the higher one containing a glacier (to be referred to as the Metalline Tributary Glacier) and a moraine formation which originates at about 2,400 m and falls in 3.25 km to the main valley at 1,750 m, and the lower one which is headed by a glacier-moraine complex and is not discussed in this paper.

Processes active, or formerly active, in the valley include the formation of talus, rock glaciers, solifluction terraces, patterned ground, stone steps and stone stripes. The terms commonly accepted in classification are used here to give an indication of the variability in the valley environment. It has proved difficult in this study to relate some of the forms in the valley to the mechanisms that are known to have been operative. Most of the forms identified in the valley would previously have been classed as rock glaciers, but the differences in morphology suggested that an approach on the basis of the cause of the movement would be more valuable to an understanding of the landforms.

TALUS AND ROCK GLACIERS

Along the sides of Metalline Creek there are a number of examples of a progression between talus and lobate 'talus rock glaciers' (Fig. 3) (Johnson 1974). The forms under discussion here have a highly-convex lobe, with a sharp concavity marking the junction of the talus slope and the lobate form. Very little research has been done, however, into whether there is a direct connection between talus-forming processes and movement processes such as produce 'rock glaciers'.

The problems which arise during a study of these forms are a) what determines whether movement characteristics will develop in the material at the base of a talus slope; b) what was the cause of this movement; and c) what was the main period of occurrence of the movement. Rapp (1959) among others, considered the extension of talus at the base of the main slope, but found the extension to be due to normal surface processes. Close observation of the talus shows that at present very little addition of material is occurring with respect to the mass of material in the slope, and very little modification is taking place in it due to the fall of rock onto the slope from exposed rock faces. In spite of its spectacular

FIG. 3. Avalanche rock glacier, Metalline Creek.

nature, such a fall of rock disturbs very little material on the talus surface and rarely accounts for more than very minor changes in the surface configuration of the form. The extent of the effect is dependent on the volume of falling material and the distance through which it falls. These conclusions are similar to those drawn from many other studies (for example: Gray 1971, 1972; Luckman 1972; Rapp 1960), in which data have been presented on present rates of talus accumulation by rockfall. Other evidence of the relative inactivity of talus-forming processes at the present can be found where the maximum Neoglacial position of the Metalline Glacier can be traced across a rock-covered slope. The situation is similar to that described by Rapp (1960) from Bjonahamma, Spitsbergen. The distinction between the lateral morainal material, derived from the cirque basin, and the talus slope above it is still clear despite the fact that in most places concerned there is very little change in the angle of slope. The break is marked by a small terrace form in at least one location. Only small amounts of material derived from the exposed rock face at the head of the talus occur on the lateral morainal material — indicating the relatively insignificant role of rockfall processes since the retreat of the glacier from its maximum Neoglacial position. This fact, together with dates obtained from the Donjek and Kaskawulsh Glaciers (Denton and Stuiver 1966, 1967) for the maximum Neoglacial moraines, would indicate about 400 years of relative absence of rockfall. A third source of evidence for this relative inactivity is the occurrence of solifluction lobes on talus slopes of up to 35° in angle. Very little new material is being added to these talus slopes from the free faces at their heads.

The only process which could be shown to be producing any significant change in the form of the talus slopes at present is the more complex activity of snow avalanches. The work of avalanches has been demonstrated by Gardner (1968), Gray (1971, 1972), Luckman (1971, 1972), Rapp (1959, 1960), amongst others. It is this process which is the main present-day source of material supply for the talus slopes. The concentration of snow and ice and its mode of movement are responsible for the erosion of large amounts of material from the exposed rock face, following upon which the mixture of snow and rock acts on the talus in a manner similar to the turbidity current in oceanic or lacustrine environments. This process is more effective with avalanches of wet snow in the spring than with ones of powdered snow. There was little evidence of other forms of mass movement such as were discussed by Gray (1971) and Rapp (1959), and which the latter found to be responsible for the extension forms.

The movement of avalanches down the talus can cover large areas rather than being concentrated in channels and, consequently, the erosive activity is widespread on the slope. The configurations of the termini of the flows also explain the presence of benches in the talus material or at the base of the slopes where the momentum is dissipated in a lobate terminus form. Other evidence discussed above suggests that little formative activity by rockfall has occurred in the valley since the maximum of the Neoglacial period.

