
Abstract

On the evening of 9 May 1986, a hot, newly extruded portion of the lava dome in the crater of Mount St. Helens collapsed onto the late spring snowpack, generating a flow which traveled the length of the crater with an average velocity of 5 m/s. At Loowit gaging station, 2.4 km from the dome, the flow had an instantaneous peak discharge of 230 m³/s and was a high discharge water event, not a debris flow. However, within the next 1-2 km the flow incorporated sufficient solids to evolve into a debris flow with a velocity of 5.5-6.5 m/s and a peak discharge of 870 m³/s. The debris flow attenuated rapidly upon reaching the flat expanse of Step Fan and left recognizable deposits for only 3 km beyond the base of the mountain. Small-scale events such as this are probably quite common in the eruptive history of a volcano but are rarely preserved in the stratigraphic record. Recognition of such events as a component of eruptive activity is important in creating a realistic volcanic hazards assessment of individual volcanoes.

Introduction

On 9 May 1986, at 1948 PDT (Pacific Daylight Time), the upper two flood warning switches in a tier of four at Loowit gaging station (Figure 1) tripped, indicating a flow having a depth of at least 1.8 m (height of the uppermost switch above mean water level) had passed the station. Concurrent telemetered data from seismographs located near the mountain indicated a large, prolonged event was occurring within the crater. These events represented the culmination of two weeks of increasing seismicity and deformation of the dome within the crater of Mount St. Helens that had led to the prediction of an imminent eruptive event, probably a dome-building eruption. Because of this prediction, personnel at the Cascades Volcano Observatory were keeping a 24-hour watch over the telemetered data at the time the switches tripped. Seismographs located 5.5 km and 11.5 km from the crater recorded only background or low-level seismicity, not the gradually increasing, prolonged signal associated with lahars flowing along the upper North Fork Toutle (Brantley et al. 1985). Elk Rock gaging station, 23 km flow path west from the crater, showed no abrupt increase in stage that would be indicative of a large, potentially dangerous flow. The scientist on duty therefore decided that the event was not large enough to necessitate immediate mobilization of field study crews or to present a hazard to downstream property.

It was not until 12 May that the authors were able to make a short reconnaissance visit to the Loowit Ravine-Step Fan area. Through marginal weather, evidence of flooding in Steam and Lake Creeks and a veneer of boulder litter and granular debris on the central and eastern portions of Step Fan was readily apparent, as was a slump scar on the east wall of Loowit Ravine downstream from Loowit Falls. In the crater, a large avalanche deposit at the base of the talus chute on the north side of the dome was also observed. The avalanche occurred when a large piece of the hot, newly extruded lobe detached from the main mass on the top of the dome and tumbled down the steep northern face, fragmenting as it went. Evidence of flow was obvious from the toe of the avalanche deposit to the head of Loowit Ravine (Figure 2).

Deposits and Interpretations

The hot avalanche and accompanying surge of hot ash and gases (Mellors et al. 1988) induced rapid melting of the crater floor snow cover and created a flow which entered the main crater drainage system. Aerial reconnaissance of the head of Loowit Ravine showed that deposits from this flow veneered the late spring snow-pack, attesting to the generally passive, non-erosive nature of the early stages of the flow. These deposits were not investigated on the ground by the authors owing to time constraints and the unstable and therefore unsafe nature of the ravine walls upstream from Loowit gaging station.
At Loowit gaging station, the upper two flood-warning switches tripped at 1948 PDT; the two lower switches did not transmit and apparently were carried away or incapacitated before they could trip or were inoperative at the time of the event. The fact that both upper switches tripped at the same time indicates a very rapid rise in stage; essentially a wave at least 1.8 m high. A telemetered tiltmeter, located 300 m north of the base of the dome at a research site named Sauna, made its last routine transmission at 1940 PDT (it was programmed to transmit at 10 minute intervals) and did not transmit again. Crews visiting the crater on 14 May found that the tiltmeter had been destroyed by the avalanche, apparently sometime between its last transmission at 1940 PDT and its next scheduled transmission time of 1950 PDT. Assuming the event that destroyed the tiltmeter was the same event that initiated the flow (there may have been multiple episodes of avalanching over the space of a few minutes), travel time of the flow from Sauna site to Loowit gaging station was a maximum of 8 minutes. Estimating a flow path of 2.4 km from Sauna to the gaging station from existing maps yields a minimum average velocity of 5 m/s for the flow through the crater and the upper portions of Loowit Ravine.

