OBSERVATIONS OF A SLUSHFLOW ON A LOW-ANGLE SLOPE IN WEST KARAKOL VALLEY, KIRGIZSTAN, MIDDLE ASIA

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ABSTRACT

A rare observation of a slushflow that released on a low-angle slope was made on 16 May, 1992 in the West Karakol Valley, southern Kirgiz Range, Kirgizstan. The slushflow released on a short slope of 6° and traveled a distance of 140 m over a slope with a mean angle of 3° with a mean channel width of about 4 m. Total volume of snow and slush transported by the slide was 224 m^3 with an estimated mass of 208,000 kg. Estimated velocity of the the flow was 5 m s^{-1}. Meteorological conditions preceding the event were mixed weather with warm temperatures and both heavy cloud cover and clear skies. The day before the event rain fell for about 6 hours. Mixed rain and snow precipitation continued through the preceding night accompanied by steady high winds. The day of the release was hot with overcast skies and light rain. The snowpack was saturated to the surface at the time of the release with visible surface water flow.

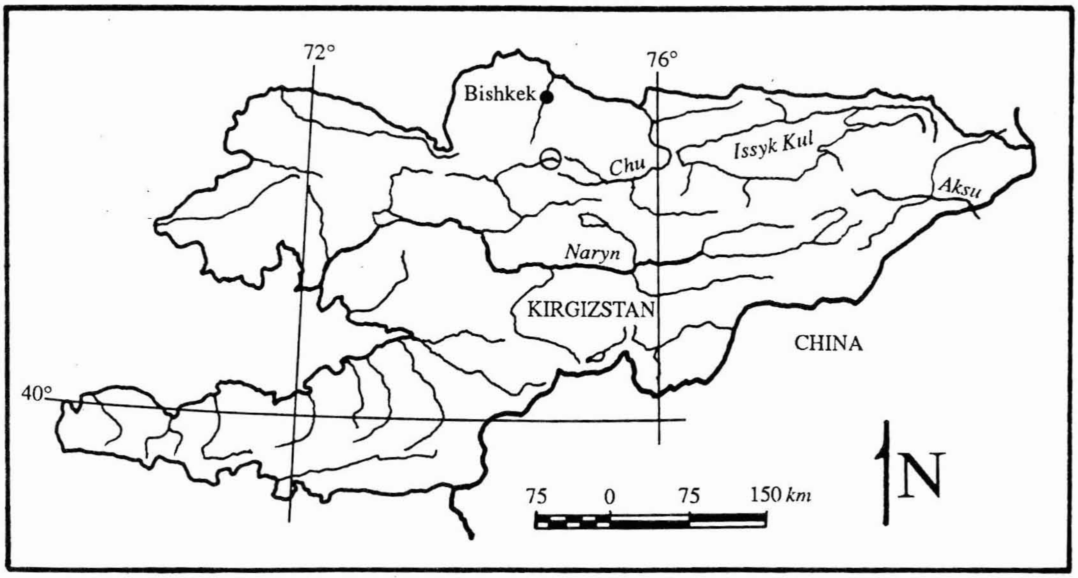

FIGURE 1. Location map of Kirgizstan. The circle south of Bishkek is the approximate study area in the West Karakol Valley.

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INTRODUCTION

A rare observation of a slushflow that released on a low-angle slope was made on 16 May, 1992. The location of the flow was in the headwaters of the West Karakol Valley, southern Kirgiz Range, Kirgizstan (Figure 1). This valley has an east/west orientation with drainage to the west and is located about 60 km due south of Bishkek, the capital city of Kirgizstan. The approximate coordinates of the flow release point measured by a portable global positioning system (GPS) receiver were 42°21′48′′N, 74°48′52′′E. The flow traveled almost due west at about 3140 m a.s.l. (Figure 2). The observed event is interesting because it represents an extreme case when compared to the statistics of other documented slushflows: low-angle starting zone, low mean path angle, relatively low latitude, and high elevation. Because of the rare nature of observations of slushflows, detailed field notes were taken immediately after the event. The following is a presentation of those notes, combined with observations taken for a hydrological study occurring during the period surrounding the event.

