DEPOSITS AND EFFECTS OF DEVASTATING LITHIC PYROCLASTIC DENSITY CURRENT FROM MOUNT ST. HELENS ON 18 MAY 1980--FIELD GUIDE FOR NORTHEAST RADIAL

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INTRODUCTION

At 08:32 PDT (15:32 UT) on 18 May 1980, a magnitude-5+ earthquake triggered a gigantic retrogressive landslide of at least three successive slideblocks that removed the summit and high north flank of Mount St. Helens volcano, Washington. The suddenly depressurized intruding cryptodome and surrounding hydrothermal system exploded, propelling a gas-rock mixture upward and northward. The hot mix, the so-called 'blast', swept off and away from the mountain as a ground-hugging pyroclastic density current--a sediment flow driven mainly by gravitational acceleration. From more than 600 km/hr on the lower volcano flanks, the front of the turbulent current gradually slowed to less than 100 km/hr as within 5 minutes it expanded north, east, and west across 600 km^2 of high-relief terrain.

The most turbulent leading edge leveled a mature coniferous forest; gravel-to-sand-size material began to accumulate swiftly, followed by accumulation of sand-size material, in turn followed by more gradual settling of silt-sized ash. The commonly clast-supported, even openwork texture of the massive lower part of the deposit, the only sparsely battered motor vehicles, the only partly removed fallen timber, standing timber debarked orders of magnitude higher than the density-current deposit is thick, the survival of people in such areas, and other evidence testify that the current was mainly a turbulent, low-concentration flow of particles and gas--mainly a pyroclastic 'surge'. Deposits of the primary current ponded in parts of some proximal valleys, into which secondary high-concentration pyroclastic flows of this material were also shed by the steep valley sides and tributaries. From broad areas of the hot density-current deposits north, northeast, and northwest of the mountain, a black column began to convect upward at about 08:36; within 5 minutes it reached altitude 15 km and within 10 minutes had enlarged into a colossal mushroom cloud, from which pisolites and silt-size ash began to fall widely by 08:55.

This fieldtrip along a radial northeast from the mountain shows diverse evidence revealing of the nature of the devastating current. Analysis of processes is based on observations scattered broadly about the devastated area, but the northeast radial is as good as any for analyzing the nature of the pyroclastic density current. This guide is intended only to provoke argument while confronting field evidence; it is not a finished synthesis.

GUIDE

Start at Randle, Washington, about 55 miles east of Interstate Highway 5 on U.S. Highway 12 at intersection of USFS Road 25. Travel to Mount St. Helens National Volcanic Monument southward along Road 25. At junction of Road 99 (big sign), turn west toward Windy Ridge (Fig. 1). Most of the stops are at conspicuous parking areas along the road, most of them marked by signs.

STOP 1. Bear Meadows (restrooms).

Site of 18 May 1980 magnificent eruption photographs by Keith Ronnholm and by Gary Rosenquist.

