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Origin of rock glaciers

I should like to add some of my own observations on Arapaho Rock Glacier to those presented recently (Benedict, 1973; Carrara, 1973).

Despite the general rejection of Howe's (1909) original view of the formation of rock glaciers in the San Juan Mountains of Colorado, there seems to be little doubt that at least some rock-glacier material may be derived from rock falls or cliff falls. However, whether this material falls on top of an existing glacier or becomes a rock glacier by the addition of interstitial ice still seems to be a contentious issue (Whalley, 1974). There is considerable evidence showing that large-scale cliff-fall ($> 10^3 \text{ m}^3$) events are important geomorphic occurrences in mountainous areas (Rapp, 1960; Kjartansson, 1967; Abele, 1972). The way in which the debris accumulated on top of a glacier (as appears to be the case at Arapaho Rock Glacier) is important with respect to the past mass balance of the glacier.

As studies after the 1964 Alaskan earthquake have shown (Bull and Marangunic, 1968; Post, 1968), debris cover over a glacier can greatly modify its behaviour and this may be important in the formation of rock glaciers.

At Arapaho Rock Glacier, the cliff above the small Arapaho South Glacier and below South Arapaho Peak (Fig. 1) bears evidence of a cliff-fall scar. This can be seen from the difference in lichen cover across the cliff. Large vertical cracks and unstable blocks with a scanty (Gannett Peak age (Benedict, 1968)) lichen cover can be seen within this area. It is suggested, therefore, that some of the Arapaho Rock Glacier debris came from these cliffs as a "one-shot" event. Further evidence can be seen in Figure 1. There is an area on the right of the rock glacier where the predominant block size is much greater than the remaining area. Examination in the field and with air-photograph enlargements bears this out. The lichen cover on most of the large blocks on the rock-glacier surface is of two kinds. Some surfaces have a relatively heavy cover of *Rhizocarpon geographicum* sp. and *Lecanora thomsonii* which has been cut across by breakage of the apparently original surface. Adjacent surfaces usually only have a very sparse cover of *R. geographicum* but somewhat more *L. thomsonii*. Though no detailed investigation could be undertaken, it appears that the heavy cover of lichen relates to the original cliff surface and the sparse areas to subsequent lichen colonization after the cliff fall, the latter being of probable Gannett Peak age.

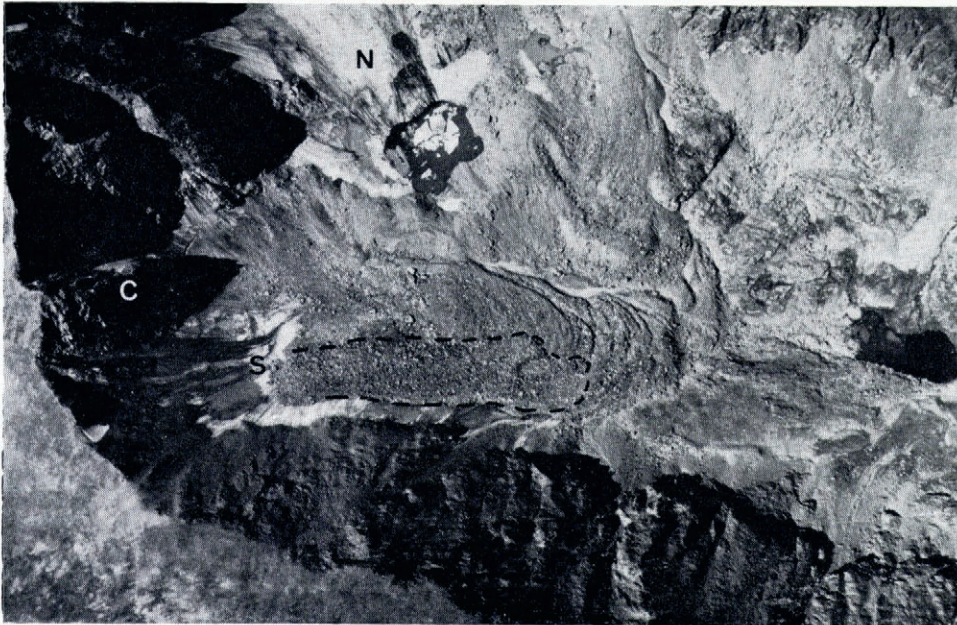


Fig. 1. Arapaho Rock Glacier with the area of larger boulders on the surface delimited on the true right. Arapaho South (S) and North (N) Glaciers are marked together with South Arapaho Peak and the cliff from which the fall is thought to have occurred (C). (Photograph by Falcon Air Maps, Denver, Colorado, 24 September 1963; 3120, negative 75 by courtesy of Dr D. D. MacPhail, NSF project GP-1484.)

The large size of the blocks on the surface in one area can also be directly compared with large blocks below steep rock buttresses in the surrounding area (Fig. 1). A χ^2 test showed that this is a highly significant correlation. Similar size distribution of blocks from cliff falls can be found in other parts of the world; they contrast with the size of debris which accumulates below gullies as a result of minor rock falls (Fig. 1). Though this evidence suggests that only a part of the rock-glacier debris may have come from a single, relatively large event, it does at least give an idea as to how rock-glacier material may build up.

Arapaho (north) Glacier (Outcalt and MacPhail, 1965) is the largest in the Colorado Front Range (c. 0.2 km²). The extent of ice traced below Arapaho Rock Glacier (Benedict, 1973) shows that this glacier was once at least as extensive as the north glacier. The fact that none of the other rock glaciers in the Colorado Front Range appears to have a "one-shot" origin for much of their debris makes it possible that the original Arapaho South Glacier was greatly modified by the cliff fall.

These ideas tend to support a modified view of that proposed by Benedict (1973): that Arapaho Rock Glacier at least was formed at a time of greater glacier extent than at present and that this may be related to a higher rate of debris production from cirque headwalls in the past.

The process of debris accumulation by shear-plane deformation as envisaged by Carrara (1973) is a possibility, though investigations, e.g. Hooke (1970), suggest a deforming zone rather than a plane. General observations in temperate glaciers have generally failed to show evidence of either shear planes or deforming zones bringing debris to the surface. The exception to this appears to be on thin retreating tongues where the winter "cold wave" can freeze material to the sole of the glacier. This debris is then brought to the surface very near (5–20 m) the ice margin. This process has also recently been suggested by Boulton (1972). An accumulating thickness of debris would progressively restrict this mechanism so that its overall importance would be very limited.

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