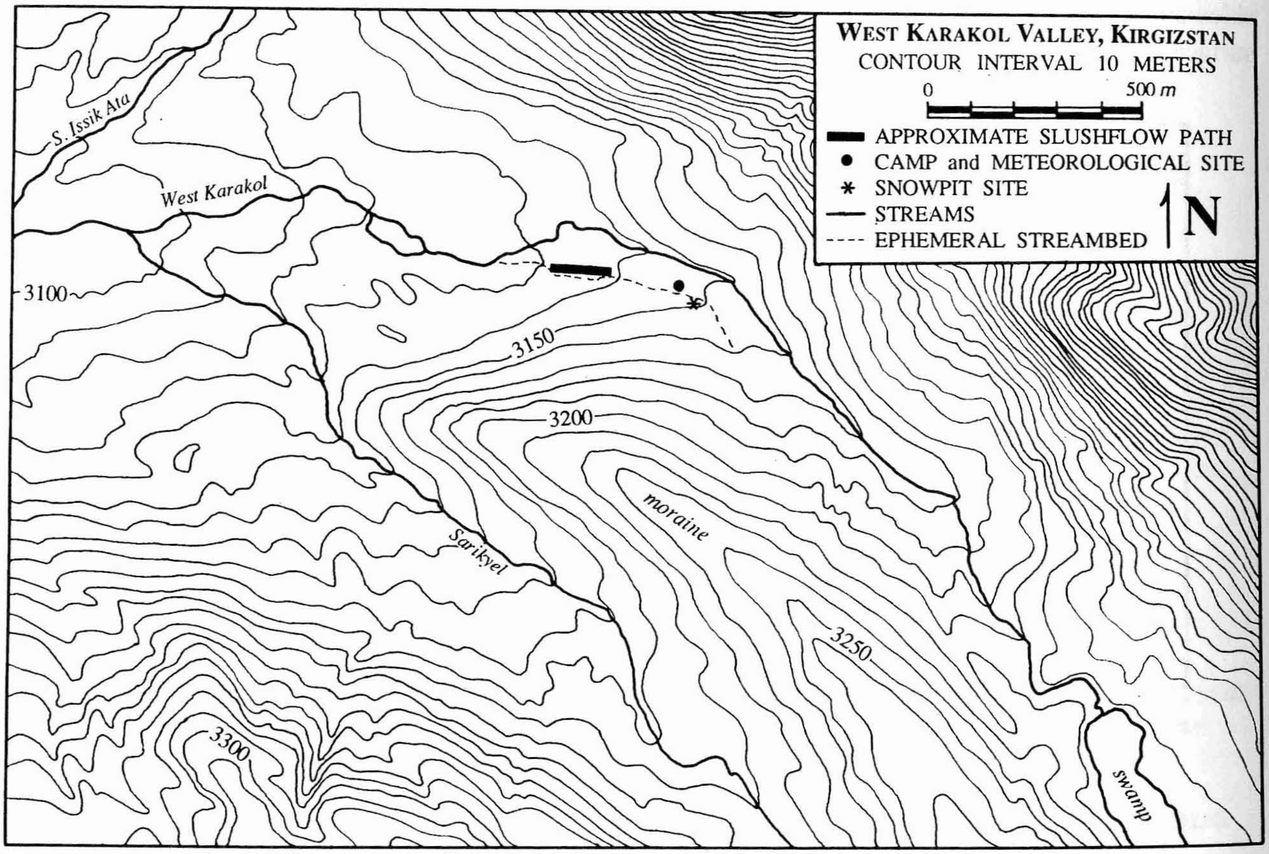

FIGURE 2. Study site in the West Karakol Valley, Kirgizstan.

BACKGROUND

Slush avalanches are the rapid mass-movement of water saturated snowpacks [Washburn and Goldthwaite, 1958; Hestnes, 1985; Nyberg, 1985]. These powerful and destructive avalanches are described over 30 years ago [Washburn and Goldthwaite, 1958; Rapp, 1960], and more recently by others [Nobles, 1966; Luckman, 1977], but little work has been done on slushflows as compared to other types of snow avalanches, partly because observations of events are rare. In the last decade a small group of researchers have examined the specifics of slushflow avalanches [Hestnes, 1985; Nyberg, 1985; Onesti, 1985; Hestnes and Sandersen, 1987; Onesti, 1987].

