Pyroclastic Flows of the 1992 Crater Peak Eruptions: Distribution and Origin

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CONTENTS

ABSTRACT

Two of the three 1992 eruption events at Crater Peak generated pyroclastic flows on the flanks of the cone. The pyroclastic-flow deposits are very coarse, generally fines poor, poorly sorted, and clast supported; 60 to 80 percent of the clasts are dense to slightly vesiculated cobble to boulder-sized blocks of juvenile andesite. Accessory and accidental clasts are chiefly fragments of lava but include some spectacularly vesiculated metasedimentary rocks (buchites). The pyroclastic flows traveled a maximum distance of about 3.2 km and had a combined bulk volume of about 400,000 m^3, or less than 0.5 percent of the bulk volume of the entire eruption. They were avalanches of hot debris that produced sluggish, poorly inflated dense-clast flows. The flows may have been generated at least in part by directed ballistic ejection of debris rather than by "boilover" through a low point on the crater rim. The lack of correlation between the distribution of pyroclastic flows and the low part of the crater rim has important implications for hazard analysis of vulcanian and subplinian eruptions elsewhere because it reminds us that all flanks of a volcano can be at risk from pyroclastic flows.

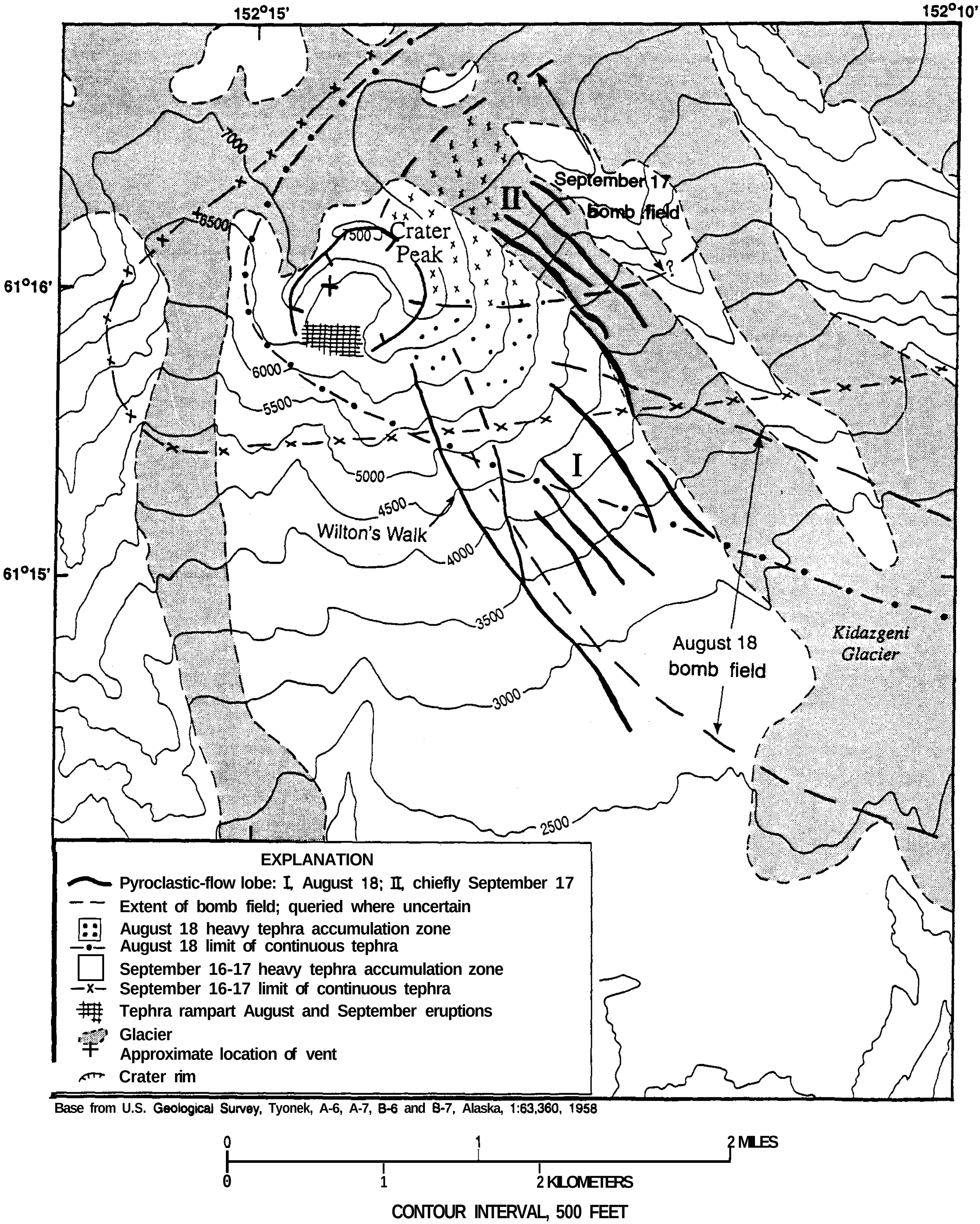
INTRODUCTION

Crater Peak, a 2,309-m-high satellite cone on the south flank of the Mount Spurr volcanic center 125 km west of Anchorage erupted on June 27, August 18, and the night of September 16–17, 1992 (see Eichelberger and others, this volume) after 39 years of quiescence. The three eruptions were similar in that they each produced vulcanian to subplinian eruption columns as high as 18 km above sea level, formed extensive bomb fields, lasted 3 to 4 hours, erupted pyroclastic material only, had ejecta bulk volumes of 44 to 56 x 106 m^3 each (see Eichelberger and others, this volume), and were of andesitic composition. The July 9, 1953, eruption, the only other historic Crater Peak eruption, had similar characteristics, according to the fragmentary accounts available (Juhle and Coulter, 1955).

