LAHARS IN CRESCENT RIVER VALLEY, LOWER COOK INLET, ALASKA

By
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Cover photo: Redoubt Volcano in eruption, January 1966. (Taken by Jon Gardey from an airplane on north side of volcano looking west.)

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By James R. Riehle,[1] Juergen Kienle,[2] and Karen S. Emmel[1]

ABSTRACT

Previously unrecognized lahars (volcanic mudflow deposits) occur in the Crescent River valley, west side of lower Cook Inlet. The lahars extend from glacier valleys on the southwest flank of Redoubt Volcano to the shore of Cook Inlet, a distance of more than 25 km. Radiocarbon analyses of large pieces of wood suggest that the lowest lahar exposed in sea cliffs was deposited about 3,500 yr ago. The lahars may have been produced by events similar to the 1966 eruption of Redoubt Volcano, which resulted in mudflows and flooding of nearby Drift River. Although it has been several thousand years since lahars reached the shore of Cook Inlet via the Crescent River valley, such events could occur again.

INTRODUCTION

A lahar is a flowing mixture of rock debris and water that originates on the flanks of a volcano or the deposit of such flows (Crandall, 1971, p. 3, following van Bemmelen, 1949).[3] Lahars are either mudflows or debris flows. Sharp and Nobles (1953) defined 'debris flow' as the deposit of a rapid flowage of loose soil and rock debris mixed with water. Varnes (1958) restricted 'mudflow' to moving debris containing at least half sand-sized and finer material. Poor sorting of mudflow materials results in high density and high transport competency, but there must be a fluid phase (clay-water mixture) with sufficient strength and density to support the smaller granular constituents (Rodine, 1975). Each size range of granular constituents in turn supports the next larger range.

Mudflows are more than 80 percent sediment during flow; another type of flow, called 'hyperconcentrated flow' is intermediate between normal streamflow (less than 40 percent sediment) and mudflow (Beverage and Culbertson, 1964). Because the processes of transport are gradational from mudflow to normal streamflow, lahar deposits may range from nonsorted deposits of mudflows to interbedded deposits of fluvial sand and gravel (Crandall, 1971, p. 5).

Lahars originate in many ways. Some form directly through volcanic activity, such as eruptions through a crater lake, direct eruption or ejection of mud through volcanic vents, or avalanching of hot rock debris. Meltwater lahars originate by the eruption of lava, hot ash, and blocks onto snow or ice or by subglacial volcanic heating. Other lahars are only indirectly related to volcanic activity. Failure of crater walls, for example, may occur at times other than during an eruption. Blankets of ash and pumice, which are common on flanks of active volcanoes, frequently slide and flow when saturated during heavy precipitation. Volcanic rocks weakened by alteration around fumaroles and hot springs occasionally fail by sliding, resulting in lahars. Some volcanic landslides dam rivers; these dams later fail, generating floods and lahars. Among the most spectacular floods are "jökulhlaups," caused by subglacial volcanic heating, commonly observed in Iceland. These large floods are the result of the sudden release of meltwater stored in subglacial or englacial reservoirs (Crandall, 1971, p. 8-10; MacDonald, 1972, p. 170-81; Williams and McBirney, 1979, p. 171-78).

DESCRIPTION AND INFERRED ORIGIN OF THE DEPOSITS

LOCATION

Redoubt Volcano is an active, andesitic stratovolcano located 175 km west-southwest of Anchorage and 20 km inland from the west shore of Cook Inlet (fig. 1). Four periods of activity have been recorded between the discovery of the volcano in 1778 by Captain James Cook (Beaglehole, 1967), and 1933 (Coats, 1950). Events in 1778, 1819, and 1933, when only 'smoke'[4] was reported, were apparently minor. In 1902, however, an eruption spread ash about 200 km northeast to the towns of Knik, Hope, and Sunrise.[5] The most recent activity occurred from 1966 to 1968, when ash clouds reached heights of 13,500 m (Wilson and others, 1966; Wilson and Forbes, 1969).

The inferred extent of the Crescent River lahar deposits is based largely on photointerpretation (fig. 1). The surface morphology of the deposits is fanlike in the area east of Crescent Lake (fig. 2) and adjacent to Cook Inlet. The deposits are probably thickest in the fans and

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[3]'Lahar deposit' is used hereafter to emphasize the distinction between the process of flow and the resulting deposit.

[4]'Smoke' is frequently used in historic records, and refers to steam or steam and ash clouds.
[5]Various articles in the newspaper "The Alaskan" in March 1902.

