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Map showing late 1977 debris avalanches southwest of Asheville, western North Carolina

by

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Introduction

Torrential rains caused by a low-pressure system that originated in the Gulf of Mexico fell upon several sections of the Blue Ridge in western North Carolina during November 2-7, 1977. In most of the severely flooded areas, precipitation exceeded 15 cm (6 in), but as much as 35.5 cm (14 in) fell at Mt. Mitchell, northeast of Asheville (Stewart and others, 1978).

Slope movements, chiefly debris avalanches of saturated colluvium, took place in at least two areas mostly within the Pisgah National Forest in western North Carolina. The eastern side of the Black Mountains (Mt. Mitchell region - see inset map) was affected by three gigantic debris avalanches ranging in length from 3 to 5 km and involving about 900 m of relief from head to toe. A larger (about 109 km² or 42 mi²) but less rugged area experienced debris avalanches. This area is bisected by the Blue Ridge Parkway and lies southwest of Asheville. Logging was not a factor in the slope movements.

The purpose of this investigation was to document and describe the debris avalanches caused by this storm in the area southwest of Asheville and to relate the geologic and other factors to the slope movements. Nearly four weeks were spent in the region during March 1988 and March 1989. All portions of the major debris avalanches were examined. Inclement weather days were utilized with the study of aerial photography at the National Forest Service office for Pisgah National Forest at Asheville. The author gratefully acknowledges the assistance of D.M. Manning in arranging for office space and providing access to the aerial photographs and unpublished 1977 debris avalanche locality data (U.S. Department of Agriculture, 1979).

Infrared photographs taken May 6-7, 1983, and color photographs taken March 23, 1986, of the Pisgah National Forest, both at a scale of 1:24,000 were analyzed. Some minor 1977 debris avalanches might have been overlooked because of rapid vegetative regeneration that might have occurred in relatively small and narrow slope declivities where bedrock might not have been exposed. Of course, small slope failures roughly 100 m² in size that were encountered in the field could not be detected on the aerial photographs.

Color photography at a scale of 1:24,000 flown in 1975, USGS high-altitude photography taken in 1984 and 1985, and the unpublished report by the U.S. Department of Agriculture (1979) existed in the time emplacement of the debris avalanches. No known debris avalanching in the region has occurred during the generally rainfall-deficient 1978 to early 1989 period.

A discussion of the 1977 debris avalanches and rainfall thresholds in the Bent Creek Experimental Forest, which lies close to the center of the map area, is contained in Neary and others (1986) and Neary and Swift (1987).

The term "debris avalanche," the most common type of slope movement feature produced by this storm, was originally defined by Sharpe (1938). A debris avalanche "has a long and relatively narrow track, occurs on a steep mountain slope or hillside in a humid climate, and is almost invariably preceded by heavy rains" (Sharpe, 1938, p. 61). Varnes (1978, p. 18) continued to use the term and defined it as a variety of very rapid to extremely rapid debris flows. Both authors concluded that the transport mechanism for debris avalanches is chiefly flowage of the viscous soil-water matrix.

Although many workers in the eastern United States have adopted the term "debris avalanche," other investigators have preferred the term "debris slide" or "debris slide/debris flow" to describe similar movements (Pomeroy, 1980; Bogucki, 1976, 1977; Clark, 1987). The term "debris slide" is used by the author to define only those movements that are commonly rapid and that involve translational or planar movement without flowage (Varnes, 1978). The term "debris flow" has been utilized in several recent reports concerning slope movements in the western United States (Ellen and Wieczorek, 1988; Wieczorek and others, 1989).

The storm

Precipitation began in the Asheville area on November 2nd. Rainfall was continual and even for the November 2-5 period until the night of the 5th-6th when intense downpours (originating by both convective activity and orographic lifting) initiated the debris avalanching (Neary and Swift, 1987). Total precipitation in the map area generally ranged from 18 to 21.5 cm (7-8.5 in) based on official and unofficial gauges. Though total storm and 24-hour rainfalls were not exceptional for the area, high 1-hour peak intensities were notable. For example, 69 mm (2.7 in) fell in the southern part of the map area at the Mills River gauge site (Neary and Swift, 1987, table 1). Neary and Swift (1987) stated that the intense rainfall during the night of the 5th-6th following constant precipitation during a 3-day period produced ideal conditions for debris avalanching.