Crater Peak is capped by a circular summit crater 300 m deep and 800 m in diameter (fig. 1); rim elevation ranges from 1,980 m (6,500 ft) at the low point on the south-southwest to 2,309 m (7,575 ft) on the northeast. Before the initial June 27 event, the crater contained a considerable thickness of ice, snow, and an 800-square-meter lake. Most of the ice and snow was melted or removed during the 1992 eruptions, particularly the one on June 27: the lake disappeared a few days before the June 27 eruption. A terrace of 15 m or more of massive, locally well bedded surge deposits capped by 1 to 2 m of fine ash formed in the southern third of the crater during the June 27 eruption; 1- to 2-m lithic blocks were scattered across the surface of this terrace. Later eruptions modified this feature into two tephra-covered terraces that now occupy the southern two-thirds of the crater.

The crater walls changed little during the 1992 eruptions other than steepening of the north wall. The eruptive vent, estimated by aerial observations to be less than 30 m across at the surface, is in the northwest and deepest part of the crater about 70 m below the surface of the lower terrace.

Small-volume, dense-clast pyroclastic flows moved down the outer south and east flanks of Crater Peak cone during the August 18 and September 16–17 eruptions (fig. 1). During the June 27 event, either pyroclastic flows were not generated or were turned quickly into "snowflows" or "mixed" flows (see Waitt, this volume). The total volume of the pyroclastic-flow deposits is estimated at 0.4 x 106 m3, or less than 0.05 percent of the approximately 150 x 10^6 m3 bulk volume of the 1992 eruption products (see Eichelberger and others, this volume).