Deposits near Loowit gaging station consist of 0.2 to 0.5 m of discontinuously bedded, fines depleted, coarse sand and gravel that form a terrace on the left bank along the outside of a gentle bend. A sandy coating covered rocks on the right bank below the high water mark. The incipient bedding and fine-grained nature of the terrace deposits indicate they were emplaced by a fluvial event, probably a clearwater or muddy flood, not a debris flow. Well-defined lower and horizontal upper surfaces of the terrace combined with a lack of well-developed bedding argues for a single event, not a succession of waves. An indirect estimate of flow made at the gaging station based on surveyed slope, cross-sectional area, and roughness of the channel, gives an instantaneous peak discharge at the gage site of about 230 m³/s (T. Hale and D. Childers, oral communication, 1986).

Just downstream from Loowit gaging station, the channel drops abruptly over 75 m at Loowit Falls. At the base of the falls the flow apparently undercut the right bank of the ravine and initiated a partial bank collapse approximately 50 m long by 30 m high and of unknown thickness. Rubble from this collapse may have temporarily dammed the flow and eventually all of the loose material was incorporated into the flow. It was
through incorporation of the bank collapse material and of channel bank and floor sediments in the reach directly downstream from the base of Loowit Falls that the flow bulked up sufficient solids to evolve into a debris flow. The debris flow apparently dammed and remobilized a number of times in the narrow, twisting, bedrock channel below Loowit Falls, creating a series of terraces 3 to 4 m high. These terraces possess essentially horizontal upper surfaces and formed when the debris flow momentarily slowed during the damming episodes. Because they do not parallel the local stream gradient, the terraces thin rapidly and disappear upstream. Material composing the terraces consists of unsorted, angular clasts up to 2 m across set in a sand-gravel matrix. The deposit is massive and generally ungraded, though a slight concentration of large clasts in the lower central portion of the deposit was occasionally apparent.

A large part of the material incorporated into the debris flow came from channel floor debris and the apron of talus along the walls of the ravine. This is supported by the observation that about 50 percent of the gravel- and sand-size matrix clasts were composed of dome-derived phaneritic dacitic debris carried from the avalanche by the initial stages of the flow, but essentially all of the cobble-size and larger clasts were from dark, aphanitic basaltic and andesitic flows which form the lower slopes of the mountain beyond the crater. The ravine downstream from Loowit gaging station is floored over its entire length by resistant lava flows, but much of the ravine wall is composed of fragmented pyroclastic debris or the shattered, ice-contact basal zones of stratigraphically higher lava flows. The walls usually possess an extensive talus apron of coarse material and the channel floor is littered with bouldery debris. However, when the ravine was visited one week after the flow, none of this easily erodible material was present. The channel floor was almost devoid of loose material and the walls were vertical with no talus development.

Loowit Ravine divides into 3 distributary channels, known as the north, central and south...
distributaries, about 200 m upstream from Step Fan (Figure 1). Two of these distributaries, the northern and the southern, are occupied only during extreme discharge events; the central distributary is the channel which contains normal stream flow. A portion of the debris flow broke out of the central distributary through a depression in the ravine wall on the outside of a gentle, right-hand bend and entered the southern distributary channel; none of the debris flow entered the northern distributary. This breakout occurred when the debris flow ran along a bedrock shelf and then super-elevated over a vertical wall resulting in a total height gain of at least 8 m. The cross-sectional area of the flow through the depression (estimated from strand lines seen on scaled oblique photos) is about 50 m². Based on this area and the average velocities derived at the mouth of the central distributary (as discussed below), an instantaneous peak discharge of 300 m³/s is estimated for the portion of the flow passing through the depression.