Geology

The region lies within the Blue Ridge physiographic province. Elevations range from slightly over 2,000 feet to 4,064 feet at Ferrin Knob.

As shown on the state geologic map (North Carolina Geological Survey, 1985) the region is underlain by the generally northeast- to southwest-striking Ashe metamorphic suite and Tallulah Falls Formation of the Ocoee Supergroup of Late Proterozoic age and is part of a high-grade sillimanite facies terrain. Geologic mapping at a scale of 1:24,000 (Dabbagh, 1975, 1981) covers a large part of the region and refines an earlier reconnaissance map of the region (Hadley and Nelson, 1971).

Most of the rock in the map area is a fine- to medium-grained paragneiss consisting of quartz, plagioclase, muscovite, and biotite. Interlayered with the paragneiss is garnet-mica-plagioclase-quartz schist and migmatite.

Discussion

Precipitation, slope, and geologic factors contributed to the initiation of the debris avalanching and smaller related failures in the area southwest of Asheville.

The intense rainfall on the night of the 5th-6th following constant precipitation during a 3-day period, coupled with a record wet September and October (177% of normal), provided ideal conditions for debris avalanching (Neary and Swift, 1987). Rainfall data at the Bent Creek Experimental Forest (National Oceanographic and Atmospheric Administration, 1977) indicate that the 60-day pre-storm totals were considerably above normal (312 mm-12.3 in).

Wolman and Gerson (1978) concluded that intensive rainfall is the most important prerequisite for extensive slope movements in humid montane environments. In addition, an abnormally high total precipitation during the weeks preceding the catastrophic event is a significant element in debris avalanching. Pre-storm rainfall data in western Pennsylvania at Johnstown and East Brady (Pomeroy, 1980, 1982, 1984) further illustrate the importance of a well-saturated terrain.

The approximate threshold amount necessary to saturate soil and initiate debris avalanching in eastern United States has been suggested by Eschner and Patric (1982, p. 346) at 13 cm (5 in) per day. This figure may be invalid because the wetter the soil is at the onset of a storm, the less rain that is needed to start debris avalanching. Thus, antecedent moisture is a critical factor concerning the quantity of rainfall in a single storm event that is required to initiate slope failure.

Orientation (or aspect) of the head areas of the debris avalanches shows a definite affinity towards the northeast, east, and southeast. East-facing slopes are exposed to the sun only in the morning when temperatures are lower indicating an inherently high soil moisture content compared to south- and west-facing slopes. Interestingly, Gryta and Bartholomew (1987) found debris avalanche scars to predominate on northeast-, east-, southeast-, and northwest-facing slopes in the Virginia Blue Ridge area devastated by Hurricane Camille in 1969.

About 75 percent of the total debris avalanches took place along existing hillside depressions or laterally concave slopes; about 25 percent occurred along planar slopes. However, virtually all of the largest debris avalanches took place within hillside depressions. Slopes in the head areas of debris avalanches average 37° (75 percent), ranging from 26° (49 percent) to 46° (100 percent). All failures in the head areas of the debris avalanches showed translational movement. No true slumping (involving rotational failure) was seen at any debris avalanche head.

Most colluvium affected by debris avalanching has accumulated within hollows or laterally concave slopes. Hollow development is at least partially controlled by the underlying density of tension joints in the bedrock being greater there than in adjacent slopes, as suggested by Gray and Gardner (1977 and Woodruff (1971). Outcrop is abundant only in the hollows where debris avalanche chutes have carved their paths which makes a comparison of fracture density difficult. Nevertheless, intensive ground-water activity over a period of time in the hollows has produced a deeper regolith than that along adjacent slopes. Usually heavy precipitation occurs infrequently, at which time the loose rock and soil material is flushed out. Drainages are further deepened by sliding and flowage of rock and soil material from higher on the slopes.

Debris avalanching is believed to have taken place on the bedrock-soil or bedrock-colluvium interface. In some instances detachment might have occurred within soil horizons or colluvium, but evidence leading to this speculation has been destroyed during the greater than 10 years that have elapsed since the slope movements. Surface water percolating through the 0.5 to 2.0 m thick relatively permeable soil (and colluvium) tends to accumulate on top of the less permeable bedrock surface.