152°15'
152°10'
61°16'
61°15'
7000
6500
7500
Crater Peak
II
September 17
bomb field
?
6000
5500
5000
4500
Wilton's Walk
4000
3500
3000
2500
I
August 18
bomb field
Kidazgeni Glacier
EXPLANATION
Pyroclastic-flow lobe: I, August 18; II, chiefly September 17
Extent of bomb field; queried where uncertain
August 18 heavy tephra accumulation zone
August 18 limit of continuous tephra
September 16-17 heavy tephra accumulation zone
September 16-17 limit of continuous tephra
Tephra rampart August and September eruptions
Glacier
Approximate location of vent
Crater rim
Base from U.S. Geological Survey, Tyonek, A-6, A-7, B-6 and B-7, Alaska, 1:63,360, 1958
0
1
2 MILES
0
1
2 KILOMETERS
CONTOUR INTERVAL, 500 FEET

Similar pyroclastic flows, often called scoria flows, have been reported from historic eruptions at Ngauruhoe volcano in New Zealand (Nairn and Self, 1978) and at Manam volcano in the western Bismarck arc near Papua, New Guinea (McKee, 1981). Such flows are commonly thought to have formed by column collapse or by boilover of a low eruption column (Cas and Wright, 1987) and flowage through low points on crater rims. The limited distribution of the Crater Peak pyroclastic flows and the lack of any association with low points on the crater rim suggest that other mechanisms were responsible for their formation. This possibility is important for assessing hazards from similar eruptions elsewhere. Because pyroclastic flows were not observed during daylight hours, the processes that formed them must be inferred.

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DISTRIBUTION

Crater Peak is bounded on the north, west, and east by glaciers (fig. 1). The August 18 pyroclastic flows moved down the steep (31" to 7") south and southeast flanks of Crater Peak to elevations of 820 to 1,000 m (2,700 to 3,300 ft) at distances of as much as 3.2 km from the crater rim. The flows were channeled into gullies, where they formed elongate lobes of debris (fig. I) with steep-sided margins and flow fronts 0.5 to 1.5 m high. The westernmost flows of the August 18 eruption were channeled into a well-developed, intermittent stream drainage (informally known as Wilton's Walk; figs. 1 and 2) on top of thin snowflows of the June 27 eruption. The easternmost pyroclastic flows followed swales and low gullies lined with brush and other low vegetation. None of the pyroclastic flows descended to tree line.

Most of this report is based on study of the August 18 pyroclastic-flow deposits, which are the most accessible—although lahars from the September 16–17 eruption overlapped many of the August pyroclastic-flow deposits in Wilton's Walk gully. The September 16–17 pyroclastic flows moved down the east-northeast flank onto a high ice field (fig. 1), causing much melting of the ice and were soon transformed into lahars; access to these pyroclastic-flow deposits is difficult and hazardous.

The pyroclastic-flow deposits of the August 18 and September 16–17 eruptions have a close spatial association with large bomb fields (figs. 1 and 3) that covered areas of 7 and 2 km^2, respectively. Field relations show that for the August eruption, most of the bombs were ejected after the pyroclastic flows were emplaced (see Waitt and others, this volume).

◄ Figure 1. Crater Peak area of Mount Spurr volcano, Alaska, showing distribution of pyroclastic-flow deposits and tephra accumulation zones from the August 18 and September 16–17, 1992, eruptions and the August 18 bomb field. Bomb field from September 16–17 eruption not completely mapped because of inaccessibility.

Figure 2. View of south flank of Crater Peak cone (summit obscured by clouds) with pyroclastic-flow deposit in foreground. Prominent drainage, locally known as Wilton's Walk, was the site of numerous pyroclastic flows during August 18 eruption and lahars during the September 16–17, 1992, eruption.

Figure 3. View toward southeast of bomb field developed on top of the August 18 pyroclastic-flow deposits, southeast flank of Crater Peak, Mount Spurr volcano, Alaska. Craters in foreground are 3 to 5 m in diameter.

COMPOSITION

The pyroclastic-flow deposits are very coarse, clast supported, and generally fines poor (fig. 4). Most clasts (60 to 80 percent) consist of dense to slightly vesiculated (15 to 20 percent vesicles), dark gray to brownish-black compositionally homogeneous, porphyritic juvenile andesite (56 to 57 percent SiO_2, table 1; see Nye and others, this volume); this material forms blocks as large as 1 m in diameter. The andesite contains about 20 percent phenocrysts consisting of plagioclase, clinopyroxene, orthopyroxene, iron oxides, and sparse hornblende in a microlite-rich groundmass of brown andesitic glass. A second and comparatively minor type of juvenile clast is a light gray-green andesite scoria that is compositionally similar to the dark andesite in spite of containing a clear rhyolite glass in the groundmass (see Nye and others, this volume).