The lower position of the regional snowline towards the maximum of the Neoglacial glacier activity would imply greater efficacy of the avalanche mechanism at this time, and this could explain the initial formation of the large lobate structure at the base of the slopes (Fig. 3). The flow of the main lobate form was due to the presence of ice produced from the avalanche snow mixed with the talus material. Avalanche termini which were examined consisted of a mixture of ice and rock throughout the depth of the flow, and most of the ice had survived in this talus through to the middle of the summer. The survival of ice in the interstices of rock glaciers has been widely discussed (*e.g.* Thompson 1962). It would suggest that the avalanche snow was an integral part of the formations produced during the period of greater efficacy of the avalanche mechanism. No ice core exposures were found on the landforms under discussion, but seepage of water around the frontal lobes throughout the study period was interpreted by the author as indicative of the existence of ice below the surface, especially as drainage through the form was limited in this period. Outcalt and Benedict (1965) concluded that the ice core of the valley-wall rock glaciers in the Colorado Front Range area was formed from avalanche snow, but they did not report the surface detail that occurs on the Metalline Creek forms.

Following the main period of formation of the lobes a period of less effective avalanching may have been responsible for the minor lobate structure on the surface of the landform. The minor lobes are localized in occurrence and do not in general conform to the orientation and structure of the main lobe, suggesting an origin due to superimposition on the main lobe rather than to its internal movement. The production of these surface forms probably occurred by a similar mechanism to that described by Rapp (1959) on the Tarfala landforms.

Apart from the surface lobes, the most prominent surface feature of the landforms is the depression between the main lobe and the base of the talus slope (Fig. 4). There is no evidence of any collapse structures such as would demonstrate

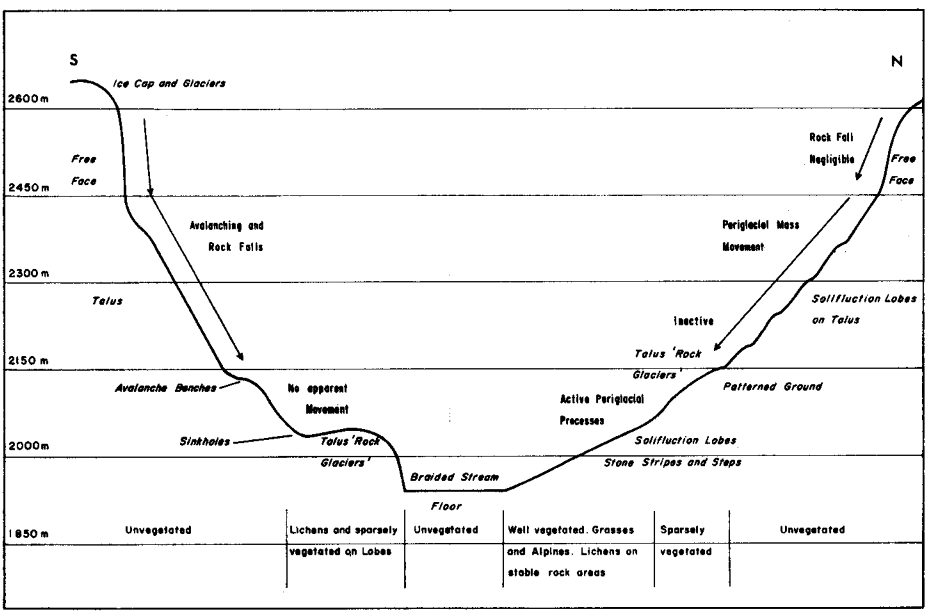

FIG. 4. Generalized cross section, Metalline Creek.

an origin in the melting of massive subsurface ice. The generally smooth profiles of these depressions is indicative of the movement away from the base of the talus slope and is also important to the drainage of the talus. Meltwater draining from the talus is concentrated into the depressions where it gives rise to subsurface courses which produce distinct sinkhole forms. No resurgences were found around the base of the main lobes, which indicates either that water was contributing to the ice core of the lobe or that it was seeping into Metalline Creek from beneath the surface level of the braided stream deposits.

The period of the Neoglacial maximum ice position, which can still be traced across one rock-covered slope (see above), would also have been a period of lower regional snow line. At such a period there would have been more frequent occurrences of avalanches in the Metalline Creek valley than there is at present. This would suggest that the main formation period of the 'talus rock glaciers' occurred at about the time of the advance to the maximum of the Neoglacial period and would also explain why the major forms in the valley are now relatively inactive. The forms on the north-facing side of the valley are much greater in size and extent than those on the south-facing side. This variation was probably caused by differences in the height of the snow line from north to south across the valley.

