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DEBRIS AVALANCHING IN THIN SOILS DERIVED FROM BEDROCK

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INTRODUCTION

In southeast Alaska, many valley slopes that are greatly oversteepened by glacial erosion support mature forests rooted in shallow soil over bedrock. Debris avalanches on these slopes are one of the most frequent types of mass wastage in the region. They are especially common along the mainland and interior islands of the Alexander Archipelago where glacial till deposits are often thin or absent due to the resistance of local bedrock to glacial erosion.

At present, the forest land manager does not consider large-scale debris avalanching of this type an important erosion hazard in existing sale areas. Because of the poorer quality of timber on these soils and the steep and difficult terrain, slopes with shallow soils are often excluded from logging. As the logging industry expands to these sites in southeast Alaska, however, an understanding of this type of debris avalanching will become important in land management.

FIELD METHODS

During the summers of 1964 and 1965, reconnaissance investigations were made of debris avalanches in shallow soil. The study sites were chosen according to frequency of landslide occurrence and ease of access. The main site criterion was that glacial till be absent at the point of slide initiation. At each location, configuration of the slide trace and bedrock type and attitude were determined, and the angle of slope at the point of slide initiation was measured. Also at each locality, the soil depth was measured, and a probable cause of initial sliding was determined by reconstruction of events that apparently occurred when the slope failed.

SITE CHARACTERISTICS

The location and measured characteristics of each investigated site are shown in figure 1 and table 1.