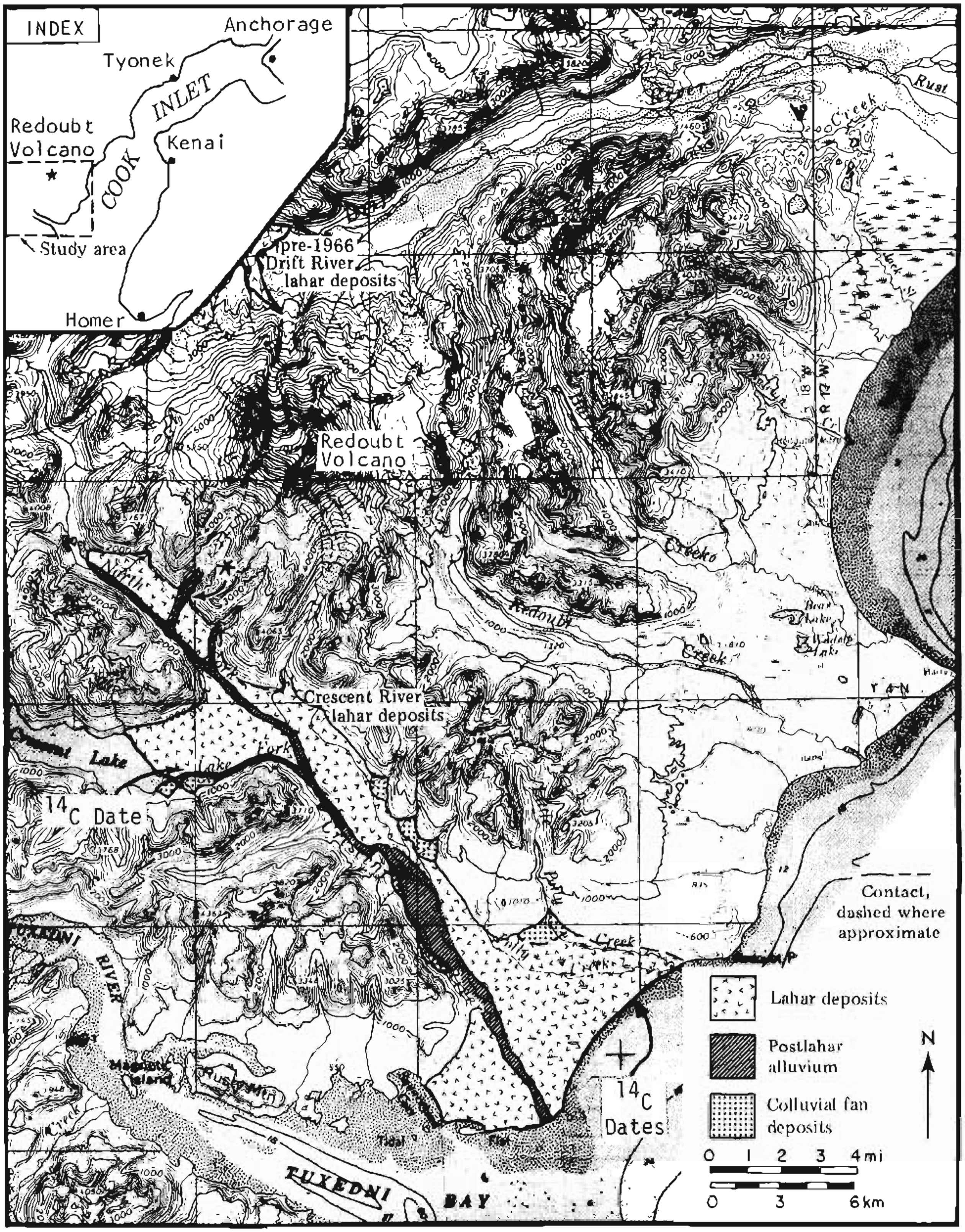

Figure 1. Photointerpretation map showing inferred extent of lahars in vicinity of Redoubt Volcano. Most lahar deposits may have originated high up on the volcano, at the head of the tributary valley marked by an asterisk.

thinner in the narrow linear valleys (cf, Crandall, 1971, p. 7). The total area inferred to be underlain by lahar deposits is about 87 km^2. At a conservative figure of 5 m for the average thickness, a minimum estimate of the volume is 435×10^6 m^3. This estimate may be in error by an order of magnitude, but it serves to emphasize the enormous size of the deposits.

Photointerpretation suggests the lahars originated at the head of one, and possibly all four, tributary valleys that drain the summit region of Redoubt Volcano southwest to the North Fork of Crescent River (fig. 1). Glaciers occupy three of these four valleys. Three of the four fans formed at the mouths of the tributary valleys have coalesced on the floor of North Fork valley. The fan of the tributary shown by an asterisk (fig. 1) is dissected by stream erosion, and exposes several meters of poorly sorted material comprising two distinct beds. On the basis of brief examination, we tentatively interpret the exposed materials as lahar deposits. Because this fan is also by far the largest of the four—in fact, displacing the North Fork to the far valley wall—we infer that this particular tributary valley may have been the principal source of the Crescent River lahars.

The original seaward extent of the lahar deposits is unknown. Large blocks of fresh andesite, similar to blocks in the lahar deposits exposed in the sea cliffs, occur in the intertidal zone off the mouth of the Crescent River. The seaward extent of these blocks has not been mapped, but the deposits have certainly been reduced from their original extent by marine erosion.