The deposit formed at the mouth of the southern distributary where it emerges onto the gently sloping, low relief surface of Step Fan, possesses a well defined left lateral boulder levee and contains clasts up to 2 m in diameter, but is generally less than 10 cm thick. The course of a small, intermittent stream which passed in front of the mouth of the southern distributary was covered for a distance of over 100 m by the deposit. However, the stream still appears to be following its pre-event channel and was not permanently dislocated by the debris flow. This observation suggests that, while the instantaneous peak discharge was very high, the actual volume of material in the flow was small and the resulting deposit was merely a veneer of insufficient thickness to permanently change the course of the stream.

Along the last 50 to 100 m of the central distributary, boulder levees found along the right bank of the gully delineate the peak height of the flow at 4 m above the channel bottom. The area between the levees is covered by only a scattering of clasts larger than gravel size and in places exhibits longitudinal scour marks. These scour marks and the lack of deposits indicate that the debris flow was still actively eroding and bulking-up as far as the mouth of the central distributary. Beyond the mouth of the central distributary is a deposit consisting chiefly of large, angular boulders of red and black flow rock, generally between 0.5 m and 2 m in diameter but ranging to over 3 m, eroded from the slopes of the mountain. A massive, 4- to 6-cm-thick, medium to coarse sand and gravel layer from the matrix of the debris flow covered the ground between the large clasts beyond the mouth of the distributary and veneered snow drifts immediately behind but lower than the tops of the levees mentioned previously. A hand lens inspection revealed that about 50 percent of this sandy deposit consisted of granular dacite and phenocrysts from fragmented dome rocks, the remainder being fine-grained, dark rock fragments incorporated from the channel below Loowit Falls.

For about 50 to 100 m downstream from the mouth of the central distributary at Step Fan, a coating of the sandy matrix material could be found on all boulders, even those near the center of the flow path, suggesting that a single, large surge or wave occurred and was not followed by a sustained recessional flow. This coating was fairly non-cohesive and had slid off boulder surfaces steeper than 30° to 40°. A broad, shallow channel about 0.3 to 0.5 m deep and tens of meters wide was incised into the fan near the right margin of the flow in this area. The cut face from this incision was also coated with the sandy, matrix material, indicating that the incision occurred early in the event, not by recessional flow. Margins of the deposit were sharp and well-defined, tapering to a thickness of 1-2 cm. By 12 May the deposit had de-watered and was not thixotropic.

Beyond 50 to 100 m from the mouth of the central distributary the deposit no longer resembled those of a debris flow but instead were the incipiently bedded sand and gravel material of a flood deposit. The debris flow must have started de-bulking immediately upon leaving the confines of the gully, depositing all of its cobble- and boulder-sized clasts and most of its matrix material within 100 m of the mouth of the distributaries.

At the mouth of the central distributary, the flow left noticeable mudlines that displayed run-up of 1.5 to 2 m on vertical walls and splashes from turbulence to over 3 m (Figure 3). Velocities inferred from the run-up range from 5.5-6.5 m/s (based on the formula \( V = \frac{0.5gh^{0.8}}{g} \), where \( V \) is the velocity, \( g \) the gravitational constant and...
Figure 3. Run-up of about 2 m (mudline is near tip of shovel) on a vertical wall near the mouth of the central distributary. Note splash marks up to 3 m above ground level and lack of clastic debris on the channel floor.

"h" the height of the run-up). A "tape and Brunton" survey of the channel gave a cross-sectional area of 95 m², which, when combined with the average velocity, yields an estimate of 570 m³/s for the instantaneous peak discharge at the mouth of the central distributary. Combined with the flow estimate from the southern distributary (300 m³/s), the total instantaneous peak discharge for the event was about 870 m³/s. Even though this value may seem extreme (the flood of record, 1981 to 1986, for Tower gaging station on the main stem of the Toutle River is 1,026 m³/s; McGavock et al. 1986), it must be remembered that this flow, while possessing a very large instantaneous peak discharge, probably lasted for only a matter of seconds and was not a sustained event.

The rapidly attenuating flow from the southern and central distributary channels united along the west side of Step Fan before entering the system of gullies that drain the fan. About 70 percent of the flow entered Lake Creek and eventually reached Spirit Lake at its southwest shore. About halfway between Step Fan and Spirit Lake (1.5 km from the mouth of the central distributary), velocities calculated from run-up on large boulders were 1-2 m/s. Deposits in this area consisted of less than 0.3 m of discontinuously bedded fluvial sand and gravel. The remaining 30 percent of the flow went into Steam Creek. Deposits along this channel, while not visited on the ground, appeared from the air to form a veneer on low (1 to 2 m above water level) stream terraces as far downstream as 3 km from the Step Fan.