No gross differences in bedrock lithology could be detected within the region. Though most of the generally northeast-southwest striking bedrock is a fine- to medium-grained gneiss consisting of quartz, plagioclase, muscovite, and biotite with or without garnet, some schist with the same mineralogic make-up is interlayered with the gneiss. Migmatitic rock was found in the northern part of the area and, locally, in the southern part.

No apparent relationships between lithology, foliation, jointing, to debris avalanche siting seemingly exist. Significant joint trends are not characteristic of this terrain. Intense precipitation probably minimized the possible influence of any structural features conducive to debris avalanche emplacement.

Summary

Rainfall and slope factors contributed to the occurrence of debris avalanches and smaller slope movements in a 128 km² area southwest of Asheville in November 1977. Geologic factors related to structural features such as foliation or compositional and jointing appear not to have been a significant control to the debris avalanching.

Above normal pre-storm precipitation and intense downpours during a steady precipitation period are characteristic of this and other recent debris avalanche localities. Slopes varying from 26° to 46° (and averaging 37°) with hollows or lateral concavities have been loci of past and present movements. A strong preference for easterly-facing slopes is diagnostic of the debris avalanching formed during the November 1977 storm.

Debris avalanches occurred primarily on the colluvium-bedrock interface; slippage surfaces within the colluvium were probably minor. Well-drained soils form a relatively permeable mantle over shallow bedrock (0.5 to 2.0 m deep) in upper slope areas.

The debris avalanches averaged 453 m in length with a 139 m difference in elevation between head and toe. Heads averaged 8.7 m in width and showed an average failure depth of less than 1 m of earth material.

References Cited

Bogucki, D.J., 1976, Debris slides in the Mt. LeConte area, Great Smoky Mountains National Park, U.S.A.: Geografiska Annaler, v. 58A, no. 3, p. 179-191.

____1977, Debris slide hazards in the Adirondack province of New York State: Environmental Geology, v. 1, no. 6, p. 317-328.

Clark, G.M., 1987, Debris slide and debris flow historical events in the Appalachians south of the glacial border: Geological Society of America Reviews in Engineering Geology, v. 7, p. 125-138.

Dabbagh, A.E., 1975, Geology of the Skyland and Dunsmore Mountain quadrangles, western North Carolina, Unpublished Ph.D. thesis, University of North Carolina at Chapel Hill.

____1981, Geologic map of the Skyland quadrangle, North Carolina: North Carolina Geological Survey Map 193-NE, scale 1:24,000.

Ellen, S.D., and Wieczorek, G.F., editors, 1988, Landslides, floods, and marine effects of the storm of January 3-5, 1982, in the San Francisco Bay region, California: U.S. Geological Survey Professional Paper 1434, 310 p.

Eschner, A.R., and Patric, J.H., 1982, Debris avalanches in eastern upland forests: Journal of Forestry, v. 80, no. 6, p. 343-347.

Gray, R.E., and Gardner, G.D., 1977, Processes of colluvial slope development at McMachan, West Virginia: International Association of Engineering Geology Bulletin 16, p. 29-32.

Gryta, J.J., and Bartholomew, M.J., 1987, Frequency and susceptibility of debris avalanching induced by Hurricane Camille in central Virginia, in Landslides of eastern North America, Schultz, A.P., and Southworth, C.S., eds.: U.S. Geological Survey Circular 1008, p. 16-18.

Hadley, J.B., and Nelson, A.E., 1971, Geologic map of the Knoxville quadrangle, North Carolina, Tennessee, and South Carolina: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-654, scale 1:250,000, with text.

National Oceanographic and Atmospheric Administration, 1977, Climatological data, November 1977, and annual summary, North Carolina: Asheville, North Carolina, NOAA Environmental Data Service, National Climatic Center, v. 82, nos. 11, 13, p. 16 and 19.

Neary, D.G., Swift, L.W., Jr., Manning, D.M., and Burns, R.G., 1986, Debris avalanching in the southern Appalachians--an influence on forest soil formation: Soil Science Society of America Journal, v. 50, p. 465-471.