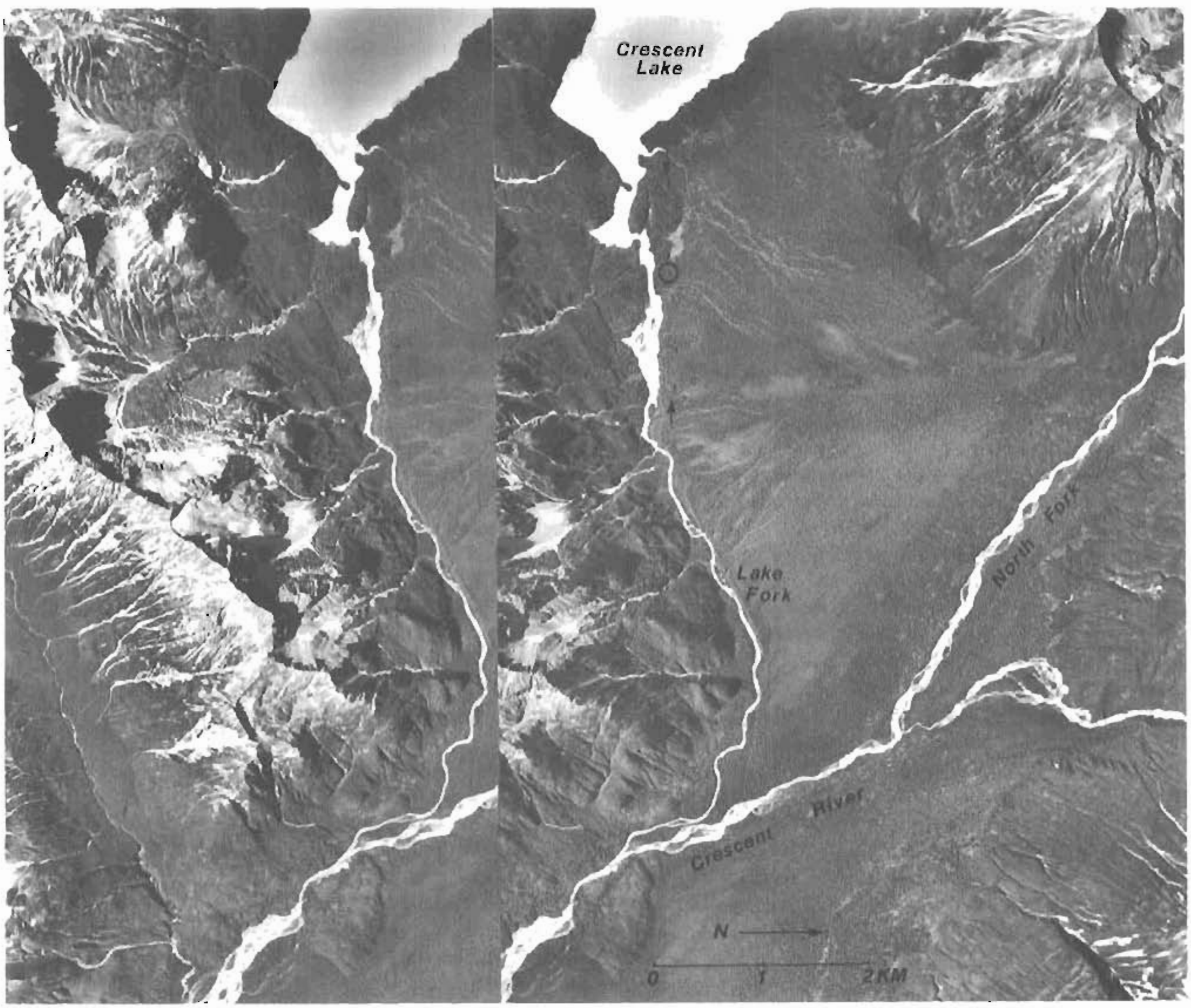

Figure 2. Stereo pair showing morphology of lahar fan north of Lake Fork of Crescent River. Low mounds between arrows are probably piles of large blocks deposited by lahars. Note relict radial channels and apparent absence of active surface drainage. Radiocarbon sample was collected from crest of circled mound (fig. 1). U.S. Geological Survey photos M 4H54-125 and -126, August 29, 1954.

An interesting geomorphic feature in figure 2 is a series of low mounds, from 15 to 60 m across and up to 15 m high, along the banks of the Lake Fork of the Crescent River. At the top of one mound we observed 45 cm of alternating layers of light ash and dark organic-rich ash atop a lahar deposit, which we excavated to a depth of 75 cm.

INTERNAL CHARACTERISTICS

Deposits of at least two individual lahars are exposed in 10-m-high sea cliffs along Cook Inlet (fig. 3). The thickness of each lahar deposit is from 1 to 3 m. Stratified fluvial sediments make up only a minor part of the material exposed in the sea cliffs. Up to 1 m of fluvial sediments crops out beneath the lowermost lahar deposit at most locations; other lahar deposits may exist at depth. Stratified deposits between or atop exposed lahar deposits comprise thin sheets or lenses rather than cut-and fill channel deposits. Such stratified deposits may have formed during the final stages of lahar activity when some flushing of fines by internal drainage may have occurred.