Hestnes [1985] found that the starting zones were usually located in small streams. Most of the streams were ephemeral or periodically dry and some had poorly defined or nonexistent streambeds. Three types of starting zones were defined. Linear or channel zones had narrow crown surfaces and were typical of areas with drainage channels. Scar and bowl zones have large release areas with crowns ranging between 10 and 100 m. Nyberg [1985] found that minimum vertical displacements of slushflows were 40 to 50 m, with an average of 330 m from 224 sites studied in Sweden. A distinguishing factor of slushflows from other avalanche types is the release and travel over extremely low-angle slopes. Slushflows are important geomorphic agents and constitute a serious hazard to life and property, making further study of this phenomenon important [Hestnes, 1985; Nyberg, 1985]. Readers are referred to Hestnes [1985] and Nyberg [1985] for excellent details and summaries on slushflows.

OBSERVATIONS

Snowpack Conditions

Snowpits were excavated for hydrological and chemical studies close to the area of release on 5 and 8 May 1992 (see Figure 2 for location). Although these dates precede the event, the observations are a good description of the snowpack before the release. The pit profile from 8 May is shown in Figure 3. The new snow found at depths from 0.65 to 0.80 m and week-old snow (0.50 to 0.65 m) was altered to large-grained melt-freeze snow by 16 May following several days of warm weather and rainfall. The base of the snowpack (0 to 0.20 m) was made up of large kinetic forms (depth hoar). Water was observed running over the ground at the base of the snowpack in both snowpits.

There was a great increase in the depth of the water running through the snowpack in the few days immediately preceding the slushflow release, as observed in the camp which was located close to the release point. Observations of the snowpack in the camp before, and at the release site after the event, showed a homogeneous snowpack of large rounded noncohesive grains with a large free water content. The snowpack at this time was isothermal at 0°C. A few hours before the event we noticed areas of surface saturation in the snowpack and were surprised at how rapidly the saturated area grew, on the order of tens of square meters per hour. Water flow over the surface of the snow was observed at this time.

Meteorological Conditions

Meteorological conditions preceding the event were mixed weather of heavy cloud cover and intensely hot, clear skies. The day before the event rain fell for about 6 hours. Mixed rain and snow precipitation continued through the preceding night accompanied by steady high winds. The day of the release was hot with overcast skies and intermittent rain.

Runoff Conditions

Streamflow in the major drainage increased rapidly over the few days preceding the event as a result of hot days and rainfall. A diurnal signal was present in the discharge but it was minor compared to the rise caused by snowmelt and rainfall. The base of the snowpack in the camp became saturated and cohesionless over a period of several days. Saturation and flow increased rapidly on the afternoon of 15 May and in a period of a few hours we excavated several channels in camp that combined to carry about $0.5\,m^3\,s^{-1}$.

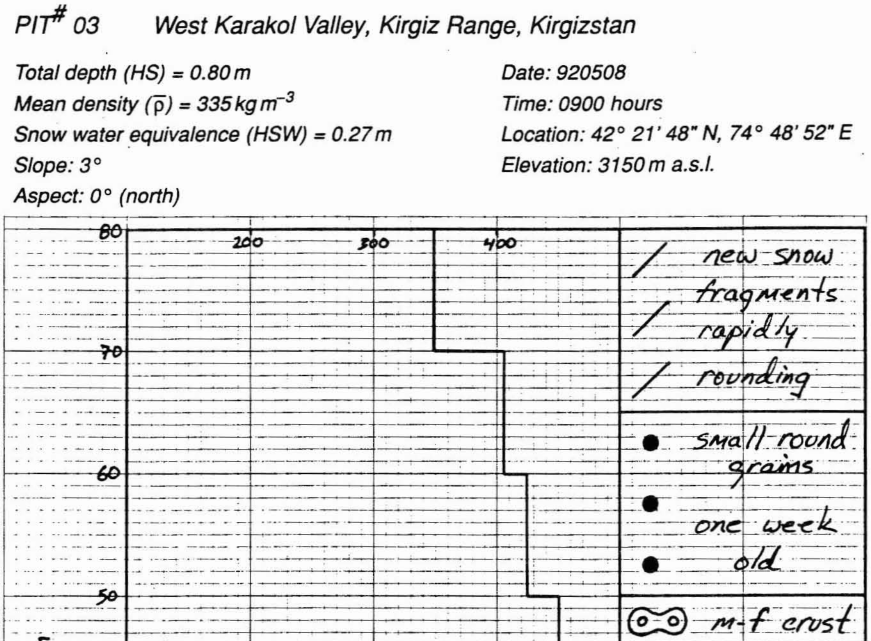

FIGURE 3. Snowpit data summary.