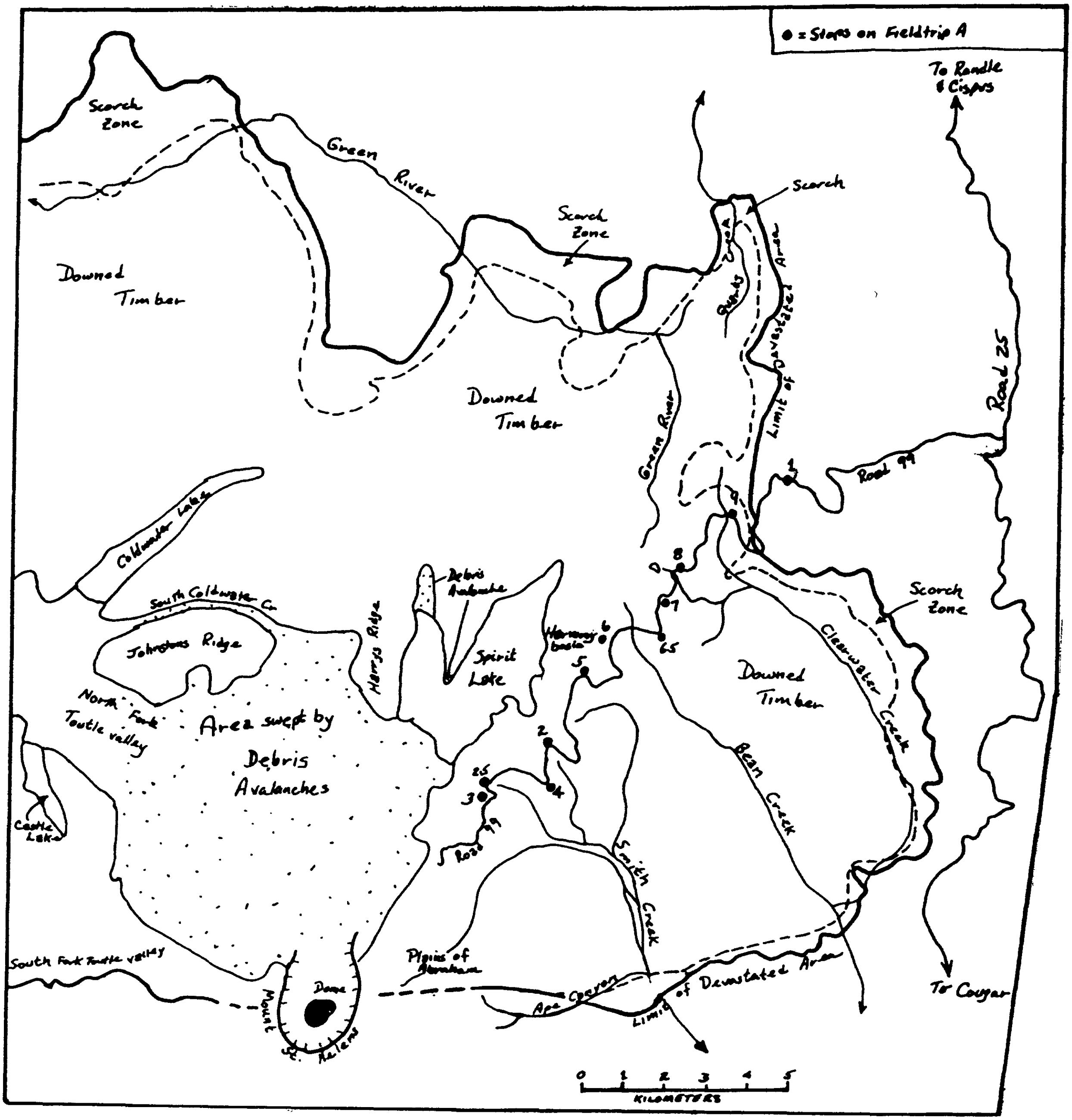

Figure 1. Sketch map of Mount St. Helens area showing locations significant to fieldtrip and indicating limits of downed-timber and scorch caused by devastating pyroclastic density current of 18 May 1980.

From Bear Meadows we enter devastated area whose outer edge is marked by a fringe of standing scorched timber retaining limbs, branches, and in 1980 even the scorched needles. Then we drive several kilometers through the downed-timber zone from a distal to proximal area. There will be several stops on return trip to photograph and to examine deposits, timber, automobile, etc.

STOP 2. Donnybrook overlook of Spirit Lake.

We pause here because lighting is better than it will be when we return in afternoon. Inferred from stratigraphy of deposits (Waitt, unpub. report), the general sequence of catastrophes at Spirit Lake on morning of 18 May 1980 is:

(1) Front of pyroclastic density current sweeps northeast at 400 km/hr, leveling mature coniferous forest and depositing gravel layer;
(2) Toe of first landslide enters lake at > 250 km/hr and plows northward along west arm of lake; material from colossal landslide mass west of Harrys Ridge descends the ridge eastward into lake basin;
(3) First landslide suddenly displaces lake water, causing catastrophic wave to sweep northward up both arms of lake (trimline rises up both arms and is conspicuous where wave swept across middle spur from west to east arm of lake);
(4) The water, having sloshed up both arms of lake and around side valleys, rushes back into lake, now dammed 60 m higher by the landslide;
(5) Meanwhile waning density current continues, depositing sandy layer;
(6) All this excitement lasts perhaps 2 minutes; various ensuing airfalls of mid-morning to late afternoon are better discussed at Stop 3.

STOP 2.5. Windy Ridge parking lot (restrooms).

Pass through locked gate toward Restricted Area (permission required from Mount St. Helens National Volcanic Monument headquarters [USFS] at Chelatchie Prairie). About 0.5 km beyond gate, park in slot on right. Hike north along ridgecrest to summit. Alternatively, leave by foot from Stop 2.5 and hike south to summit. This way you need not pass through the gate and may avoid need for permission (Stop 3 lies along boundary of Restricted Area, not within it).

