

# RATE OF COLLAPSE OF SNOW-BANK KAMES IN ADAMS INLET, SOUTHEASTERN ALASKA<sup>1, 2</sup>

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## ABSTRACT

Mounds formed by the differential ablation of snow covered by varied thicknesses of sand that has slumped onto a snow bank from an adjacent bluff are here named snow-bank kames. The rate of collapse of these mounds, calculated from temperature observations in the sand and using the temperature-gradient method, was  $2.2 \text{ cm day}^{-1}$ . The observed rate of lowering for these mounds was between  $2.6$  and  $3.2 \text{ cm day}^{-1}$ . The difference in rates may be due to mechanisms of heat transfer other than conduction.

## INTRODUCTION

Hummocks or hills of debris, formed by the differential ablation of ice buried by sorted glacial drift, have been termed kames. In Adams Inlet, Alaska (fig. 1, inset), several hummocks were formed by the differential ablation of snow covered by unconsolidated material that had collapsed onto a snow bank. Mounds produced in this manner are similar in form to kames, although genetically different; the term snow-bank kames is here proposed for these mounds.

A related feature is the protalus rampart (Bryan, 1934), which is a ridge formed at the base of a slope by talus that has slid down a sloping snow or ice bank. The snow-bank kames in Adams Inlet differ from a protalus rampart in that the snow did not act as a transporting agent for the debris. Instead the debris apparently collapsed directly onto the snow at the base of the bluff. It is conceivable that parts of a protalus rampart could develop hummocks if the talus were deposited directly on the snow, and if the talus provided sufficient insulation.

The purpose of this study was to determine the rate of collapse of snow-bank kames in the Adams inlet area, both by the rate of melting of the snow bank and by measurement of the surface lowering. The observations on the snow-bank kames were made in the summers of 1966 and 1967. To achieve the first purpose, soil temperatures in one of the mounds were recorded during the 1967 field season. In addition, meteorological observations were made at the base camp, 3.3 km to the northeast of the kames during the 1966 and 1967 field seasons. The weather in the area of the kames was approximately the same as that at base camp, although there were fewer hours of sunshine and lower winds near the kames because of the greater relief. A summary of the meteorological observations and a description of the climate are given by McKenzie (1969).

## SNOW-BANK KAMES

The mounds referred to here as snow-bank kames covered an area of approximately  $2000 \text{ m}^2$  at the base of a 100-m-high bluff of sand and gravel. A fine-grained blocky brown sand covered the snow in a layer that was about 0.5 m thick on the sides of the mounds, and slightly thicker in the depressions (fig. 2).

Snow was exposed beneath the sand in several places (fig. 1), including a cave that led beneath the kames. A stream flowed from the cave during both summer seasons, and an "outwash" fan with an average slope of  $16^\circ$  was formed in front of the kames. Maximum snow thickness in 1966 was 4 m. Near the base of the snow there was a 0.6-m-thick layer of frozen sand that had probably been deposited early in the winter season. Part of the  $32^\circ$  slope of the talus behind the area of

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mounds was also underlain by snow. This fact was revealed by the crescentic collapse fractures surrounding a 4-m-wide depression in the talus slope.

Between the summers of 1966 and 1967, a decline in the surface elevation and relief of the snow-bank kame field was noted. This was mainly the result of ablation of the underlying snow; however, some leveling of the surface was also caused by wind. In the stable portions of the field, where all the snow had melted, a few small hummocks remained. During this period, the area of outwash advanced 15 to 20 m into the snow-bank kame field (fig. 1, dashed line).