The Slushflow Event

The slushflow released at approximately 1500 hours on 16 May, 1992. It made sufficient noise upon release to attract the attention of field workers in their mountain camp about 100 m upslope from the fracture line, and was loud throughout the flow's duration. Release was of the type described by Hestnes [1985] as a sudden release from a crown surface. The flow itself resembled a rapid, fluidized mudflow with some splashing observed. Although a great deal smaller in scale, the movement resembled quick-clay flow. The release point was located in a long depression saturated with meltwater and occurred about 50 m down from the upslope edge of the saturated area. The saturated area directly above the fracture line quickly drained a distance of about 15 m after the release. Another saturated zone of a few hundred square meters area existed upslope about 100 m distance from the fracture line but did not release.

The failure and flow took place near an ephemeral channel that drains a low-angle slope separated from the main basin stream by a small ridge and drains a moraine to the south (Figure 2). The channel carries snowmelt runoff on an annual basis and may carry rainfall runoff at other times. The fracture did not take place in the ephemeral channel, but immediately to the north side. It was close enough in the first 80 m to be able to see the channel in several places from the undercut flanks of the flow (Figure 4). The channel was full of fast ice at some points of observation, perhaps explaining why the saturation of the snowpack and the slushflow itself took place primarily outside of the channel bed. In the first 80 m the flow actually contacted the stream bed in two places. At a distance of 120 m a terrace pushes the stream bed abruptly to the north at which point the slushflow joined the channel and remained in it for the duration.

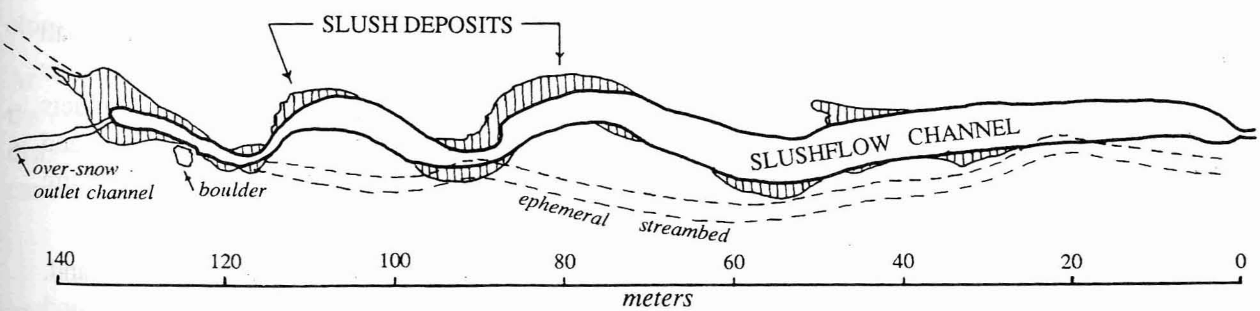

FIGURE 4. Plan view of the slushflow. Shaded areas are slush deposits. Direction of flow was from the right to the left.

The snowpack depth at the fracture line was about 0.30 m and the crown was 3 m in length. The release point was at the upslope margin of an abrupt rise in the topography relative to the surrounding terrain, about 0.50 m rise over a distance of 5 m, with a mean slope of 6°. The observation of the release point morphology is consistent with that observed by Hestnes [1985], where he found that crown surfaces were usually located at localized changes in slope with irregularities in the ground surface. Below this drop the ground surface was relatively smooth and gentle with a mean slope angle of 2.5° for a distance of 30 m. The slope averaged 3° over the entire 140 m length of the path. This value is lower than the smallest value reported by Hestnes [1985] and considerably smaller than the mean of his observations. Of the 34 events studied by Hestnes, maximum mean slope was 20°, minimum was 5°, and the average was 12.5°. Above the release zone the slope was constant at 3° for a distance of more than 100 m. All slopes were measured with a clinometer. Statistics of the flow are summarized in Table 1.

TABLE 1. Slushflow Statistics

Total Length	140 m
Total Vertical Drop	7 m
Total Volume Displaced	224 m^3
Total Mass Displaced	208,000 kg
Starting Zone Angle	6°
Starting Zone Length	5 m
Starting Zone Width	3 m
Mean Path Angle	3°
Mean Path Width	4 m
Maximum Path Width	5 m
Minimum Path Width	1.5 m
Estimated Velocity	5 m s^{-1}
Elevation	3140 m a.s.l.
Aspect	275° (west)

The release zone ground surface was mixed exposed soil and dead grass 20 to 80 mm long and small plants about 5 mm in height. The vegetation and surface conditions were typical of the area, which is heavily grazed in the summer by sheep, cows, and horses. Some large partially-exposed boulders interrupted the surface, but did not protrude sufficiently to alter the gross flow direction. Boulders and the decrease in slope may have combined to prevent release of the saturated zone above the fracture line.