STOP 3. Windy Ridge, summit south of parking lot.

Overview of north flank of Mount St. Helens showing major effects of 18 May 1980 eruption: great landslides, devastating lithic pyroclastic density current, pumiceous pyroclastic flows and ash clouds. On Pumice Plain 18 May deposits are overlain by June-October 1980 pumiceous pyroclastic flows (Rowley and others, 1981) and by snow-avalanche and flood deposits of March 1982 and later (Waitt and others, 1983). At head of west arm of Spirit Lake see hummocky deposit of 18 May landslide that traveled entire length of lake.

Prepared trench near summit shows 18 May 1980 deposit of the lithic pyroclastic density current (unit A) containing more than 50% of characteristic poorly inflated gray juvenile dacite from the March-May 1980 cryptodome. About 1 m thick, deposit is normally graded from pebble gravel at base to silt at top. In the field terminology of 1980 (Waitt, 1981; Waitt and Dzurisin, 1981): layer A1 (gravel) is about 85 cm thick, layer A2 (sand) 14 cm thick, and layer A3 (silt) 1 cm thick. The lower half of unit A is rich in downed logs and in litter stripped from trees, and it contains gray dacite and denser lithic clasts as large as 20 cm diameter. Lower half of A2 is massive granular sand, the fine graded top of massive layer A1; upper half of A2 is laminated sand akin to classic 'surge' deposits. Layer A3, mainly airfall from great mushroom cloud, began accumulating 20 minutes after beginning of eruption. Layer A3 is overlain by 18 May 1980 airfall pumice (unit B) and co-ignimbrite ash (unit C), which is capped by airfall pumice from 22 July 1980 (Waitt and others, 1981).

Only 4 years after the devastating density current, the published literature on the event already includes controversy:

A. Field investigators in 1980 inferred that the devastating event emanated from Mount St. Helens and began with the initial explosions (Hoblitt & others, 1981; Moore and Sisson, 1981; Waitt, 1981; Kieffer, 1981; Rosenbaum and Waitt, 1981); but Moore & Rice (1983) infer that the main devastating explosion occurred several kilometers north of the mountain about 2 minutes after the initial explosions (Fig. 2).

B. The same investigators in 1980 inferred that the devastating current was a relatively low-concentration 'surge' that generated small high-concentration 'flows' into proximal valleys; but Walker & McBroome (1983) infer instead that it was mainly a high-concentration 'flow' that locally generated minor 'surges'. This issue is discussed in a comment-and-reply exchange (Hoblitt and Miller, 1984; Waitt, 1984; Walker and Morgan, 1984).

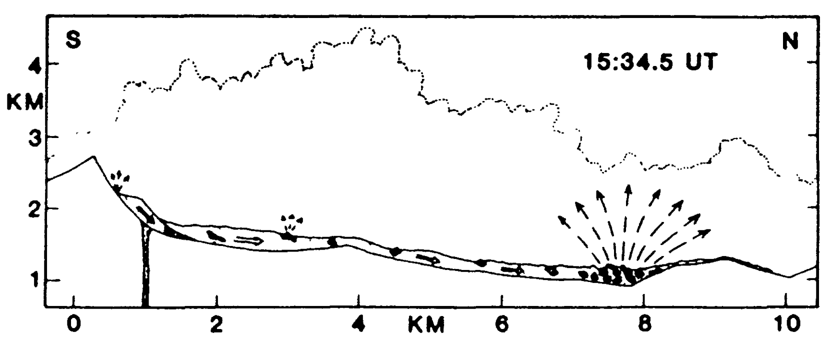

FIGURE 2. Section showing the development of the northern explosions when the hot fragmented cryptodome (stippled) of avalanche block II collided with the Toutle River valley wall or encountered water in the Toutle River drainage and Spirit Lake about 8 km north of the posteruption back crater rim. (Moore and Rice, 1983).

Comments on Controversy A. The Moore & Rice idea of a second explosion away from the main vent is based on interpretation of satellite data. But neither independent field evidence nor eyewitness accounts and photographs support this idea; rather, the deposits, downed timber, and eyewitness photographs indicate that the devastating current flowed from the cone of Mount St. Helens.