MORAINES AND 'MORAINE GLACIERS'

In the valley two moraine complexes were investigated, one at the terminus of the Metalline Glacier (see Fig. 5) and the other at the terminus of the Metalline Tributary Glacier. Both moraine complexes date from the maximum of the Neoglacial period up to the present day. At a number of locations on both of the moraines the core of glacier ice is exposed, and from the morphology of the rest of the forms it may be inferred that both complexes are completely ice cored. The two moraine complexes have, however, been affected by different processes since their deposition.

The Metalline Glacier moraine has mainly been affected by mass movement of the whole of the landform, and there is little activity of localized degradational

FIG. 5. Metalline Creek glacier and moraine glacier.

processes such as those reported from the Donjek Glacier moraine (Johnson 1971), whereas the moraine of the Metalline Tributary Glacier is affected by a variety of localized degradational processes and there is little evidence of mass movement of the whole form.

The moraine of the Metalline Tributary Glacier consists primarily of lateral moraine sequences of high and low level which grade into a complex terminal lobe. The ice core varies in depth below the surface from 1-2 m on parts of the terminal lobe to less than 0.25 m on the lower lateral moraine. Drainage water from the glacier has cut through and beneath the terminal lobe, contributing to a large extent to its degradation by promoting the movement of material over the ice core. At its maximum Neoglacial extent the glacier blocked off the upper part of Metalline Creek, and in recent time the stream from the upper valley has been actively eroding the terminus of the moraine complex. The localized slip of material that this erosion has promoted has maintained the stream in a constricted course against the north side of the valley.

In sheltered locations along the flanks of the moraine, nivation processes are responsible for degradation of the form. Slip of material due to drainage beneath snow patches is evident in these locations. There is no evidence for widespread mass movement. The morphology of the moraine is similar to that reported for ice-cored moraines in British Columbia and Alberta by Østrem and Arnold (1970), and the processes of degradation are similar to those discussed for the Donjek Glacier end moraines by Johnson (1971). The 760 m difference in altitude between the Donjek site and the Metalline Creek site, together with the more constricted form of the Metalline Creek valley and its tributary valleys, explains the longer duration of snow patches at the latter site and the consequent greater importance of nivation processes there. The snow patches occur especially in the channel between the lateral moraine and the valley side, and produce a concentration of meltwater in the surficial materials between the moraine ice core and the overlying snow, thus promoting downslope movement.

The Metalline Glacier moraine exhibits much less evidence of degradational processes. The meltwater stream draining the proglacial lake at the glacier terminus does not appear to promote erosion and, unlike the drainage stream of the Metalline Tributary Glacier, remains on the surface of the moraine. This contrast is probably due to the 400 m difference in elevation between the two moraines, the higher one being affected to a much greater extent by periglacial conditions. The Metalline Glacier moraine has an unstable steep frontal slope of up to 45° in angle and 30 m in height at its apex. The surface of the moraine consists of a series of concentric ridges and an associated pattern of frost cracks and surface periglacial phenomena which follow the curvature of the ridges. Three processes of movement could have been responsible for the formation of the flow ridges.

i) Continued flow of the glacier ice core beneath the ablation material.
ii) Sliding of the ablation material over a saturated ice-material interface.
iii) Movement within the ablation material under periglacial conditions.

Seepage of water occurred along the whole of the frontal slope of the moraine, indicating that some melting of the ice core was taking place. The extent of this seepage suggested that the interface between the ice and the ablation material could be saturated close to the terminus. Movement of the material over the ice could then have occurred on this lubricated layer. It is unlikely that conditions of saturation at the ice-till interface are more widespread, as permafrost occurs beneath the greater part of the moraine. Under these conditions general slippage at the ice-material interface is unlikely and would not, therefore, explain the formation of the flow ridges, but only the processes at the moraine terminus.