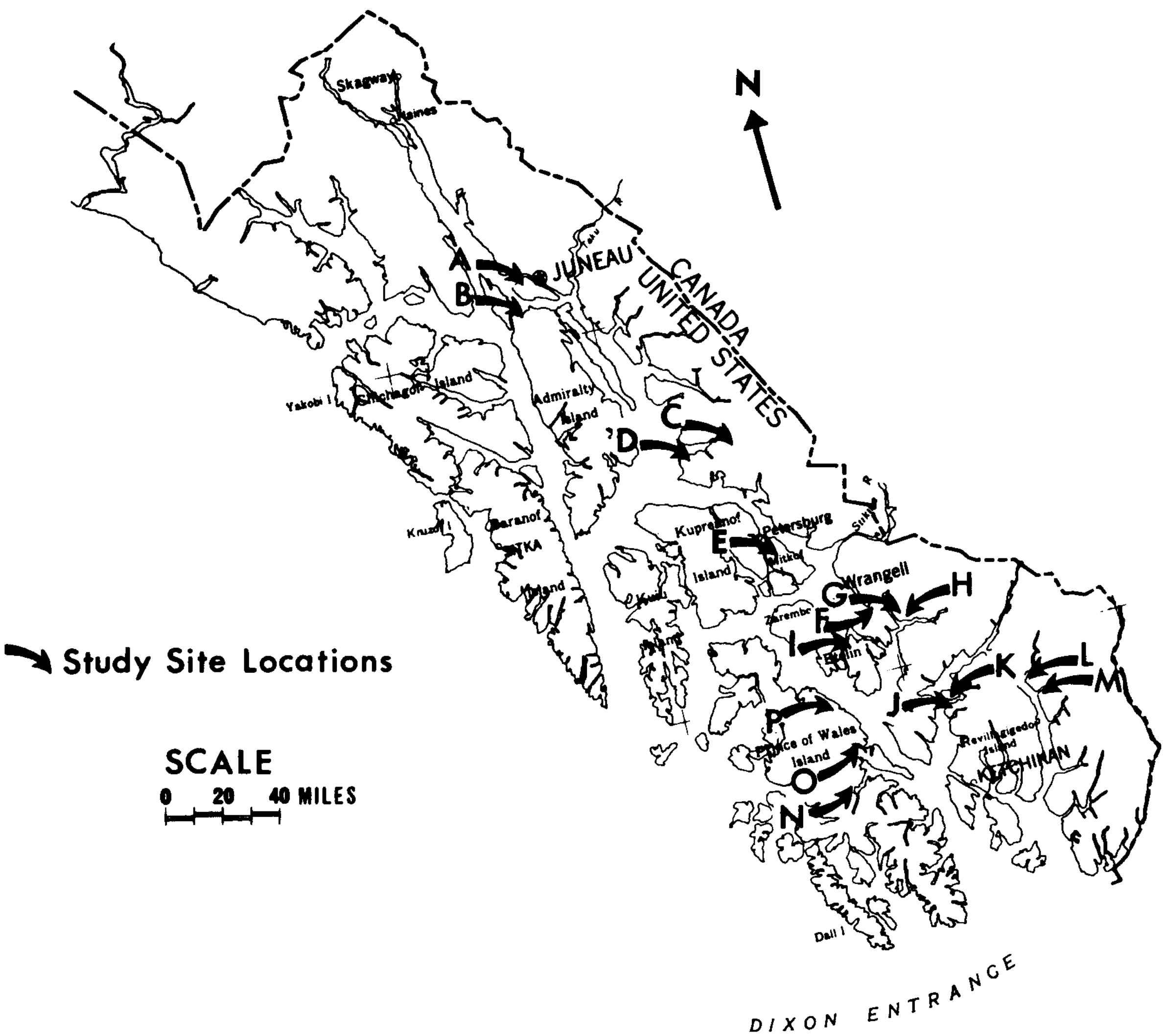

Figure 1.--*Map of southeast Alaska showing study site locations.*

Table 1.--Measured study site characteristics and probable causes of sliding

Location	Aspect	Slope at head of slide	Debris deposit area	Bedrock type	Strike and dip	Soil thickness	Circumstances of slides
A. North end of Douglas Island	NE.	≈40°	Very small; slide did not reach bottom of slope	Interbedded graywacke and gray shale	N. 38° W., 30° NE.	≈3 feet	Slide occurred on lower edge of Treadwell ditch; failure of outer ditch wall
B. Young Bay--in drainage of East and West Creeks	N.	32°-40°	Very small; confined to alluvial flat at mouth of creek	Graywacke and black slate interbedded	N. 35° W., 45° NE.	1-3 feet	Small slides occur on extremely steep side slopes of both creeks by gravity sliding
C. Walter Island Arm	SW.	≈45°	Very small; ≈ 10 percent of total slide area ponded on the beach	Schist and schistose conglomerate	N. 60° W., 58° NE.; in-dipping bedrock smoothed by glacial scour	≈3 feet	Extremely steep to vertical bluffs overhanging head of slide
D. 1/2 mile east of Steamboat Bay near Cape Fanshaw	W.	≈40°	Not discernible in heavy undergrowth at slope base	Black argillite	N. 60° W., 78° NE.; in-dipping bedrock smoothed by glacial scour	≈3 feet	Extremely steep slope at slide head, with many indications of windthrow in area
E. Blind River, 12 miles south of Petersburg	NE.	35°-40°	Small; less than 10 percent of total slide area; debris ponded principally on or directly below logging road	Black argillite and graywacke interbedded. Overlain by thin patches of glacial till	N. 40° W., 60° NE.; bedrock surface smoothed by glacial scour	≈2 feet	Slides developed as slip-outs in shallow but steep-faced till banks along narrow stream channel in slope
F. Blake Channel Narrows	NE.	≈50°	Very small; most debris ponded at base of slope near beach	Schist	N. 45° W., 80° NE.	≈2 feet	Slide developed approximately half way up small creek as result of slip-out in thin soil covering a very steep pitch in slope
G. Blake Channel	W.	50°-60° (Slope dip controlled by jointing)	Very small; much of debris carried into channel	Quartz-diorite gneiss	Bedrock rounded and smoothed by glacial scour. Dominant joint set: N. 40° W., 30° NE. and N. 10° E., 70° NW.	2-3 feet	Extremely steep to vertical bluffs overhanging head of slide, apparently initiated by rockfall
H. Martin Creek Valley	E.	36° (Slope dip controlled by jointing)	Very small; debris ponded at base of slope, some emptied into Clay Lake	Quartz-diorite gneiss	Bedrock rounded and smoothed by glacial scour. Dominant joint set: N. 40° W., 30° NE.; N. 10° E., 70° NW.	2-3 feet	Principal jointing surface parallel to or slightly less than slope angle at head of slide; appears to have been an outward movement of blocks of bedrock along joint plane coupled with windthrow
I. Burnett Inlet	W.	40°	Very small; ponded in creek valley	Massive interbedded graywacke and black slate	N. 80° E., 38° SE.	Variable, but less than 3 feet	Bluffs overhanging head of slide, apparently initiated by rockfall