1. The mature trees on the northeast side of the ridge about 0.5 km south of Stop 3 were toppled northeastward--appropriate for a flow from Mount St. Helens but perpendicular to the direction they would have been toppled by an explosion near Spirit Lake. This area lies well within Kieffer's (1981, p. 392-395) "direct-blast zone", where directions of the current, inferred to be supersonic, were not radically affected by topography. At and north of Stop 3, the timber downed toward azimuth 075 also is wrong for a current emanating from a source well north of Mount St. Helens. The erosive head of flow therefore came from Mount St. Helens, not from a northern source.
2. The south sides (facing Mount St. Helens) of eastwardly downed logs are much more abraded than the north sides (facing Spirit Lake and lower Pumice Plain: the sustained, waning phase of current behind the front was even more aligned with Mount St. Helens, not with a northern source.
3. The preferred accumulation of density-current deposit against the south side of downed logs further indicates sustained waning flow was from Mount St. Helens, not from near Spirit Lake.
4. On the Pumice Plain there is no known deposit of large blocks of gray dacite that should be conspicuous had there been a great explosion of cryptodome blocks there after they descended in landslide block 2 (Fig. 2).

Comments on Controversy B. The deposits and timber here and at other proximal sites suggest that the devastating density current here was a relatively low-concentration 'surge', not a high-concentration 'flow'.

1. Much of the coarse basal half of the deposit is clast supported and thus 'deficient' in fines compared to unequivocal pyroclastic-flow deposits; if the erupted mix contained much fine material, much of it was winnowed out, suggesting a turbulent, low-concentration surge.
2. The clasts are angular to very angular; gravel-sized clasts traveling in intimate contact with other clasts of similar hardness and size should show some rounding after more than 3 km of transport.
3. 'Warbonnet' stumps: how could such delicate upward-fanning splinters withstand the passage of a high-concentration flow? (The abraded west-facing undersides of upturned root discs demonstrate a considerable sustained flow after the initial tree-felling phase.)
4. Many or most tree trunks lie where they fell. How could a high-concentration flow of dense lithic clasts not transport most of these lower density logs?
5. There is unfilled space beneath some of the felled logs; how could this occur if the flowing material was high concentration to begin with?
6. The upper surfaces of downed logs that project above the deposit are far more abraded than the undersides, which commonly retain bark. Therefore particles fell on downward trajectories as well as moved laterally; any high-concentration flow should have done more to the undersides of downed logs.

7. Even in this proximal area, some small-diameter trees managed to remain upright and rooted; is this possible had they been engulfed in a high-concentration flow?

Stop 3.5. Windy Ridge parking lot again (restrooms). Continue northeastward along Road 99.

STOP 4. Smith Creek viewpoint (Lunch stop). Pull into large bulldozed area on right on outside of sharp bend in road where it crosses prominent southeast-trending spur (Fig. 1).

From parking area walk southeastward along spur crest to former road crossing, where density-current deposit is exposed in gullies. Compare characteristics of the deposit and of the standing and downed timber with those at Stop 3.

Standing trunks of large trees on lee (east) side of ridge show that front of density current lofted off ridgecrest; many standing trunks are debarked, but many retain bark even at their bases. Most of the small-diameter trees remained upright in the current. These relations seem inconsistent with the idea that the density current was mainly a dense, high-concentration 'flow' but are consistent with the idea of relatively light, low-concentration 'surge'.

The graded deposit on the former roadbed is thinner and the base finer than at the more proximal Stop 3. The deposit 'ponded' decimeters thick on the near-level roadbed, but it pinches out abruptly on steep faces both upslope and downslope. Slopes steeper than about 25^{o} did not permanently accept deposits of the density current, though some airfall (A3, B, C) accumulated there later. The unstable, fluid density-current material laid on such steep slopes must have drained off as secondary flows.

Smith Creek valley: the valley fill consists of several deposits in stratigraphic succession: (1) ponded primary density-current material, (2) debris flow emplaced in at least 2 separate plugflows, (3) secondary lithic pyroclastic flows derived from valley sides and tributaries (Waitt, unpub. report). The paths taken by water melted on the Mount St. Helens cone by the hot density current can be followed down two tributaries into head of Smith Creek. The flows and the consequent plugflows on the valley floor must have taken several minutes to descend from Plains of Abraham to the valley floor. (Calculated from runup on ridges, flow velocities exceeded 100 km/hr at Plains of Abraham, but were much slower in upper Smith Creek.) Therefore the pyroclastic-flow material overlying these debris-flow deposits is truly secondary--emplaced at least 5 minutes after the primary density current swept through the valley. All these deposits are capped by layer A3, which shows that the entire sequence of diverse flowage material accumulated and stabilized in less than 20 minutes.