Summary and Discussion

The failure of a portion of a hot, newly extruded lobe on the dome at Mount St. Helens onto the late spring snowpack generated a flow which moved out of the crater through Loowit Ravine. Based on examination of deposits at Loowit gaging station, the flow above Loowit Falls was not a debris flow. By timing the interruption of telemetered data from instrumentation near the dome and the tripping of flood warning switches at the gaging station, a minimum average velocity of 5 m/s was calculated for the flow through the crater. An indirect estimate of flow at the gage site yielded a peak instantaneous discharge of 230 m³/s.

Below Loowit Falls, deposits indicate that the flow had bulked up to a debris flow. This was accomplished through incorporation of coarse talus and channel floor sediments and through entrainment of material from a slump immediately below the falls. The presence of numerous tapering terraces suggest that the debris flow moved by damming and breaching.

Near the base of the mountain, a portion of the flow broke out of the main channel and emerged onto Step Fan through the southern distributary. An estimated instantaneous peak discharge of 300 m³/s escaped into this channel.

The bulk of the flow reached Step Fan through the central distributary. Velocities calculated from run-up ranged from 5.5 to 6.5 m/s. An instantaneous peak discharge for this channel was estimated at 570 m³/s. Flow from the two distributaries attenuated rapidly upon reaching Step Fan and merged into a single flow. This flow then divided once again with about 70 percent of the remaining volume entering Lake Creek. Less
than 2 km downstream on Lake Creek the flow had decreased to a depth of less than 0.3 m and a velocity of only 1 to 2 m/s. The remaining 30 percent of the flow left recognizable deposits for at least 3 km along Steam Creek, mainly as thin sediment veneers on low-lying stream terraces.

The combined instantaneous peak discharges from both distributaries was about 870 m$^3$/s, yet deposits were recognizable for only about 3 km beyond the mouth of the distributaries. Apparently this very high discharge occurred in the form of a single wave or surge that lasted only a matter of seconds. Therefore, even though the instantaneous peak discharge was comparable to a major flood on the main fork of the Toutle River, the actual volume of material involved was small. Judging from splash marks seen on the channel walls (Figure 3), the flow was very turbulent, which suggests that at least a portion of its volume may have been entrained air. The dramatic increase in peak discharge from Loowit gaging station (230 m$^3$/s) to the mouth of the distributaries (870 m$^3$/s) resulted from the active incorporation of large amounts of loose debris from within the channels right up to the passage of the flow onto the lower gradient of Step Fan. Bulking-up by debris flows on the steep, upper slopes of volcanoes and the rapid switch to deposition with lessening gradient has also been documented on Mount Hood, Oregon (Cameron and Pringle, 1986). The average stream discharge in Loowit Ravine at Loowit gaging station is insignificant (less than 0.1 m$^3$/s, T. Hale, oral communication, 1986). This would mean that the majority of the increase in discharge was in the form of coarse material possessing little interstitial fluid, with relatively minor amounts of water incorporated from stream flow within the channel. This probably explains the rapid attenuation of the flow upon reaching Step Fan; there was insufficient water to keep the solid portion of the flow mobilized except in confined, high gradient reaches.

Events such as this underscore the problems encountered in volcanic hazards assessment. Though small in scale, this flow moved at high velocities through an area soon to be opened to the public. Given the velocities calculated and the length of the flow path, the initial wave of the event may have reached the Step Fan area in as little as 10 to 12 minutes and with almost no warning.

A year after this event no identifiable deposits could be found to document this debris flow. The limited distribution of the deposits and the rapidly changing topography of the area had erased all evidence of this event. Assessment of hazards at most volcanoes is accomplished through examination of past eruptive events preserved in the stratigraphic record. Many events, such as the 9 May, 1986, debris flow at Mount St. Helens may simply not be preserved and bias the picture of a volcano's activity toward the larger phenomenon.

**Literature Cited**


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