J. Neets Bay	N. and S.	40°-60°	Many individual slides; generally small; majority of slides ending in bay	Interbedded schist, black argillite, and graywacke	Variable, but predominantly NW. with dip SW.	Variable, but less than 3 feet	Extremely steep slope at slide head, some bluffs and rock cliffs indicating initiation by rockfall or slip-out of bedrock units; windthrow common; perhaps some destruction of root stabilization by logging
K. Gedney Pass	N.	40°-50°	Numerous slides; small; generally ending in the water	Biotite, schist, granite, diorite, gneiss	N. 70° W., 25° NE.	Variable, but less than 3 feet	Extremely steep slope at head of slides with overhanging bluffs
L. Walker Cove	N.	35°	Small; slide ending at water line	Granite, gneiss	(1/)	Less than 2 feet	Extremely steep side walls of stream channel; slide apparently caused by slip-out of lithosols from these side walls
M. Rudyerd Bay	N.	35°	Small; ending at water line	Granite, gneiss	(1/)	(1/)	Extremely steep slope with overhanging cliffs
N. Hollis, Prince of Wales Island	S.	40° (Begins above zone of till deposition)	Small; ponding in valley bottom before reaching creek	Interbedded black argillite and graywacke	N. 35° W., 36° SW.	(1/)	Extremely steep slope near head of slide with evidence of windthrow
O. Thorne River Valley, Prince of Wales Island	SW.	38° (Occurs in zone of no till deposition)	Small; ponded on logging road	Granite, gneiss	(1/)	≈3 feet	Very steep slope in logged area
P. Luck Lake, Prince of Wales Island	W.	40° (Occurs in area of no till deposition)	Small; ponded on creek bottom	Granodiorite	(1/)	≈2 feet	Steep slope with overhanging bluffs

1/ Data not available.

In every case, the slopes on which these slides occurred are extremely steep, lying between 35° and 40° or more, and support an old-growth forest of Sitka spruce and western hemlock rooted in a thin, rocky soil (figs. 2 and 3).

Figure 2.--*View of a debris avalanche path. The timber is growing on a thin soil overlying metamorphosed graywacke. Note the broken nature of the bedrock surface indicative of frost wedging and the prying action of growing roots.*

Figure 3.--*A debris avalanche path in a thin soil. The bedrock is a glacially rounded, metamorphosed granite jointed parallel and perpendicular to the slope.*

The soils are coarse and permeable with a high proportion of angular rock fragments and overlain by a thin organic mat consisting of intertwining roots and forest litter. The soils appear to drain very rapidly since overland flow was never observed, even during intense rainfall.

Bedrock slopes on which these soils have developed are smoothed off and dip into the valley at angles that approach or exceed the angle of internal friction for these soil materials[1/] (fig. 3). This angle has been arbitrarily set, based on practical engineering experience, between 34° and 46° depending on density of the soils and weight of the overlying materials.[2/] When the slope approaches or exceeds the angle of internal friction, the soil and slope conditions are such that downslope movement under the force of gravity is imminent.