Neary, D.G., and Swift, L.W., Jr., 1987, Rainfall thresholds for triggering a debris avalanching event in the southern Appalachian Mountains: Geological Society of America Reviews in Engineering Geology, v. 7, p. 81-92.

North Carolina Geological Survey, 1985, Geologic map of North Carolina, scale 1:500,000.

Pomeroy, J.S., 1980, Storm-induced debris avalanching and related phenomena in the Johnstown area, Pennsylvania, with references to other studies in the Appalachians: U.S. Geological Survey Professional Paper 1191, 24 p.

____1982, Geomorphic effects of the July 19-20, 1977, storm in a part of the Little conemaugh River area northeast of Johnstown, Pennsylvania: Northeastern Geology, v. 4, no. 1, p. 1-9.

____1984, Storm-induced slope movements at East Brady, northwestern Pennsylvania: U.S. Geological Survey Bulletin 1618, 16 p.

Sharpe, C.F.S., 1938, Landslides and related phenomena--a study of mass movements of soil and rock: New York, Columbia, University Press, 136 p. (reprinted 1960, Paterson, N.J., Pageant Books).

Stewart, J.M., Heath, R.C., and Morris, J.N., 1978, Floods in western North Carolina, November 1977, 23 p., Water Resources Research Institute, University of North Carolina, Chapel Hill.

U.S. Department of Agriculture, Forest Service, Southern Region, 1979, Final report on emergency flood repair: Asheville, North Carolina, National Forests in North Carolina, 12 pages (unpublished).

Varnes, D.J., 1978, Slope movement types and processes, Chapter 2 in Schuster, R.L., and Krizek, R.J., eds., Landslides--analysis and control: National Research Council, Highway Research Board Special Report 176, p. 11-33.

Wieczorek, G.F., Lips, E.W., and Ellen, S.D., 1989, Debris flows and hyperconcentrated floods along the Wasatch Front, Utah, 1983 and 1984: Association of Engineering Geologists Bulletin, v. 26, no. 2, p. 191-208.

Wolman, M.G., and Gerson, Ron, 1978, Relative scales of time and effectiveness of climate in watershed geomorphology: Earth Surface Processes, v. 3, p. 189-208.

Woodruff, J.F., 1971, Debris avalanches as an erosional agent in the Appalachian Mountains: Journal of Geography, v. 70, no. 7, p. 399-406.

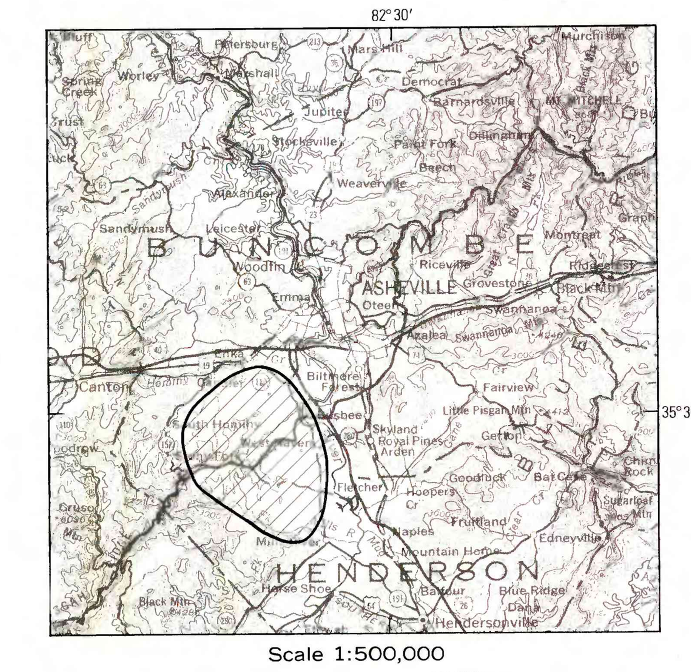
Base from U.S. Geological Survey. Asheville, 1961, Dunsmore Mtn., 1967, Enka, 1961, and Skyland, 1978

SCALE 1:24 000

Contour intervals 20 and 40 feet
DATUM IS MEAN SEA LEVEL

EXPLANATION

- Debris avalanche. Numbered movements are discussed in Table. Unnumbered debris avalanches were not examined.
- Example of a debris torrent. Deposits formed by a debris torrent (or debris flood) show more sorting than those formed by a debris avalanche. Most spectacular debris torrent is located on south side of Pine Mountain below Blue Ridge Parkway.
- Planar or rotational slope failure >110 m² along drainage
- Planar or rotational slope failure along drainage or on hillslope <110 m²



Scale 1:500,000
0 — 10 Miles
0 — 10 Kilometers

Area discussed

MAP LOCATION

[1] Head areas varied in width from 10 ft to 73 ft with the average of 29 ft.

