Reports

Bentonite Debris Flows in Northern Alaska

Abstract. *Seasonal freezing and thawing and the extreme cold of the arctic lead to the development of a variety of characteristic geomorphic features. A new one, bentonite debris flow channels, has been identified near Umiat, Alaska. These flows form when bentonite-rich Cretaceous shales are exposed to surface water on slopes of 5 to 30 degrees. The characteristic landform developed is a U-shaped channel 1 to 2 meters deep and from 8 to 10 meters in width. The channel shows a fluted floor and walls and is commonly flanked by a levee. The flow material is apparently derived from the entire surface of the head portions of associated gullies. When this surface layer hydrates during snowmelt and runoff or during prolonged rain, the bentonite imbibes water and swells to a point at which its viscosity is lowered sufficiently to initiate creep or viscous flow.*

The geomorphic processes associated with the extreme environments of the arctic lead to a number of unique and interesting landforms such as patterned ground, the pingoes, and the thermokarst lakes of the coastal plains, altiplanation terraces in the mountains, and distinctive solifluction lobes on the hillsides. Herein is a description of another distinctive geomorphic feature believed to be unique to the arctic environment. For want of a better term, we propose, in harmony with the classifications of Parizek and Woodruff (*1*) and Ritchie (*2*), that these features be called bentonite debris flows.

The conditions necessary for the development of these distinctive landslides appear to be: (i) the presence of easily hydrated interbedded bentonite deposits which are not extensively vegetated; (ii) relief exceeding about 100 m, with slopes of 5 to 30 degrees or more; and (iii) water in moderate quantities for at least several weeks' duration. An important factor may be the water-logged nature of the adjacent upland scarps, in that permafrost at shallow depths prevents downward percolation of surface water. These conditions are met in many localities in the northern Foothills Province of the Arctic Slope both east and west of the Colville River where thick bentonitic shales of Cretaceous age are of widespread occurrence (68°30′ to 70°N; 144° to 166°W).

On the cover (*3*) is a view of the north bank of the Colville River about 30 km northeast of Umiat, Alaska, where bentonite debris flows are numerous and active annually during the arctic summer. A portion of the Prince Creek Formation is shown; it is exposed in a 125-m bluff that forms the west bank of the Colville River. Montmorillonite of high purity occurs throughout this formation in numerous well-defined beds up to slightly more than 30 cm thick; these are interspersed among much thicker (250-m) zones of bentonitic shale, silt, and tuff that are interstratified in turn with occasional beds of sandstone and coal (*4*). In the section of bluff shown on the cover, some 20 flow channels of varying ages and sizes are observed. The channels tend to be symmetrical and U-shaped. At their widest points they are typically 1 to 2 m deep and from 8 to 10 m across.

In the courses of these flows, three zones are distinguishable: (i) the upper reach, sometimes including tributary sources of the swollen bentonite; (ii) a distinct middle zone, through which the debris is transported; and (iii) the lower reach or mouth, where the viscous bentonite finally comes to rest, discharges out over earlier accumulations, or is dumped into the river (*5*). The middle portion is conspicuous in the flows shown on the cover. Here, the U-shaped channel is well developed and flanked by lateral levees composed of dried aggregates of broken clay. The floor and walls of the channels are scoured smooth and fluted, much like that typical of glacial polish on bedrock.

In the lower reach of a typical flow, the channel has become clogged with bentonite in various stages of hydration ranging from fluid gel underlying the mass to the dried, blocky fragments shown by Fig. 1. Solidification of the surface layer due to drying leads to the fragmentation of material and the building up of levees and a broken surface, similar to that of a lava flow. Grasses, sedges, mosses, and eventually shrubs of willow and alder vegetate the older channels, making it easy to distinguish active from dormant channels. It is not known, in general, how long a given channel remains active; however many channels seem to be active for more than one season.

Fig. 1. The lower reach of a typical bentonite debris flow near Umiat, Alaska.

The nearly pure bentonite beds found in this locality are derived from volcanic tuff of Cretaceous age. Some of the characteristics typical of the material making up these beds have been described (*6*); one property that was not mentioned, however, is the unusual ability of this bentonite to imbibe water and swell rapidly. Most bentonites when wetted tend to be self-sealing; that is, they swell rapidly at the point of contact with water, but in swelling they become highly impermeable to water so that it may take several days for a wetting front to advance significantly. Umiat bentonite is different in that even large fragments, when put in contact with water, imbibe and swell rapidly. Undoubtedly the flows shown on the cover are greatly facilitated by this unusual ability of Umiat bentonite to imbibe water, but the degree to which this property governs the occurrence of flows like those shown in the cover photo is as yet unknown.