Lithic clasts, mostly accessory but including a few accidental ones, are the second most abundant clast type (20 to 40 percent) and are typically quite large (as much as 2 m in diameter). The accessory clasts are chiefly unaltered andesite and basalt that were probably picked up from the conduit and the crater walls; accidental clasts were obtained from lava flows exposed on the flanks of Crater Peak. Some clasts of indurated pre-1992 pyroclastic material are also present. Accessory and accidental lithic contents of several pyroclastic-flow deposits from August 18 increase from west to east across the southeast flank of the cone.

Figure 4. Dense clast, fines-poor August 18 pyroclastic-flow deposits in Wilton's Walk. Photo taken August 20, 1992, 2 days after eruption of Crater Peak vent, Mount Spurr volcano, Alaska.

Table 1. Chemical analyses of juvenile andesite clasts in August 18 and September 16–17 pyroclastic flows (see Nye and others, this volume).

Table 1. Chemical analyses of juvenile andesite clasts in August 18 and September 16-17 pyroclastic flows (see Nye and others, this volume).

	August 18	September 17
SiO_2	56.5	55.75
Al_2O_3	19.2	18.7
FeO	6.9	7.0
MgO	3.6	3.7
CaO	7.6	7.5
Na_2O	4.1	4.0
K_2O	9	9
TiO_2	.67	.68
P_2O_5	.29	.28
MnO	.15	.15
Total	99.9	98.6
Number of analyses	3	4

Particularly exotic metamorphic xenoliths make up less than 0.05 percent of the clasts in the flows, but they are important for determining the type (and depth) of wallrock enclosing the crustal magma chamber in which the andesitic magma may have resided immediately before eruption. These xenoliths consist of highly expanded pumice-like material that forms smooth rounded clasts as much as 60 cm in diameter. This partly glassy material is composed of plagioclase+orthopyroxene±sillimanite±biotite±cordierite±spinel±garnet±quartz and has SiO_2 contents of about 65 percent (see Harbin and others, this volume). The clasts have a well-developed compositional banding and range from slightly to highly vesiculated. Similar material at Ngauruhoe, New Zealand, was described as "quartzofeldspathic gneisses" or "buchites" that have been "frothed" (Steiner, 1958; Nairn and Self, 1978; Graham and others, 1988).

A less abundant but equally exotic component is a white, fine-grained, sugary-textured rock composed of plagioclase+quartz+glass. This material is friable but occurs in blocks as large as 60 cm and it makes up less than 5 percent of the exotic lithics. Rounded pieces of this material as large as 15 cm across have been found in juvenile andesite blocks. Contacts between the two materials are sharp suggesting only minor interaction between the "white-rock" and the andesitic magma. This relation was observed in tephra fragments as well (see Neal and others, this volume; Harbin and others, this volume).

A few clasts of dense white garnetiferous calc-silicate skarn as much as 20 cm in diameter were found in the eastern pyroclastic-flow deposits of August 18. The garnets form large (1.5 cm) euhedral amber-colored porphyroblasts in a dense mosaic of wollastonite and plagioclase.

Metasedimentary rocks of these compositions have not been recognized within many tens of kilometers of the volcano. Although the basement surrounding the Mount Spurr volcanic center consists chiefly of Mesozoic plutonic rocks (Magoon and others, 1976) of the Alaska-Aleutian Range batholith, few plutonic rocks have been found in the 1992 ejecta. The almost total domination of vesiculated metamorphic rocks compared to other basement rocks suggests that they form the wallrock for a crustal magma reservoir that fed the 1992 Crater Peak eruptions. The lack of plutonic xenoliths indicates that the magma reservoir could be deeper than any upper-crustal granitic pluton.

