Progress on Rock Glacier Research

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INTRODUCTION

This report is an account of research progress on rock glaciers of Afghanistan, Colorado, and Utah. Because of the preliminary nature of this work, some speculation is present; nevertheless, we think there is evidence for each major, new point expressed. The main thesis of our work is that rock glaciers are polygenetic and appear to be part of a continuum of similar landforms grading morphologically and, presumably, mechanically from one type to another type.

DEFINITION AND CHARACTERISTICS OF ROCK GLACIERS

Definitions of rock glaciers are diverse (Wahrhaftig and Cox, 1959; Potter, 1972; White, 1976; Barsch, 1977; and others), but most researchers consider these landforms to be lobate or tongue-shaped bodies of rock fragments with internal ice, which move slowly downslope to produce a tongue-shaped feature with a steep front and sides near the angle of repose. Presumably because of the lack of basal slip under the front along with an upward increase in flow velocity, the front is continually oversteepened. These steep fronts have been observed on some debris-covered ice glaciers and along the base of some talus slopes. These observations, together with limited but important subsurface investigations, have led to differentiation of ice-cored and ice-cemented types of rock glaciers (Potter, 1972). Barsch (1977) suggests that the ice-cored type can be derived either from glacier ice or segregated ice of permafrost origin. He also noted a difference between velocity measurements of ice-cored and ice-cemented types which is an order of magnitude smaller than between ice-cored rock glaciers and actual ice glaciers. Therefore, he feels both types of rock glacier appear to have a similar rheology and the ice-cored rock glacier is not a transitional form between glaciers and rock glaciers. We interpret Barsch to mean this only in a very narrow, rheological or mechanical sense because the statement cannot be supported when considering histories of genesis of a wide variety of rock glaciers. Also, velocity measurements are not yet available from both types or within various areas of rock glaciers. In fact, much evidence suggests a continuum between ice-cored rock glaciers and actual ice glaciers. In this model, increased ablation of a glacier produces a massive morainal cover, the basal shear resistance of which ultimately exceeds the ability of the ice to move it, resulting in velocity increases upward away from the resistance and producing a steep front at the angle of repose. Whether this upward velocity increase is entirely a regular-flow phenomenon or the result of multiple shear surfaces is presently unknown.

It is likely also that the ice-cored and ice-cemented rock glaciers are transitional because of the similarities in morphology and velocity; Barsch (1977) considers it unnecessary to distinguish between the two types. In spite of the lack of confirmatory subsurface observations, Vernon and Hughes (1966) and White (1976) feel that surface morphology can be used to distinguish between debris-covered glaciers, ice-cored rock glaciers, and ice-cemented rock glaciers. These researchers are certainly correct in some obvious cases, but we suspect that the situation is not nearly so simple and that in fact the "tyranny of the pigeonhole" is probably operative.

THE STUDY CONTEXT

In Afghanistan observations, together with the detailed work of Grotzbach (1965) and Grotzbach and Rathjens (1969), show a transition between ice glaciers and rock glaciers. The extensive recent glacial retreat so evident throughout the Hindu Kush (Braslau, 1974; Porter, 1970; Gilbert, et al., 1969) has produced large masses of loose debris at glacial fronts. These debris-covered glaciers are characterized by a small glacier in the upper part with the "porridge-like" surface morphology and the steep front and sides of the rock glacier in the lower region. In some adjacent cirques, glacial wastage has been great enough to eliminate completely the upper ice mass at the surface and has left only the rock glacier form.

The Koh-i-Baba range of central Afghanistan has plentiful small glaciers and tongue-shaped boulder deposits which are shown on maps at a scale of 1:100,000. These boulder deposits may be debris-covered glaciers with exposed ice at their heads or they may be rock glaciers without surficial ice. Eighteen small glaciers occur, averaging about 0.5 km^2 in area and having north exposures. The lowest elevation of exposed glacial ice ranges from 4075m to 4657m, with an average of 4365m. All glaciers terminate in large tongue-shaped boulder deposits; four have one or more circular depressions on them which are referred to as "kettles." These boulder deposits could be classified as debris-covered glaciers, ice-cored moraines, or ice-cored rock glaciers, depending upon certain fine distinctions made between relative activity or inactivity, steep front or gentle front, and general surface morphologic differences. The lowest elevation of these landforms ranges from 3850m to 4600m with a mean of 4232m.

In addition to the above glaciers, 35 other boulder deposits which do not have surficial ice exposed at their heads are also present. Aerial reconnaissance of these features have shown clearly that because of their surface morphology most workers would map them as rock glaciers. Three of these features have large kettles on them which suggest the presence of a meltwater source. Twenty-eight have north exposures; four face towards the east; and there is one each in the south and west quadrants. The lowest elevation of these forms ranges from 3650m to 4425m, with a mean of 4078m.

The wide range in overlap of altitude of all these features, combined with their similar morphology, obviously supports the hypothesis of genetic linkage between the forms. When a classification scheme can be applied only in an arbitrary fashion, the usefulness of the scheme is much reduced. In this instance, the lack of a clear distinction demonstrates morphological similarities and, therefore, suggests mechanical similarities as well.