Lahar deposits exposed in the sea cliffs are nonsorted and internally massive. Largest clasts are about 1 m in maximum dimension, but most of the coarse clasts are less than 0.75 m. Coarse clasts are predominantly fresh porphyritic andesite; a few are equigranular and composed of plutonic rocks of the Aleutian Range batholith (Detterman and others, 1976) on which Redoubt Volcano is constructed. There is an upward decrease in the mean size of cobbles and larger clasts within individual deposits (inset, fig. 3), and a quick point count suggests that the abundance of pebble and larger clasts decreases from about 40 percent at the bottom to about 20 percent at the top. X-ray diffraction analyses of the fine fraction from two lahar samples identify mainly plagioclase and hornblende with little clay or chlorite. Thus, the lahar material apparently is derived from fresh flows and volcanic ash. We have no data to indicate that hydrothermal alteration products are present in significant amounts.

The size distribution of the fine part of a Crescent River lahar deposit compares closely with size distributions of Mount Rainier lahar deposits and till (fig. 4). Bull (1964) used sorting coefficient, phi-standard deviation, and phi-quartile deviation to classify alluvial fan deposits into water-laid, mudflow, and intermediate categories. Our grain-size analyses fall into Bull's mudflow category according to all three parameters; the sand-sized-and-finer fraction is greater than 50 percent (at least at the top of the lahar deposits).

A tilted block of stratified sand and gravel occurs midway between Polly Creek and Crescent River (fig. 5). The steep dip and absence of an obvious channel in the surface of the lahar deposit suggest that the block is an accidental inclusion of prelahar fluvial sediments in the lahar deposit. A sand dike in the block suggests that the block failed brittlely while the enclosing lahar was still fluid.

Airfall ash layers locally underlie the upper and lower lahar deposits. Near the mouth of Crescent River, for example, 1 cm of medium-to-coarse sand-sized ash underlies the upper lahar deposit. Beneath the ash, up to 1 m of laterally discontinuous, stratified sand and gravel overlies another lahar deposit.

We have no data that bear specifically on the temperatures of emplacement. Colors of the lahar deposits are purple gray and red brown. At one locality 6 cm of red-brown sand and silt occur between an ash layer at the base of the lower lahar deposit and above cross-bedded fluvial sediments. The red-brown color may be due to heating by the lahar or it may be primary. Wood fragments in the lower, purple-gray lahar deposit have a thin black rind, which may be carbon produced by postdepositional oxidation or by heat during emplacement.

Lahar deposits were examined at only three inland localities. Observations at the tributary fan on the North Fork and in a pit excavated in a mound near Crescent Lake have been previously discussed. The third locality is a riverbank exposure about 1 km upstream from the confluence of Lake Fork and North Fork (fig. 1). Four individual beds, each from 1 to 2 m thick, compose most of the 9-m-thick exposure. Three beds are mixtures of pebbles and cobbles with some sand and boulders; the fourth bed is about 80 percent pebbles, cobbles, and boulders and 20 percent silty sand. The largest clast observed in place was about 1 m in maximum dimension, but clasts as large as 2 m were observed nearby on the modern flood plain. Vertical size gradation of larger clasts was not apparent. These deposits differ from those exposed in the sea cliffs in their coarser matrix, their lack of obvious vertical size gradation, and their apparent lack of interbedded, well-stratified fluvial deposits or ash. Either the differences in the riverbank exposure are due to lateral variations within the lahar deposits, or the deposits simply do not correlate with those exposed in sea cliffs.

INTERPRETATION OF OBSERVATIONS

On the basis of grain-size distribution (fig. 4), the Crescent River deposits exposed in sea cliffs may be classified as mudflows. As figure 4 shows, the deposits also resemble till; however, the distinction between till and lahar deposits cannot be made solely on the basis of grain-size distribution. For example, Crandall (1971, figs. 3 and 11) reports size distributions of till from Mount Rainier that are similar to nearby deposits of the Osceola Mudflow, a lahar.

Features other than grain-size distribution support the inference that the Crescent River deposits are lahars rather than till. First, upward fining has been noted in lahar deposits elsewhere and Crandall (1971, p. 6) suggests that such vertical gradation aids in