DEPOSIT CHARACTERISTICS

At least some of the August 18 pyroclastic flows formed early in the eruption on the basis of observations made during an hour-long aerial overflight that began about 20 minutes into the eruption on August 18 (McGimsey and Dorava, 1992). A thin but persistent cloud layer surrounded the volcano at about the 2,400 m (7,800 foot) level. Brief glimpses through breaks in the cloud indicated that pyroclastic flows had come down the south and east flanks of the cone to an estimated elevation of 1,000 m. In addition to a vigorously convecting gray-black eruption column that rose to an altitude of 18 km, a lower (3.5 to 4.5 km) lighter colored cloud was visible along the south and southeast edge of the column and probably represented fine material elutriated from the pyroclastic flows. Blocks larger than 2 m were observed falling out at the perimeter of the column 300 m above the vent. These blocks probably contributed to the large post-pyroclastic-flow bomb field southeast of the cone.

Emplacement of the September 16–17 pyroclastic flows may have taken longer. Inspection of videotape from slow-scan TV records of the night-time eruption of September 16–17, taken from a camera located 120 km south of Crater Peak, shows that inclined incandescent fountaining (and probably pyroclastic flow generation) took place sporadically throughout the 4-hour eruption.

Field characteristics indicate that the dense-clast pyroclastic flows of August 18 (and probably those of September 16–17) began as hot avalanches that were poorly inflated and slow moving. Minor sand-blasting of brush took place adjacent to the flows, but brush within 10 m of the termini of the flows showed no damage. The andesite blocks that constitute most of the pyroclastic flow deposits have a characteristic orbicular shape with irregular cauliflower-like exteriors and slightly breadcrusted surfaces; they fracture along poorly developed polygonal joints. These features suggest that extensively degassed juvenile andesitic magma was ejected explosively as hot plastic fragments, which were incandescent upon ejection (according to eyewitness reports and slow-scan video views of the September 16–17 eruption) but were too viscous to attain appreciable degrees of rounding during flight.

The pyroclastic flows of both August 18 and September 16–17 were emplaced as hot juvenile clasts and sparse silt to sand-size matrix material were still hot to the touch when first examined about 40 hours after emplacement. Pyroclastic flows were hot enough (about 300°C) to char vegetation in contact with the andesite clasts. Vegetation adjacent to the flows was not charred, indicating low temperatures in the air around the descending flows. For several weeks after the August 18 eruption, a linear axial zone of weak fumarolic activity was present in the 2-m-thick center channel of the pyroclastic-flow deposits in Wilton's Walk near their distal end.

The flows were not fluidized, and gas played little if any role in their transport. Most flows probably moved so slowly that little or no air ingestion took place. Absolute flow rates are unknown; however, at a point 2.4 km from the crater rim and 0.8 km from the terminus of the flow in Wilton's Walk, a pyroclastic flow overrode a 4-m-high vertical bank and left a thin overbank lag deposit of juvenile andesite clasts. The pyroclastic flow at this point is estimated to have been traveling at about 22 km/hr on the basis of the relation $v^2 = gh$ where h is the height of bank, v is the velocity, and g is the acceleration owing to gravity (see Cas and Wright, 1987, p. 179 for a discussion).

Well-developed levees and surface ridges along the margins of the pyroclastic flow indicate that the denser main body of the flow had sufficient yield strength and momentum to push earlier deposited material aside. As the flows came to rest, clasts were dumped and formed steep lobate flow fronts 1 to 1.5 m high (figs. 4 and 5).

Fallback of pyroclastic material on interfluvial areas high on the cone deposited a veneer of chiefly juvenile debris lying at the angle of repose. The steep dip favored formation of numerous small secondary pyroclastic flows for several days after the August 18 eruption, and so most of these were soon stripped away.