DISCUSSION

Since these soils remain in position on the slopes and support extensive forest cover, a considerable resistance to downslope movement or "shearing" along the bedrock surface must exist. This shear resistance is additional to any internal friction between the individual soil particles and between the particles and the bedrock surface. The additional shear resistance is believed to be produced by the anchoring effect of root growth through the thin soil and into joints and fractures in the bedrock and, to a limited extent, by adhesion between individual particles due to soil water films.

Saturation and subsequent free water movement through the soil effectively reduce shear resistance due to adhesion and internal friction. The increased weight of the water-saturated soil and overlying organic mat increases the effective gravitational force acting to pull the soil downslope. Simultaneously, the buoyancy of the vertical component of free water movement tends to reduce the frictional resistance and adhesion between particles and along the bedrock surface. Rapid rise in piezometric level in glacial till soils during heavy rainfall periods

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1/ The angle of internal friction is defined as the angle at which the driving forces due to gravity in a soil mass are equal and opposite to the resisting forces due to friction.

2/ Terzaghi, Karl, and Peck, R. B. Soil mechanics in engineering practice. 566 pp. New York: John Wiley and Sons, Inc. 1948.

is known to occur and is believed to be a principal force in a debris avalanche on till-covered slopes.[3/] [4/] In shallow-to-bedrock soils, such rapid piezometric level rise has not yet been observed; however, it is probable that similar relationships also hold true, although the total effect may be somewhat less because of the coarse nature of the soil and resultant extremely rapid drainage of infiltrating water.

The decrease in shearing resistance of shallow soils is thought to be substantially aided by a decrease in root anchoring as the forest cover matures and the rate of root growth diminishes. The growing roots, which initially serve to anchor the soils on the slope, may actually counteract their early stabilizing effect by wedging out pieces and blocks of bedrock and loosening the underlying bedrock surface. The prying action of freezing water in the resultant root cracks probably adds considerably to this effect. Soil development adds to the proportion of greasy colloidal organic and iron compounds in the soil material over time, also adding to instability.

Slopes thus prepared are primed for sliding. During periods of maximum rainfall, only a small triggering force is necessary to cause the rapid downslope movement of a soil mass. Such a force may be produced by a sharp increase in soil water content or by a rapid increase in the weight of the soil mass. Field evidence suggests that the latter, due to tree blowdowns or the addition of rock masses resulting from gravity fall, is the principal initiating cause of these sliding phenomena. The majority of debris avalanches investigated occurred on timbered slopes and originated in areas of windthrown trees or extensive overhanging rock bluffs. A few showed indications that large blocks of bedrock had moved outward along zones of weakness at the upper slide margins with no indications of windthrow or rock fall. The triggering force here probably was excess hydrostatic pressure produced in joint cracks underlying the blocks.

In Neets Bay and Gedney Pass, where slopes of the type considered above have been logged, the initiating mechanisms are the same as those described earlier. The marked increase in sliding within the clearcut areas, first reported by Bishop and Stevens,[5/] may be the result of progressive deterioration, after logging, of the root systems anchoring the shallow soil on the slopes.

[3/] Bishop, D., and Stevens, M. E. Landslides on logged areas in southeast Alaska. U.S. Forest Serv. Res. Pap. NOR-1, 18 pp. 1964.

[4/] Swanston, Douglas N. Soil-water piezometry in a southeast Alaska landslide area. (In preparation for publication, Pacific Northwest Forest & Range Exp. Sta., U.S. Forest Serv., Portland, Oreg.)

[5/] See footnote 3.

CONCLUSIONS

On slopes steeper than the internal angle of friction and in the absence of a well-developed, cohesive soil, landslides must be considered a natural erosion process responding to the basic laws of physics. They are an inevitable result of any occurrence which tends to reduce the resistance of a slope to sliding.

Many of these slopes remain stable for years despite the action of external forces tending to reduce their resistance to sliding. The slope soils, therefore, must possess a slide resistance which is not directly related to the physical properties of the soil. Present indications are that this force is produced by tree rooting through the soil and into cracks in the underlying bedrock. Destruction of this rooting system would greatly increase susceptibility of the slope soil to slides.

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