[2] Thickness of the removed material seldom exceeded 5.5 ft and averaged 3 ft.

[3] Runout lengths stated in the table are approximations in many cases because of the difficulty in separating debris avalanche deposits from debris torrent deposits at most sites. A transition from debris avalanche to debris torrent commonly takes place in lower slope areas depending in part upon drainage density. Thus, runout length probably involves deposits from debris torrents because debris avalanche paths commonly coincide with actual drainages. The maximum length of a debris avalanche path in the area is about 4,000 ft with the average about 1,485 ft.

[4] The maximum difference in elevation from head to toe is about 1,230 ft with the average about 457 ft.

Debris Avalanche Characteristics

A) HEAD (data in feet)

Number	Elevation	Slope angle (and percent)	Scar width[1]	Topographic configuration	Thickness of removed material[2]	Aspect (orientation) (see diagram)	Rock type (quartz-q; feldspar-f; muscovite-m; biotite-b; garnet-g)	Foliation or composition layering (F) and/or joints (J)
1	3810	40° (84%)	25	concave	1-4	NNW	rusty weathering fine-grained q-f-b-m schist	N.75°E. 60°SE. (F)
(see fig. 1)								
2	3730	46° (100%)	20	concave	1-2	E	q-f-b gneiss	----------
3	2900	36° (72%)	25	planar	1-2	E	fine-grained q-f-b-g gneiss	N.31°E. 78°NW. (F)
4	2570	33° (65%)	30-35	concave	1-2	NE	No outcrop	----------
5	2470	34° (67%)	30-35	concave	2	NE	No outcrop	----------
6	2720	40° (85%)	15	planar	3-4	NNE	No outcrop	----------
7	2800	38° (80%)	15	concave	2-4	NNE	No outcrop	----------
	2750	---------	25	planar	4-5	NE	No outcrop	----------
8	2770	35° (70%)	25-30	planar	2-3	NW	q-f-b-g gneiss	N.30°E. 42°NW. (F) N.80°W. vert (J)
9	3100	40° (84%)	20	planar	1-3	WSW	fine-to coarse-grained q-f-b-g gneiss	N.32°E. 62°NW. (F) N.45°W. vert (J)
10	2860	36° (72%)	20	planar	1-2	W	q-f-b-g gneiss	N.36°E. 61°SE. (F)
11	3310	40° (83%)	20	concave	2-3	NE	No outcrop	----------
	3290	35° (70%)	20	concave	2-3	SE	No outcrop	----------
12	3220	37° (75%)	25-30	concave	1-2	SW	No outcrop	----------
13	3320	40° (84%)	30	concave	1-2	SW	No outcrop	----------
14	3320	---------	20	planar	5	NNE	No outcrop	----------
	3230	35° (70%)	70	concave	1-4	NE	fine-grained q-f-b-g gneiss	N.55°E. 33°NW. (F)
15	3000	37° (75%)	51	concave	---	NNE	massive dark fine-grained q-f-b gneiss above head	E.-W. 55°N. (J)
16	2560	38° (79%)	58	concave	3-5	SSE	medium-grained rusty-weathering q-f-b gneiss above head	N.30°E. vert (F) E.-W. 25°S. (J)
17	2730	---------	30	concave	---	SE	No outcrop	N.48°E. vert (F) N.52°W. 72°NE. (J)
18	3050	42° (90%)	10	concave	---	E	No outcrop	----------
19	3070	33° (67%)	20-25	concave	3-4	SSW	No outcrop	----------