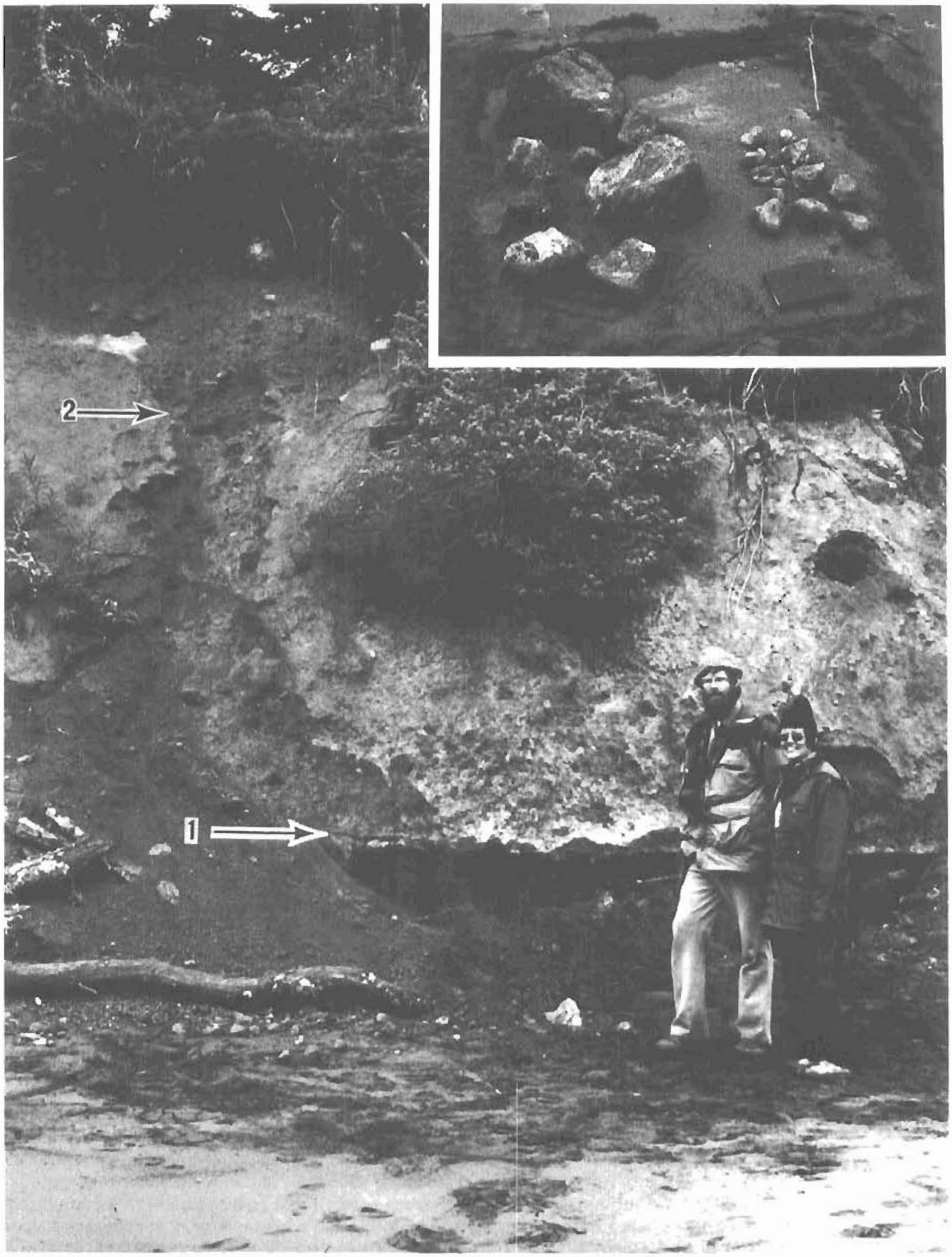

Figure 3. Lahar deposits exposed in sea cliffs 6 km northeast of mouth of Crescent River. Base of lowest exposed lahar (1) and contact between lower and upper lahars (2) are marked. Stratified alluvium underlies lahars, but is separated from them by soil horizon (1). Inset shows size variations of representative clasts from bottom (left) and top (right) of lower exposed lahar (field notebook gives scale).

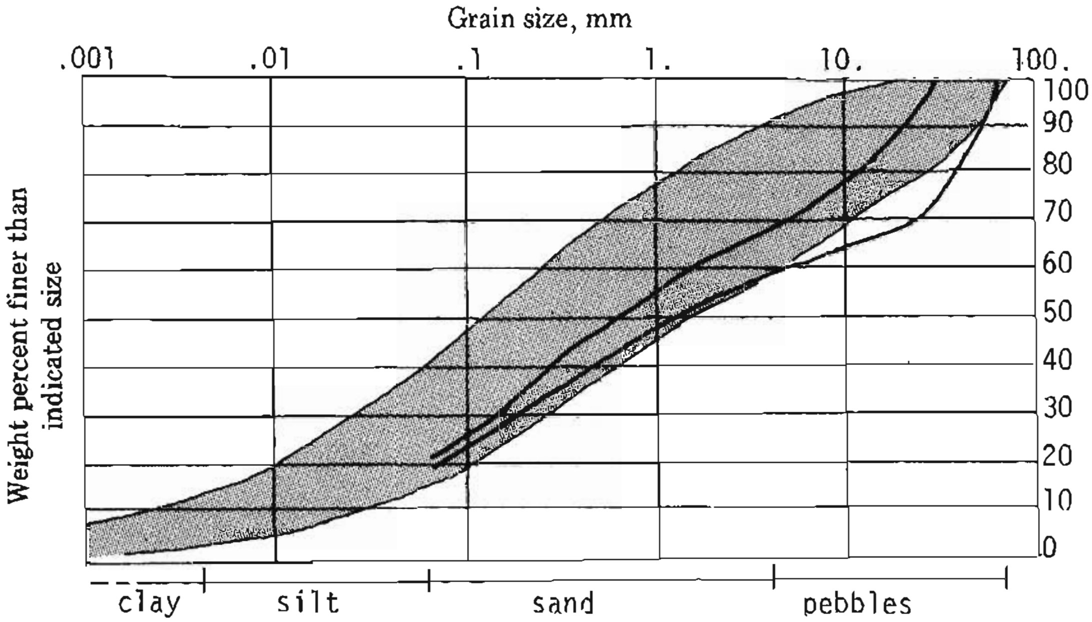

Figure 4. Solid lines are cumulative size distributions of two sea-cliff samples from Crescent River lahars. Shaded matrix envelope represents size distributions of eight samples of Osceola Mudflow and three samples of Evans Creek till, Mount Rainier (Crandall, 1971, figs. 3 and 11).