Pyroclastic flows channeled into valleys and other topographic depressions attained a maximum thickness of 1 to 3 m. The thickest flows formed in Wilton's Walk, the widest gully on the southeast flank of Crater Peak. Most of these pyroclastic flows were later covered by September 16–17 lahars that descended to an elevation of about 975 m (3,200 ft). Considerable erosion in this drainage by lahars and associated flooding during the June 27 event cut deep channels from 975 m (3,200 ft) down to the 790 m (2,600 ft) level prior to deposition of the August 18 pyroclastic flows.

Figure 5. View to northwest of terminus of overlapping August 18 pyroclastic-flow deposits in Wilton's Walk. These deposits were produced from eruption of Crater Peak vent, Mount Spurr volcano, Alaska. Width of pyroclastic-flow deposit at terminus is about 15 m.

DISCUSSION

The pyroclastic flows at Crater Peak were probably emplaced episodically during each eruptive episode. The distribution of the small-volume pyroclastic-flow deposits indicates that they did not result from boilover through low points on the crater rim or through column collapse because apparently no pyroclastic flows traveled through the low point of the Crater Peak rim during any of the three eruptions. Indeed, the pyroclastic-flow deposits of August 18 and September 16–17 are downslope from some of the highest parts of the crater rim (2,200 to 2,290 m; fig. 1) on its eastern sector.

Some of the pyroclastic flows, particularly from the September 16–17 eruption, could have originated from asymmetrical collapse of an eruption column, because they were entirely contained within the tephra-fall area of that eruption (fig. 1). The short (about 3 km) runout distances of the pyroclastic flows suggests that the debris forming the pyroclastic flows did not rise high in the eruption column. Prevailing winds would seem unlikely to have a strong influence on the collapse pattern of such coarse material.

The zones of accumulation for the August and September pyroclastic flows are each spatially associated with large ballistic bomb fields (fig. 1). This association suggests that ballistic ejection from a confined and inclined vent may have been a factor in their formation. Numerous modest explosions from an inclined or shielded vent may have repeatedly reamed the conduit of high-viscosity andesitic magma that was already extensively degassed and that occupied the uppermost part of the conduit. Some of these explosions may have resulted from clasts too large to be expelled accumulating in the vent until it became temporarily choked. The resulting increase in pressure caused the expulsion of a mass of coarse debris. These slugs of stiff, brittle, and fragmenting magma were expelled to altitudes generally high enough (probably <1 km) to clear the northeast and east crater walls (about 310 m) before falling back to form heavy, near-vent tephra deposited near the angle of repose on steep slopes. This material was quickly mobilized into coarse avalanche-like pyroclastic flows that moved downslope and into gullies that lead out of the fall-out zone.

The difference in distribution of the August and September bomb fields may reflect a change in the location and inclination of the active vent. Aerial observations indicate that the active vent shifted between eruptions from the north-central part of the crater in June to a location against and slightly beneath the overhanging northwest crater rim by September. The steep north and west walls of the vent area and a resistant east-west buttress immediately south of the vent would block ballistic material going in those directions and favor ejection to the east, as was apparently noticed on the remote slow-scan TV on September 16–17.

The lack of pyroclastic flows associated with the June 27 eruption may reflect ballistic material from this eruption being deposited in the proximal area around the cone on a high, relatively flat, undulating ice field rather than on a steep-sided cone surface. The thick pre-eruption crater fill may also have inhibited the early generation of pyroclastic flows by ballistic fountaining, whereas during the later eruptions an "open vent" situation prevailed.

The lack of correspondence between the distribution of pyroclastic flows and the low part of the crater rim and the possibility of ballistic emplacement of pyroclastic flows has important implications for hazard analyses of volcanoes prone to vulcanian or subplinian eruptions. Certainly drainages downslope of low points on crater rims would always be areas susceptible to be filled with pyroclastic flows that utilize the breach during a boilover. But the distribution of pyroclastic flows at Crater Peak is a reminder that such flows can be generated by directed ejection and inclined column collapse. Thus hazards may exist on any flank of the volcano, even without major vertical column collapse. This possibility needs to be considered in hazard analysis.

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