Our recent observations on the High Plateaus and La Sal Range of Utah, and Mt. Mestas in Colorado suggest an additional complicating factor in the genesis and movement of rock glaciers (Giardino, Shroder and Lawson, in press). In these mountainous areas, strongly jointed igneous rock in flows, laccoliths, and stocks overlies highly unstable shales and other friable fine clastics. High rubble production from the igneous rock creates a condition of copious, open-structured debris in which cold air drainage and snow-melt create interstitial ice. This initiates the permafrost necessary for "true" rock glacier development. Because of the unstable substrate, however, landslips are ubiquitous in these areas and are mapped as such by a wide variety of workers (Flint and Denny, 1958; Richmond, 1962; Carter and Gualtieri, 1958; Weir and Puffett, 1960). Classic types of rock glaciers are also characteristic of these areas and have been mapped and described on the basis of obvious characteristic surface morphology and observations of internal ice content by Patton (1910), Johnson (1967), Richmond (1962), and Giardino (1976). Nevertheless, our field observations of chaotic landslip phenomena in unstable fine clastics within what others have mapped as rock glaciers show clearly that ice-cemented rock glaciers (and perhaps also ice-cored rock glaciers by analogy) can have basal slip at least in part and in certain cases may resemble landslips more than rock glaciers.

DISCUSSION

The above observations are given added credence by the probable association of some rock glaciers with basal melt water. Barsch (1975) noted a greater movement of the Murte rock glacier in the summertime and discovered a definite relation between high summer temperature and high movement. The probable association with meltwater is obvious. The work of one of us (Shroder, 1978) shows a strong relation between increased movement and increased precipitation in an ice-cemented boulder deposit. These observations suggest that some rock-glacier-like bodies may move in the manner of some landslips: hydrostatic pressure caught beneath an impermeable upper layer (ice in this case) reducing basal shear resistance and allowing movement.

Until more borings are undertaken and a variety of subsurface measurements of movement obtained, the actual rheology will remain problematic (Johnson, 1973; Barsch, 1977b). White (1976) notes evidence of turbulent flow in his observation of individual movements of surficial boulders. A variety of causes could be responsible, including shear planes, irregular settling due to melting, or variable flow of some yet undetermined nature. Irregular patterns of surface deformation and erratic movements of trees on boulder deposit in the High Plateaus (Shroder, 1978) help confirm White's observations and further suggest deformation as discontinuous basal slip primarily in unfrozen fine clastics. On the other hand, our general observations on the rock glaciers of Mt. Mestas, Colorado, coupled with fabric analysis show highly regular patterns of transverse ridges and furrows with aligned clasts, which suggest local non-turbulent flow. Whether or not this is the result of shear planes, as has been discussed by Carrera (1973), or is some as yet undefined laminar flow-like phenomenon, is unknown.

On the basis of observations, we have constructed a preliminary model of what we perceive to be an interlinked system of glacier, rock glacier, and landslip. The model incorporates a number of subsystems which provide inputs in various ways to produce the various landforms. We presume that each subsystem will be further refined by us and others so that ultimately a clearer picture will emerge from the complex phenomena which the principle of convergence seems to have caused.

The cliff subsystem includes elements of cliff height, cliff width, cliff angle, basal slope, lithology, exposure, angle of dip of bedrock, vegetation cover, infiltration rate, fluid pore pressure of the substrate. These factors partly control the supply of strongly or poorly consolidated bedrock to the rock materials' subsystem. The external environment subsystem controls the eolian transport of fine clastics to the rock materials' subsystem.

The microclimate subsystem of the system includes elements of aspect, altitude, latitude, cloud cover, and prevailing wind, which provide energy control to the climate subsystem thus providing increases or decreases in ice, water, and freeze-thaw pressure to the rock materials' subsystem and the matrix and core subsystem.

The rock materials' subsystem is the group of processes which control the production of debris supplied to the rock fragment subsystem and the matrix and core subsystem. These processes include landslips, debris falls (talus), snow avalanches, slush flows, stream flow, and glaciers. The rock fragment subsystem consists of interstitial ice cement, an ice core, and fine clastics. All of the rock fragments, matrix, or core are then subject to various stress inputs. These are the weight of the rock fragments upon the fine clastics, water in the fine clastics, water pressure beneath ice, thaw and freeze of the ice cement, weight of rock fragments on the ice cement or ice core, and/or weight of the ice core.

The resulting strain produces active debris-covered glaciers, ice-cored rock glaciers, ice-cemented rock glaciers, or slow rock fragment flows (Shroder, 1973). When these features are inactive, it is often very difficult to determine the former mode of strain, in which case we refer to the phenomenon simply as a boulder deposit.

Further work will be required to evaluate the ideas expressed above and produce a more detailed explanation. In the interim we caution an approach based upon ideas of polygenesis and systems analysis of the resulting complexity. In our experience there is just too much variation between rock glaciers of the world to allow the application of only a few ideas about genesis and movement.

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