The majority of the particles moved by the slushflow and found along the entire path were flat sand, gravel and cobbles up to 200 mm on the a axis and 5 to 20 mm on the c axis. Three boulders were found with long dimensions of 300, 480, and 520 mm. We estimated that the largest of the three had a mass of about 25 kg. These boulders were found 50 m downstream from the fracture line. It was easy to be certain which particles had been moved by the slushflow because of their superposition over green vegetation. Clay and silt was common in slush deposits and snow banks in the lower reaches. Sand and gravel particles were found in the snowbanks but were rare. Distance of travel could not be determined for any of the particles.

Pockets or "kettles" were eroded in the snow-free area about 20 to 70 m downstream from the starting point. They were up to 2 m on a side and ranged from 1 to 4 m^2 in area. The upslope sides were steep and even undercut with depths of 0.1 to 0.4 m. The bottoms of the depressions were filled with sediments graded up to the downslope edge. Sediments included large stones but were primarily small, flat stones. There was no evidence to suggest that these depressions were formed by this particular event, but it seems plausible that such features could be created and maintained by the erosive forces of slushflow events.

The flanks of the flow ranged between 0.30 and 1.00 m height with the mean height skewed toward the lower value. Slush overflowed the old snow surface along the flanks forming lava-like deposits 0.20 to 0.30 m deep and up to 1 m wide. The first deposits occurred 25 m downstream from the release point. The deposits were sporadic but concentrated on the outside of bends in the flow path. Dirt and vegetation were found in the overflow deposits with increased concentration in the downstream direction. The channel carved by the flow varied in width between 2 and 5 m with a mean of about 4 m and totaled 140 m in length. Onesti [1987] measured slush densities and found that they ranged between 900 and 970 $kg\,m^{-3}$ with a mean value of 927 $kg\,m^{-3}$. Using his mean density value, a total length of 140 m, mean channel width of 4 m, and a mean depth of 0.4 m, we calculated the volume of snow and slush moved to be about 224 m^3 with an estimated mass of about 208,000 kg.

Narrow points in the path were controlled by a sudden drop in the streambed and by terrain constrictions. Track width varied little without these influences, a characteristic also observed by Hestnes [1985]. Vertical stress cracks formed laterally at many points in the flanks forming acute angles of 15 to 30° from the down-flank direction. Flow went over fast ice in the stream channel at one point for a distance of a few meters.

At the downstream end of the flow the channel was plugged with slush and several large, dirty deposits flowed over the surface at random angles. The stream flow after the event was routed to the south of the channel which was completely blocked. A large area stretching several hundred meters down-valley quickly became saturated to the surface of the snowpack, but no catastrophic failure was observed. Saturation reached the main stream and some erosion of the snow surface was observed, but it did not appear to be catastrophic in nature. The observed erosion may have taken place rapidly, but not while the researchers were present. The mechanism appeared to be similar to headward erosion and was close to another release mechanism for slushflows described by Hestnes [1985].

An estimate of mean velocity was made by dividing the total observed distance by the time taken for the event. The value calculated was 5 $m\,s^{-1}$ and is subject to error, but based on errors in estimates of distance and time the value should be within ±3 $m\,s^{-1}$. After the event, flow in the channel appeared consistent at about 0.2 to 0.3 $m^3\,s^{-1}$.

SUMMARY

This slushflow observation is uncommon for several reasons. Observations of events in progress are rare, most flows are documented after the fact. Few observations have been made in midlatitude regions, most of the activity being reported from high-latitude arctic or subarctic areas. To our knowledge, this event took place on the lowest angle slope documented. Contributing factors were clearly the rapid snowmelt and rainfall prior to the event. The infiltration capacity of the bed surface was clearly exceeded and the ground was saturated over a large area surrounding the path. Ponding and over-snow flow of water indicated that the runoff source exceeded the ability of the snowpack to transmit the water to open channels downslope. The large cohesionless grains in the snowpack provided little internal strength resisting the failure. The relatively smooth nature of the bed surface provided minimal resistance to failure or flow.

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