distinguishing lahars from till. Second, it is difficult to imagine that the ash that commonly underlies the Crescent River deposits would not have been eroded by glaciers depositing the overlying till. Ash layers are reported to underlie lahar deposits elsewhere and they indicate the inability of mudflows to erode during passage (Crandall, 1971, p. 8). Third, the age of the deposit (about 3,500 yr) is probably too young for till. Moraines correlated with the Tustumena Stade occur from 2.4 to 4.5 km beyond present valley glaciers in the Iniskin-Tuxedni region south of the Crescent River (Detterman and Hartsock, 1966). The Tustumena Stade on the east side of Cook Inlet ranges from about A.D. 200 to about 3500 B.C. (Karlstrom, 1964). The nearest valley glacier is more than 20 km from the Crescent River deposits at the coastline, and it is highly improbable that Tustumena-age advances of Crescent Valley glaciers reached the coastline.

The origin of the mounds near Crescent Lake is uncertain. If the preceding arguments are accepted as proof of the laharic origin of the deposits, then the mounds must be similar to one of two types of mounds found in lahar deposits elsewhere. One type consists of large blocks of rock, commonly veneered by fine lahar material. These blocks are probably deposited in an initial rush of the lahar, and the finer material subsequently drains downvalley so that the surface adjacent to the blocks is lowered. Such block-cored mounds on Mount Rainier are up to 120 m across and 30 m high (Crandall, 1971). Another type of mound is thought to result from extrusion of fluid material from within a lahar through fractures in a desiccated upper surface. Such mounds are described by Mason and Foster (1956), who attribute extrusion to hydrostatic pressure where the lahar comes to rest on an inclined prelahar surface. These extrusion mounds are from 10 to 60 m high and from 75 to 600 m across. Although we found no blocks within 75 cm of the surface of one mound at Crescent Lake, such blocks could be more deeply buried beneath fine lahar material. On the basis of their sizes, we prefer a block-pile origin for the Crescent River mounds.

AGE OF THE LAHARS

We have uncorrected ages of 3,450 $\pm$ 140, 3,560 $\pm$ 160, and 3,605 $\pm$ 145 radiocarbon yr[6] for three different wood fragments collected from the lower lahar deposit in a sea-cliff exposure about 6 km east of the Crescent River (figs. 1 and 6). Each wood fragment had a carbon rind several millimeters thick but did not appear to be internally carbonized. At the sample locality the upper lahar deposit rests directly on the lower lahar deposit, and there is no apparent weathering profile at the top of the lower deposit (fig. 6). One lahar apparently followed the other closely in time.

Near the sample locality the upper lahar deposit is overlain by soil, peat, and ash. Six distinct layers of air-fall ejecta occur in the lower part of the section (fig. 6). Although we have no data on rates of peat accumulation at the site, the presence of more than 40 cm of peat and

[6]Geochron Laboratories, samples GX6999, GX6998, and GX-5771, respectively.

organic soil above the upper lahar deposit is consistent with an apparent lahar age of about 3,500 yr. A single uncorrected age of 3,295 ± 135 radiocarbon yr[7] for peat overlying the upper lahar supports an age of 3,500 yr.

[7]Geochron Laboratories, sample GX7000

A sample from the top of a lahar mound near the outlet of Crescent Lake (figs. 1 and 2) gave a single uncorrected age of 2,955 ± 130 radiocarbon yr.[8] The sample was a fine, dark-gray to black organic soil underlain by 2 cm of white-gray ash that is in turn underlain by a diamicton. We infer that the diamicton is part of the Crescent River lahar deposit.

[8]Geochron Laboratories, sample GX7001.