Earth-flow levees and flow lobes similar in many respects to those observed along the Colville River have been described at Franklin Bluffs (*7*) overlooking the Sagavanirktok River, at Schrader Lake (*8*), and also in the St. Elias Mountains. A survey of the 1948 aerial photography of northern Alaska brought to light numerous other occurrences of slides having the same distinctive morphology of those shown on the cover. In view of the peculiar combination of circumstances required to initiate the slides along the Colville, it is likely that the existence of similar slides in nearby localities is indicative of exposed bentonitic sediments. We believe that smooth-sided, leveed, U-shaped mud-flow channels of the type described may be sufficiently distinctive on aerial photographs to differentiate bentonite debris flows from other debris and mud flows with high reliability. In view of the probability that development of the newly discovered petroleum reserves will stimulate plans for the construction of roads, pipelines, and the like in Northern Alaska, where unstable bentonitic slopes present a widespread construction hazard, the ability to locate and avoid these hazards is likely to become valuable.

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References and Notes

1. E. J. Parizek and J. F. Woodruff, *J. Geol.* **65**, 653 (1957).
2. A. M. Ritchie, *Highway Research Board Spec. Rep. No. 29, NAS-NRC Publ. No. 944* (1958), p. 48.
3. Aerial oblique photo, courtesy of T. Marlar, acquired with the assistance of the Naval Arctic Research Laboratory, Barrow, Alaska.
4. W. P. Brosge and C. L. Whittington, *U.S. Geol. Surv. Prof. Pap. No. 303-H* (1966), part 3, p. 501.
5. The coalescence of tributary sources is in some respects reminiscent of the mud glacier on the Isle of Wight, described by R. F. Moorman [*Nat. Hist. Soc. Proc.* **3**, 148 (1940)].
6. D. M. Anderson and R. C. Reynolds, *Amer. Mineral.* **51**, 1443 (1966).
7. G. S. Anderson and K. M. Hussey, *Iowa Acad. Sci. Proc.* **69**, 310 (1962).
8. G. W. Holmes and C. R. Lewis, *U.S. Geological Survey Bull. No. 1201-B* (1965).
9. R. P. Sharp, *J. Geomorphol.* **5**, 222 (1942).
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Scanning Electron Microscopy of Evaporating Ice

Abstract. *Direct observation of evaporating ice with a scanning electron microscope indicates that the surfaces of single-crystal and polycrystalline ice are markedly different. In specimens of single-crystal ice the crystal planes are revealed by evaporation, whereas polycrystalline ice develops a fibrous surface.*

Odencrantz *et al.* (*1*) have observed fine whiskers on the surface of ice crystals upon examination by a replication technique with a scanning electron microscope. These whiskers, being less than a micron thick, might be expected to fracture as the result of a collision between two ice crystals or an ice crystal and a water drop within a cloud. The small splinters thus produced could act as new ice nuclei. If the observed whiskers are a feature of the surfaces of the ice crystals and not an artifact produced by the experimental technique, the results are important in meteorology. Studies of replicas of ice crystals by means of a scanning electron microscope (*2*) indicate that the structure of the replica produced depends strongly upon the material that forms it, and that faithful reproduction of the ice surface on a microscopic scale is extremely difficult to achieve. The replicating material may either fail to conform to the ice surface or it may severely modify the ice surface. Optical microscopy is unsuited for the observation of such fine structure as that reported by Odencrantz *et al.* because of the limit of resolution and the small depth of field. Therefore I studied the ice surface directly with a scanning electron microscope without the aid of replicas.

The specimen chamber of a scanning electron microscope must be maintained at a pressure of less than 10^{-4} torr, and any specimen must have a surface electrical conductivity that is high enough to prevent charging by the electron beam. Since these two conditions can be fulfilled for an ice specimen, direct observation of the surface of ice is possible. In order to reduce the vapor pressure of the ice sufficiently to achieve the required vacuum, the specimen must be cooled. This was done by mounting the specimens on thermally insulating supports and relying upon the heat of vaporization to lower the temperature (*3*). The revealed surface structure of evaporating ice differs from the surface structure in a saturated environment. Evaporation reveals details of the underlying structure that would not be apparent in a saturated environment. All samples were made from water that had been distilled three times and had an impurity content of not more than 5 parts per million. Polycrystalline specimens were made by freezing water droplets (2 mm in diameter) on the end of glass capillary tubes in a refrigerator maintained at $-20°C$. Single-crystal samples were cut from large crystals grown by the method of Siksna (*4*); crystals of various habits were grown in a diffusion chamber.

Immediately after insertion in the microscope, the cut single-crystal samples exhibit a smooth, although not flat, surface. As evaporation continues, the surface becomes etched, and on the surfaces at an angle to the basal plane steps appear as a result of the more rapid evaporation of the prismatic faces. Figure 1 shows such a surface after evaporation for 30 minutes. The basal plane is the most prominent structural feature of the ice crystal, but prismatic planes are sometimes seen. Surfaces in the direction of the basal plane are generally featureless, although in some samples lines of hexagonal etch pits appear.