20	3100	33° (67%)	25	concave	3-4	SSE	No outcrop	----------
	3070	33° (67%)	20	concave	---	SSW	No outcrop	----------
21	3270	34° (68%)	20	concave	---	SSE	gneiss	----------
(see fig. 2)								
22	3400	---------	20-25	concave	---	ESE	gneiss	----------
(see fig. 3)								
23	2720	40° (85%)	35-40	concave	3-4	SE	fine-grained q-f-b-g gneiss above head	N.55°E. 28°NW. (F) N.40°W. 68°SW. (J)
24	2750	26° (48%)	20	planar	2-3	E	No outcrop	----------
25	3470	---------	20	planar	---	E	No outcrop	----------
26	3630	38° (80%)	30	concave	3	E	gneiss	N.28°E. 55°NW. (F)
(see fig. 4)								
27	3480	40° (83%)	30	concave	3-5	NE	No outcrop	----------
28	3500	40° (83%)	37	concave	2-3	SE	fine-grained q-f-b-g gneiss	N.40°E. 65°NW. (F)
(see fig. 5A-B)								
29	3570	40° (83%)	40	concave	2-3	E	fine-grained q-f-b-g gneiss	N.15°E. 60°NW. (F)
(see fig. 6)								
30	3540	44° (96%)	36	concave	3	ENE	porphyroblastic garnetiferous q-f-b gneiss	N.25°E. 40°NW. (F)
31	2870	36° (72%)	20	planar	3-5	ESE	q-f-b-g gneiss	N.85°W. 75°NE. (J)
32	3150	40° (74%)	30	concave	5	NE	q-f-b-g gneiss	N.10°E. 40°NW. (F)
33	3400	39° (80%)	30	concave	2-6	E	q-f-b-g gneiss	N.35°E. 11°NW. (F)
(see fig. 7A-B)	3390	38° (78%)	20	concave	2-3	E	q-f-b-g gneiss	
34	3400	33° (65%)	45	concave	1-3	NE	gneiss	N.65°E. 72°SE. (F)
	3440	34° (68%)	20	concave	3-4	NE	gneiss	N.20°W. vert (J)
35	2950	36° (73%)	44	concave	---	E	No outcrop	----------
36	2600	37° (73%)	20	planar	3-5	SE	gneiss	N.55°E. 54°SE. (F)
37	2710	35° (70%)	20-25	concave	3-4	SSE	No outcrop	----------
38	2970	34° (68%)	46	planar	3-7	ENE	fine-grained q-f-b gneiss	N.70°E. 50°SE. (F)
39	3100	32° (62%)	20-25	concave	2-3	NNW	fine-grained q-f-b gneiss	N.20°E. 80°NW. (F)
40	3010	38° (78%)	20-25	concave	2-4	NNE	fine-grained q-f-b gneiss	N.38°E. 60°SE. (F)
41	2900	37° (74%)	52	concave	1-4	ESE	medium-grained q-f-b gneiss	N.26°E. 23°NW. (F) N.25°W. vert (J)
42	2920	35° (70%)	15	concave	4	E	q-f-m-b gneiss	----------
	2900	38° (78%)	20-25	planar	3-4	ESE	q-f-m-b gneiss	----------
43	2800	31° (60%)	30-40	planar	3-4	SE	q-f-b-g gneiss	N.24°E. 80°SE. (F)
(see fig. 8A)	2750	31° (60%)	22	planar	1-3	SE	q-f-b-g gneiss	----------
44	2940	36° (73%)	31	concave	3-4	S	No outcrop	----------
(see fig. 8B)								
45	3050	39° (82%)	20	concave	2-4	SE	q-f-b-m schist	N.55°E. 70°SE. (F)
46	3020	39° (82%)	20	concave	---	SE	q-f-b gneiss	N.15°E. 63°SE. (F)
47	2980	42° (89%)	10-15	planar	1-5	SE	q-f-b-m gneiss	N.33°E. 41°NW. (F)
(see fig. 9)								
48	2610	31° (60%)	73	concave	5-6	E	No outcrop	----------
49	2700	29° (54%)	61	concave	---	E	No outcrop	----------
50	3140	38° (80%)	25	concave	2-3	E	No outcrop	----------
51	3180	42° (88%)	45	concave	---	NE	No outcrop	----------