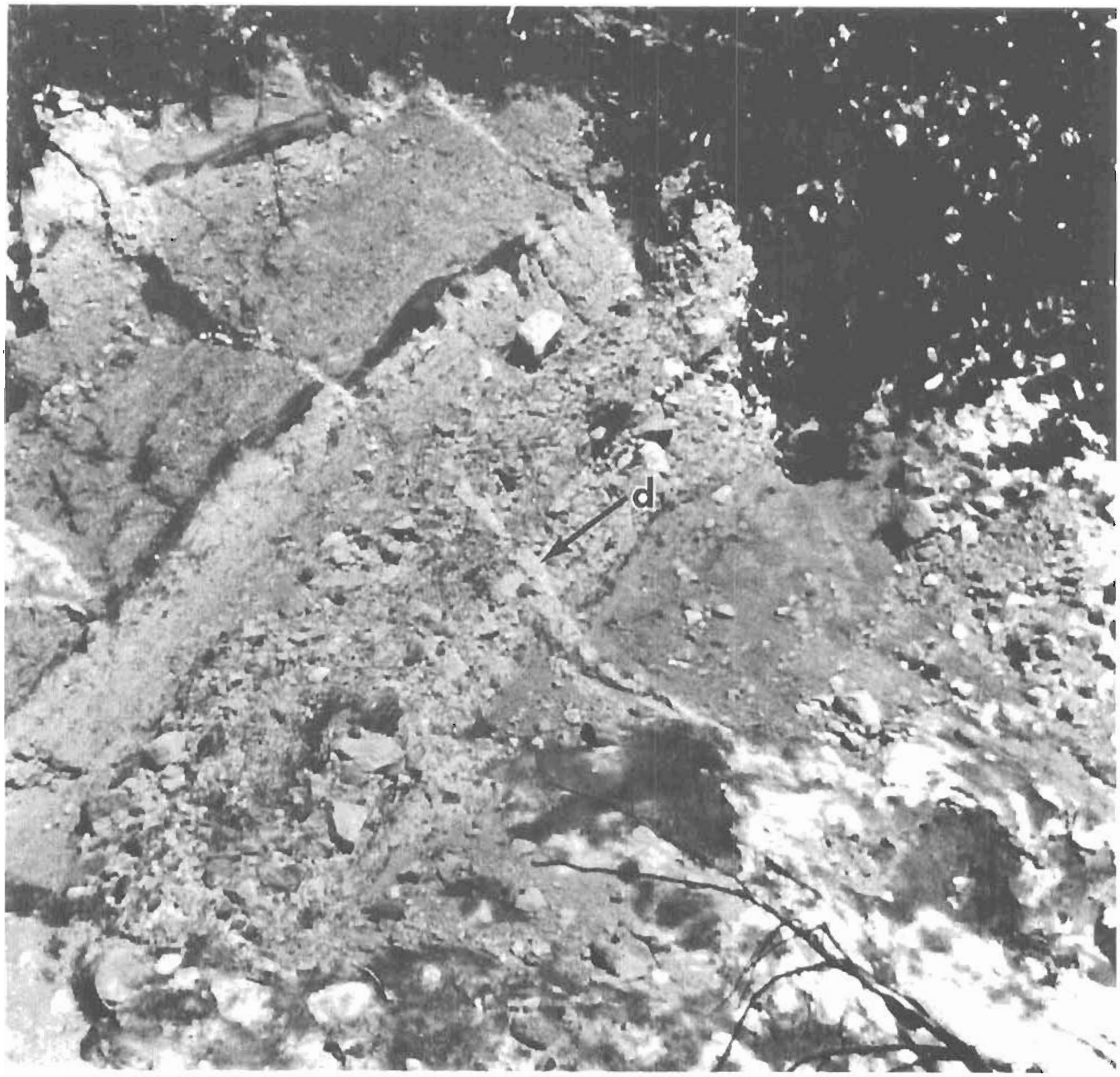

Figure 5. Inclined block of stratified sand and gravel enclosed in lahar material in sea cliffs about 4 km northeast of mouth of Crescent River. Sand dike (d) is marked. Total exposed width of block is about 2 m. Photograph by M.D. Howland, June 1978.

ORIGIN OF THE LAHARS

On the basis of available data, we speculate on a possible scenario for the origin of the Crescent River lahars. At least two lahars, each preceded by deposition of airfall ash, are documented in the sea-cliff exposures. At one locality a thin basal ash layer overlying alluvium indicates that an ash eruption closely preceded lahar deposition. In fact, the lahars were probably triggered by eruptive activity.

The apparent brittle failure of the block of sediment shown in figure 5 suggests that the block was frozen at the time of transport. If so, then the triggering eruption must have occurred during winter or early spring. Such conditions are similar to those at the time of the Drift River flooding during the winter of 1965-66. On January 25 and February 9, 1966, two flash floods with fronts as high as 4.5 to 6 m occurred on the Drift River (fig. 1). The first carried ice blocks described "as big as a D-7 Cat"; the second flood was apparently ice free.[9]

[9]The January 25, 1966 flood was reported in the January 26, 1966 edition of the Fairbanks Daily News-Miner. The article mentioned that a seismological crew was rescued from the flood plain of the Drift River. The second flood was mentioned by Mr. Frentley, Atlantic Richfield Oil Company, Anchorage, in a 1966 telephone conversation with Dr. R.B. Forbes, Geophysical Institute, University of Alaska, Fairbanks.