#### RATE OF COLLAPSE

The rate of collapse of the mounds was calculated from temperature measure-

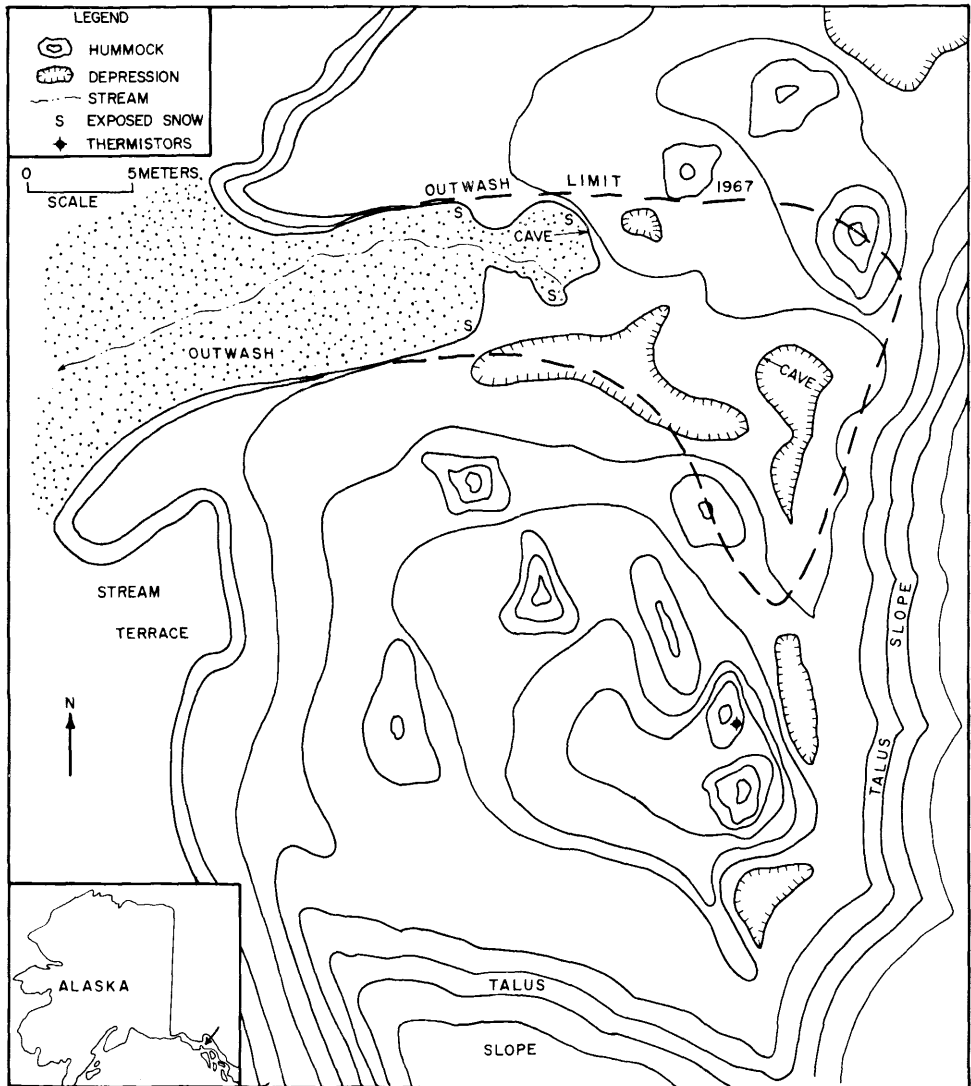


FIGURE 1. Sketch-map of snow-bank kames in Adams Inlet in 1966. Form lines outline hummocks and depressions. The maximum relief is about 5 m.

ments using thermistors in the sand of one of the snow-bank kames. A YSI Tele-thermometer readable to  $\pm 0.2^\circ\text{C}$  and accurate to  $\pm 0.5^\circ\text{C}$  was used. The thermistors of the Tele-thermometer were placed at depths of 3, 10, 20, 41, and 53 cm, the lowest being at the sand-snow interface. Readings were made every hour on the hour for a 27-hour period on June 23-24, 1967. The range of the



FIGURE 2. Hummock of blocky sand over snow. In 50 days this kame had collapsed to a slight depression.

readings is given in Table 1. At 41 cm below the surface, the maximum temperature occurred at 0400 hours. This was 10 hours after the maximum temperature was reached 3 cm below the top surface of the sand. The weather during the observations was mostly clear, although there had been 0.7 cm of rain during the preceding 25 hours.