The processes resulting from the melt of the ice core are not the only ones which are affecting the terminus of the moraine. The terminus slope is unstable, is being maintained at angles up to 45°, and there is no evidence for a decrease in angle of slope and an increase in stability. The lateral streams have been eroding into the talus and talus glaciers along the valley sides as material off the moraine glacier accumulates in the stream courses. The continued migration of these streams indicates continued activity of the moraine glacier. If the movement of the material off the moraine glacier was due to the ablation of the ice core alone, a decreasing, or lower, angle of slope than the 40°-45° could be expected at the terminus of the form. The movement of material off the terminus together with the maintenance of an unstable angle of slope indicates that there is still some activity within the ice core of the moraine. This activity was probably, therefore, responsible for the formation of the flow ridges.

The above evidence for movement of the core as the causal process for the ridges is reinforced by the geometrical conformity of the ridges to the overall shape of the landform, reflecting the probable pattern of ice movement. This fact also indicates that slope-controlled periglacial mass movement was not responsible for the major flow ridges.

OTHER PERIGLACIAL MASS MOVEMENT

In addition to the mass movement phenomena discussed above there is also a variety of periglacial mass movement phenomena in the valley. Most of these are small-scale features of solifluction lobes, stone stripes and sorted circles, and are concentrated along the south-facing slope of Metalline Creek.

There is one major form derived from mass movement on the south-facing slope which does not appear to be related to the two types of mass movement discussed above. This consists of a large lobate structure located between two of the talus rock glacier forms. The boundary between the lobate form and the material of the talus rock glaciers is a well-defined shear zone which is similar to the shear zones developed along the margins of landslips. The total amount of displacement has not been great, and the rotation of material close to the shear zones indicates that the rate of movement has been slow. The surface of the form exhibits evidence of solifluction movement and suggests that the whole form may have been caused by such movement of material, which is much finer in composition than the coarser talus material.

Surface expression of solifluction movement occurs along both sides of the valley, but there is a greater concentration, and a greater degree of development, along the south-facing slope. Similar flow forms also occur in talus material with an angle of slope of 40° on the south-facing slope, and with an angle of slope of

25° to 30° on the south-facing slope in the col through to the Duke River valley (Fig. 2). The altitude of these talus solifluction lobes varies between 2,200 m and 2,690 m. The north-facing slopes retain their snow cover for a longer period in the spring, and are more prone to the effects of snow avalanches. Solifluction lobes are only developed therefore in areas protected from the avalanche mechanism.

Other periglacial indications of downslope movement, such as stone stripes and sorted steps, again occur primarily on the south-facing slopes on the better-vegetated areas close to the valley floor. The material not affected by mass movement on the south-facing slope also appears to have been subaerially exposed for a longer period of time than that elsewhere, as there is considerable development of lichen growth and the surfaces have been pitted by weathering processes.

DISCUSSION

The causes of these variations in mass movement mechanisms are simply the marked variations in the climatic conditions in the valley with changes in altitude and aspect (Fig. 4). The rapid change in climatic conditions causes marked differences in glacier ablation, snow cover ablation, the efficacy of avalanches and in the action of freeze thaw cycles, over very short distances. The differences in the rates of ablation at the termini of the two glaciers have resulted in the Metalline Tributary Glacier becoming detached from the main ice-cored terminal moraine complex, whereas at the Metalline Glacier the active glacier ice has always been in contact with the moraine complex. As a consequence, the movement of the Metalline Glacier has resulted in movement of the moraine. The contrast in the activity of degradational processes between the upper and lower moraine complexes emphasizes the importance of altitudinal position in the valley. Vegetation, which is only sparse on the moraines, does not influence the processes as it does on the Donjek moraine (Johnson 1971).

Below the moraine of the Metalline Tributary Glacier there are far fewer mass movement forms in the valley. The small rock glacier forms are inactive and occur only on the north-facing slope, and evidence of periglacial activity, even on the south-facing slope, is encountered far less frequently. There exists down the valley, therefore, an altitudinal range of mass movement forms.

Cross-valley variations are apparent in the extent of talus formation, in the occurrence of talus rock glaciers and in the occurrence of other periglacial mass movement forms. The controlling factors appear to be the variations in the net radiation regimes and the relative availability of meltwater. On the north-facing slope the production of meltwater is less, and there is a greater supply of avalanche snow to the lower talus slopes. Thus there is a much greater ice content of the lower talus, which has been responsible for the movement of the forms, and there is also a lower degree of occurrence of movement requiring freeze-thaw cycles. On the south-facing slopes greater temperature fluctuations together with the earlier melt of winter snow has resulted in greater efficacy of periglacial processes.

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