Debris Avalanche Characteristics

B) PATH (CHUTE) AND TOE (FAN) (data in feet) — C) MISCELLANEOUS (data in feet)

Number	Rock type (quartz-q; feldspar-f; muscovite-m; biotite-b; garnet-g)	Foliation or compositional layering (F) and or joints (J)	Average channel width	Toe width	Toe elevation	Runout length[3]	Difference of elevation of head and toe[4]	Remarks
1	migmatitic q-f-b gneiss	N.70°E., 75°SE.(F)	25	---	2580	>4000	1230	Tributary to west of head area (see fig. 1)(- -) shows many large boulders from 1977 storm, but mature trees standing on bouldery debris at toe attest to pre-1977 events
2	q-f-b gneiss	N.45°E., 62°NW.(F) N.30°W., 68°SW.(J)	20-25	100+	2550	3800	1180	Small 40x40 ft planar slide from 100% slope at 3200 ft along tributary
3	q-f-b-g gneiss	----------	25-30	110	2550	1000	350	--------------------
4	no outcrop	----------	10-15	---	2440	250	130	Moderate to swift regeneration of rhododendron in path makes identification obscure on aerial photographs
5	no outcrop	----------	10-20	---	2380	300	90	--------------------
6	no outcrop	----------	10-15	---	2600	250	120	--------------------
7	q-f-b gneiss	N.50°E., 46°NW.(F)	10-20	25	2500	900	300	Micaceous mud in tree bark 1.5 ft above ground surface along path of debris avalanche
8	fine grained q-f-g gneiss/ schist	N.70°E., 39°NW.(F) N.40°W., 87°SW.(J)	20-25	---	---	---	---	Toe altered by man-made drainage diversion
9	micaceous gneiss	N.55°E., 65°NW.(F)	40-75	---	2520?	2100	580	Bedrock at crown controlled upward extent of movement. Head of neighboring debris avalanche 250 ft to northwest has similar characteristics. Debris pile-up to 8 ft above surface slightly below junction with main valley. Path widens to 75 ft before narrowing upon 100-200 ft wide older debris avalanche (flow) deposit
10	gneiss	----------	20	---	2620?	900	240	Arcuate path controlled by drainage
11	fine-grained q-f-g gneiss	N.34°E., 72°NW.(F)	10	75-90	2760	1300	540	
12	migmatite	E.-W., 56°N.(F)	10	100+	2640	2000	580	
13	gneiss	N.65°E., 63°NW.(F) N.25°W., 84°SW.(F)	15-30	see above	see above	2300	680	
14	gneiss	----------	50	50	2850	1100	470	Toe shows convex profile across width of deposit along 10° (18%) slope
15	gneiss	----------	<30	---	2440	1900	560	Site of head scarp is occupied by wood retaining wall reinforced by steel I-beams that support road
16	no outcrop	----------	10	60	2380	600	180	
17	no outcrop	----------	10	<20	2550	300	180	
18	no outcrop	----------	25-40	---	2440	2000	610	
19	porphyroblastic garnetiferous q-f-b gneiss and migmatite	N.45°E.,53°NW.(F)	20-35	see below	see below	1800	520	
20	gneiss	----------	10-40	see below	see below	2100	550	
	gneiss	----------	----	see below	see below	---	---	
21	dark-colored q-f-b gneiss	N.60°E., 46°NW.(F) N.25°W., 80°SW.(J)	10-20	100+	2550	2600	720	Debris avalanche path follows fracture orientation. Mud deposit on bark 6.5 ft above surface. Path merges at creek junction with old 15-20 ft wide northwest-southeast trending 100+ year old debris avalanche deposit
22	no outcrop	----------	<20	<40	2680	2200	720	Path below 2920 ft is debris torrent. Gorge is 15 ft deep in colluvium
(see fig. 3)								
23	no outcrop	----------	30-40	<40	2420	900	300	
24	no outcrop	----------	<20	---	2620	200	130	
25	q-f-b-g gneiss	N.16°E., 45°NW.(F)	<25	100	2560	3700	910	Numbers 25-27 are part of a multiple-headed debris avalanche with a single track at or below 3200 ft. Extensive older flow indicates toe as wide as 300 ft. A 70 ft wide 40 ft long planar slide along the west bank at x was probably caused by the debris avalanche torrent. The entire slope west of the path and x shows an extensive hummocky surface with mature tree growth and is interpreted to represent an old slide surface