The rate of conduction of heat to the snow was determined by the temperature-gradient method (Staley and Gerhardt, 1958). The following formula was used to calculate the heat flow:

$$S = \lambda \frac{dT}{dZ},$$

where  $\lambda$  is the thermal conductivity for the sand,  $\frac{dT}{dZ}$  is the temperature gradient with depth, and  $S$  is the heat flow. The average temperature gradient between

TABLE 1

*Range of temperatures at given depths in a snow-bank kame between 1200 hours 23 June and 1500 hours 24 June, 1967*

Depth of thermistors (cm)	Range of temperatures ( $^\circ\text{C}$ )
3	7.4-17.2
10	8.0-15.1
20	6.0- 8.9
41	2.3- 3.1
53 (sand-snow interface)	0.1- 0.7

the lowest two thermistors in the cover of sand was  $0.21^{\circ}\text{C cm}^{-1}$ . Determination of the conductivity of the sand in the snow-bank kames was not made directly since apparatus for this determination was not available in the field. Only an estimate of the conductivity is possible, done by comparing the properties of the sand studied to those of materials for which published conductivities exist.

Kersten (1966) found that the conductivity of a soil varies with the grain size, moisture content, density, composition, temperature, and state of the moisture (solid or liquid). He also noted that the three most important factors controlling the coefficient of thermal conductivity are grain size, moisture content, and dry density. The sand in the snow-bank kames has a grain-size distribution with 94 percent in the 2.0–0.5-mm range and 6 percent less than 0.5 mm, and a moisture content of 13 percent by weight. The Lowell sand, one of the many materials studied by Kersten (1966), has a similar grain-size distribution, with 100 percent being within the 2.0–0.5 mm range. According to Kersten's graphs and tables, frozen Lowell sand at the same moisture content as the sand in this study has a thermal conductivity of  $5.8 \times 10^{-3} \text{ cal cm}^{-1} \text{ sec}^{-1} \text{ }^{\circ}\text{C}^{-1}$ . Using Kersten's correction for unfrozen material, the conductivity of the Lowell sand would be  $4.5 \times 10^{-3} \text{ cal cm}^{-1} \text{ sec}^{-1} \text{ }^{\circ}\text{C}^{-1}$ , which is probably close to the average value of the conductivity of the sand in the snow-bank kames.

The measured density of the snow beneath the snow-bank kames is  $0.53 \text{ g cm}^{-3}$ . Thus  $42 \text{ cal cm}^{-2}$  would be required to lower the surface of the buried snow bank 1 cm. Under the observed conditions, the heat flow by conduction to the surface of the snow would be  $92 \text{ cal day}^{-1}$ , so the surface of the snow-bank kame would be lowered at the rate of  $2.2 \text{ cm day}^{-1}$ .

No direct measurements of the surface lowering of the snow-bank kames were made during the 1967 season, although, during the 1966 field season, a 2-m-high mound (fig. 2) was observed to lower to the level of the surrounding sand in a period of 50 days. In that case, the thickness of the sand cover varied from 40 to 70 cm, which is about the same as the cover over the snow-bank kame with the thermistors. During 1966, the lowering of the surface of the snow by 130 to 160 cm was measured at a rate of about 2.6 to  $3.2 \text{ cm day}^{-1}$ . This is close to the calculated rate of ablation by conduction given earlier.

#### DISCUSSION

One of the major uncertainties in the calculated rate of ablation is the figure used for the conductivity of the sand. This uncertainty could be decreased by measuring the conductivity of the sand *in situ* when the temperature readings are taken. The heat flow could also be measured directly using heat-flow plates. However this method, like the temperature-gradient method, also has several problems (Philip, 1961), one of which is knowing the conductivity of the medium in which the plates are to be used.

In addition to the conductivity problem and errors in measurements, the difference between observed and calculated rates of surface lowering may be due to other mechanisms of heat transfer. Such mechanisms include convection, radiation, percolating precipitation, and phase changes, all of which would increase the rate of melting and may account for the higher observed rate of surface lowering.

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