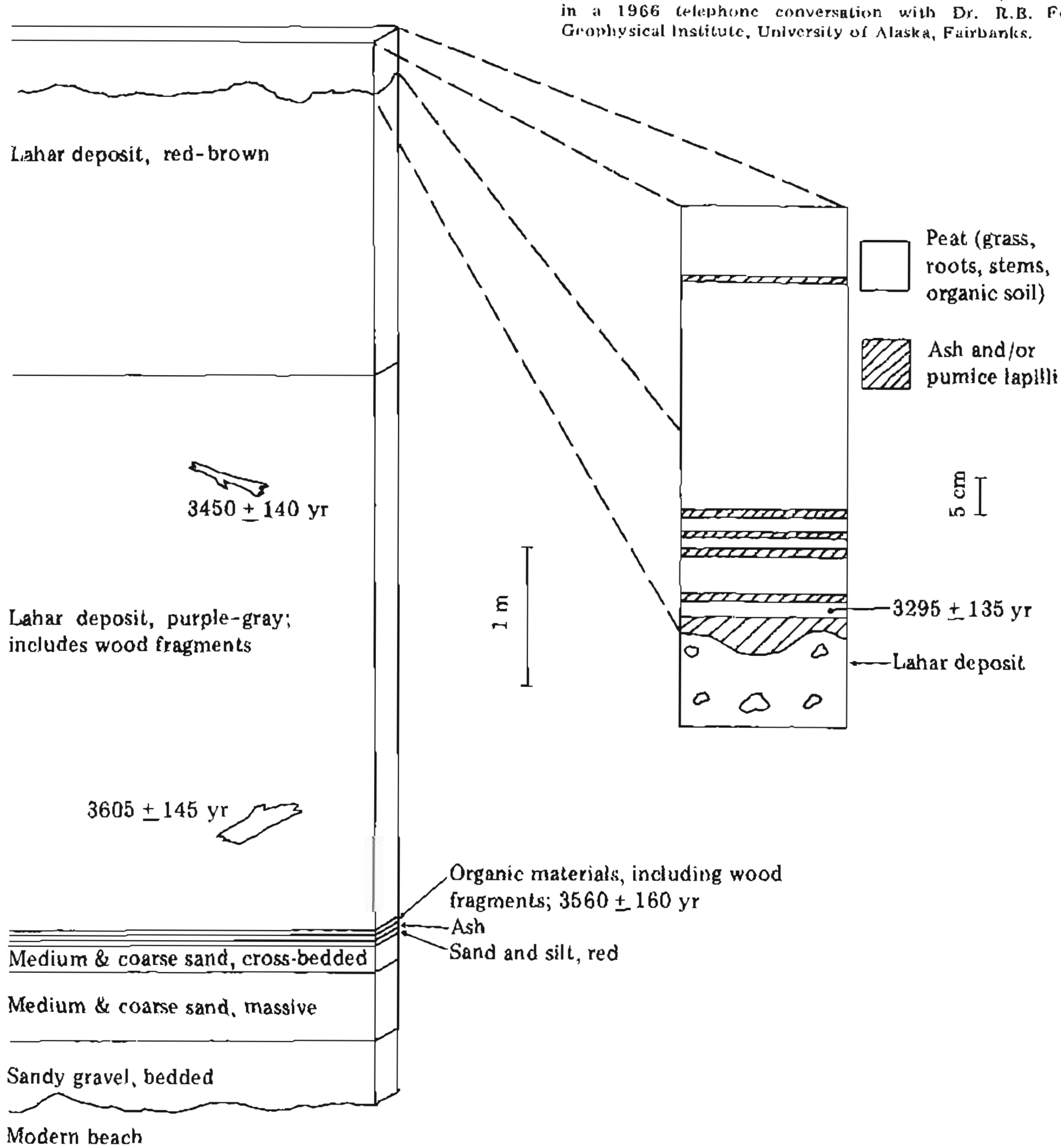

Figure 6. Generalized stratigraphic section at location of sea-cliff radiocarbon samples (fig. 1). Radiocarbon ages are uncorrected.

Flooding was probably caused by a sudden release of meltwater from the summit crater; at the same time one or more lahars flowed down the north flank of the volcano onto the Drift River flood plain (Post and Mayo, 1971; Miller, 1973). The 1966 lahars occurred in the same location as older lahars, which built a large cross-valley fan adjacent to an unnamed glacier on the Drift River flood plain (fig. 1). All lahars apparently came from the summit crater, which is breached to the north, and followed the glacial trough down into the Drift River valley. Snow and glacial ice are probably the sources of water involved in the lahars.

In the case of the Crescent River lahars, heat may have been provided by airfall ejecta, lava, subglacial heating, or all three. The presence and lithologies of large blocks in the mounds near Crescent Lake should be confirmed because very large blocks require a rock slide or fall for their origin, which could be related to a specific source area and process.

POTENTIAL HAZARDS OF LAHARS

In recent years destructive lahars have been responsible for about 40 percent of the casualties from volcanic eruptions (Williams and McBirney, 1979, p. 350). Destruction by lahars is partly due to their rapid movement and lack of advanced warning.

Velocities of very fluid lahars on steep slopes are as high as 80 to 100 km/hr; velocities on gentle slopes are generally less. Another characteristic contributing to the destructive nature of lahars is their tendency to flow in valleys where they can travel great distances. The Crescent River lahars, although large, are hardly comparable to some of those of Mount Rainier, which traveled more than 100 km.

Also, the surface of the lahar during flow is commonly higher than the surface of the resulting deposit. Presumably, the elevation of the lahar surface decreases where it spreads from a narrow valley outward into a fan. Thus, the present average thickness of individual lahar deposits exposed in sea cliffs near the Crescent River is less—by an unknown amount—that it was during flow.

The potential hazard posed by future lahars in the Crescent River valley is difficult to estimate quantitatively. Present human habitation consists of a small number of dwellings along the coastline. The lahars we studied may not be the only ones that reached the coastline. Others may be buried at depth.

An assessment of hazards due to lahars requires detailed field studies of the entire volcano. Historic lahar activity has been confined to the Drift River valley on the north side of the volcano. However, voluminous deposits provide evidence of significant lahar activity on the south side during Holocene time.

ACKNOWLEDGMENTS

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