26	gneiss	----------	<50	see above	see above	3900	1070	A 30x30 ft scar that is not connected at the surface to the described scar lies slightly above
27	no outcrop	----------	<25	see above	see above	3800	920	
28	gneiss	----------	25	100+	2840	1700	660	Notable for extensive rock rubble deposits at toe, levees along lateral margins showing imbrication, and 10+ ft-high rock dams with pile-ups of debris torrent material against trees
(see fig. 5A-C)								
29	gneiss	----------	<50	100+	2840	1800	730	
30	gneiss	----------	20-25	35	2950	1400	590	Toe shows 5 ft of relief along 12° (21%) slope. Old debris avalanches with >5 ft of colluvium within lateral concavities are nearby
31	no outcrop	----------	10	---	2700	400	170	Debris material contributed to main channel was not believed to exceed 2400[3] ft
32	no outcrop	----------	10-20	66	2880	600	270	Toe lies 70 ft west of main drainage
33	gneiss	----------	20-30	100	2540	3400	860	Both head scars lie within 200 ft lateral concavity and are separated by a 100 ft wide nose. Debris avalanche paths merge 220 ft below head scarps. V-notched chute reaches a maximum 20 ft depth. Deposition occurred between 2930 ft and 3000 ft (maximum 100 ft width) but significant debris torrent deposition took place down-stream
34	q-f-b-g gneiss	N.50°E., 50°SE.(F)	20-25	40	3060	1100	380	Terminal part of flow dammed by trees
35	q-f-m-g gneiss	N.45°E., 67°SE.(F)	40-150	120	2400	2600	550	Eight-foot white pines growing in head scar and upper part of chute. At drainage junction debris was deposited on opposing slope as high as 30 feet above drainage (toboggan effect). Terminal lobe 2 to 5 ft high sits on 4 ft of cobble debris of earlier debris flow. Toe on 7° (12%) slope with transported trees pushed outward into rhododendron thicket
36	no outcrop	----------	<30	<60	2490	300	110	
37	no outcrop	----------	<30	<25	2400	1000	310	
38	q-f-b gneiss	----------	40-60	66	2670	700	300	Toe has along 6° (10%) slope with 6 ft pile-up of tree and rock debris
39	gneiss	----------	20-25	<50	2870	600	230	
40	gneiss	----------	25-35	---	2780?	600?	230?	
41	q-f-b gneiss	N.45°E., 38°NW.(F)	50-70	<40	2450?	1000?	450?	Debris avalanche #41 and #42. Debris avalanche dropped most of their load as slope moderated. Toe elevations represent terminal part of debris torrent
42	no outcrop	----------	20-120	15-20	2370?	1200?	530?	
43	no outcrop	----------	<30	80-100	2460	2500	340	Along part at 2600 ft tree shows mud-encrusted bark 5 ft 10 in above ground surface surface and 20 ft above channel bottom. Slightly below intersection of debris avalanche #43 and drainage is tree with mud-encrusted bark 7.5 ft above ground surface and 12 ft above channel bottom. Toe of deposit shows mud-encrusted bark 4 ft above ground surface
(see fig. 8C,D)								
44	no outcrop	----------	see #43	see #43	2460	2700	480	
(see fig. 8C,D)								
45	no outcrop	----------	<20	<30	2830	600	220	
46	no outcrop	----------	20-30	see #47	2630	1400	390	Another well-defined trench. Tributary head (20 ft wide) at 3,000 ft
47	gneiss	----------	15-40	50	2630	1200	350	Sidehill slump (30 ft wide) denoted by x
(see fig. 9)								
48	no outcrop	----------	<50	<50	2410	600	200	Smaller scar in same location on 1975 aerial photographs. Estimated 36,000 ft³ of Qc has been removed from this scar with 6,000 ft³ remaining in head area
49	migmatite	----------	50-60	80	2500	600	200	Smaller scar in same location on 1975 aerial photographs
50	no outcrop	----------	<30	<40	2780	800	360	
51	no outcrop	----------	<45	<50	2960	500	220	

[1] Retired