STOP 5. Harmony basin viewpoint.

Harmony basin shows effects of the pyroclastic density current and the following catastrophic wave of lake water displaced by the landslide (Waitt, unpub. report). The inferred sequence is:

(1) Density current sweeps northeastward, leveling forest and depositing layer A1. Patterns of downed timber indicate that topography separated the ground-hugging current: (a) Most of visible area was swept by northeast-moving current channeled along Spirit Lake basin; (b) but the head of Harmony basin was swept by current moving northward up the Smith Creek tributary and over the divide into the head of Harmony basin; (c) this northeast current turned west into the southeast part of basin, into the 'lee' of a summit along the ridgecrest.
(2) Landslide entering south end of Spirit Lake at 250 km/hr creates catastrophic wave; part of wave surges up Harmony basin, rinsing slopes clean of timber and of layer A1 up to a level marked by a sharp trimline on north valley side.
(3) Losing momentum, this water descends to the basin floor and flows back westward to Spirit Lake, depositing 'rafts' of randomly oriented timber on basin floor but carrying most timber into the lake, where it remains.
(4) Gradually waning pyroclastic density current continues, depositing layer A2.
(5) Layer A3 and later airfalls accumulate.

As at other localities we have visited, the condition and nontransport of downed and standing timber in this area suggest that the density current was a low-concentration 'surge'; they seem inconsistent with the concept of a dense, high-concentration 'flow'.

STOP 6. Independence Pass Trail.

Hike along trail to ridgecrest (0.3 km); please do not dig holes in this area of heavy use by tourists.

Along the trail the density-current deposit is only about 20 cm thick. The hike through downed timber is an opportunity to explore the diverse effects of the density current on both the large and small trees. Many of these suggest that the flow had low concentration: some small trees, possibly snow-covered during the 18 May eruption, retained their bark and thus life; very few trees were transported or re-oriented after they fell; standing trunks on and behind summit to north indicate that the sedimentary flow (density current) was of low enough density to loft.

STOP 6.5. Refreshment area & restrooms.

STOP 7. Clearwater Creek headwaters.

Park on gravel road descending to right. Hike along creek bed and to ridgecrest 0.3 km to south.

In tributaries on valley floor the density-current deposit, rich in gray, juvenile dacite and as thick as 50 cm, is normally graded from sandy small-pebble gravel (A1) to medium sand (lower A2), overlain by bedded fine sand (upper A2) and airfall sandy silt (A3). The bed thins to as little as 10 cm, where its base is granular sand.

On ridgecrest south of valley, a prepared trench exposes the deposit variably 8-25 cm thick, whose base is granule gravel. Along the northeast radial from Mount St. Helens (Stops 3 to 4 to 7), the deposit thus grades steadily outward to generally thinner and finer material.

Overlying density-current layer A2 is the airfall sequence: A3 (great mushroom cloud), B (main-vent pumice), C (distal ash from pumiceous ashflows and ash clouds), D (late main vent), and 22 July pumice.

Ridge provides an overview of the intermediate to distal part of devastated area, including downed big trees, standing large trunks, standing small trees, and in distance the fringing zone of scorched standing trees with intact limbs. Do you think the devastating current was a 'flow' or 'surge', neither or both?

STOP 8. Parker-family automobile.

Density current moved the automobile only a few meters northeastward off the road, battering it most with flying timber fragments. A sustained trailing, hotter part of the current then burned off the paint and plastic parts. Nearby the owners briefly outlived the current, but died from suffocation due to clogging of trachea with inhaled ash (Eisele and others, 1981).

[Alternate return route to Randle, Road 26, branches south from here. It offers spectacular views of downed timber. To complete sequence of deposits on northeast radial, go to Stop 9, then return to this junction.]

STOP 9. Scorch zone (any convenient stopping place in this area will do).

Density-current deposit has thinned to 1-1.5 cm and consists only of sand (A2) capped by airfall layer A3. On the north and northwest radials the thinning and fining are more gradual over comparable distances than between Stops 7 and 9 on this northeast radial.

Return to Randle via Roads 99 and 25, or return to Road 26 and return to Randle that way.

End Fieldtrip A.

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