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Geologic Zoning of Slope Movements in Western Oregon, U. S. A.

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SYNOPSIS

The Japanese approach to geologic zoning of slope movement types has useful application in the geologically diverse landscape of western Oregon, U.S.A. The slope movement regime of an area can be characterized quantitatively in terms of total area affected, size distribution, and velocity and frequency of movement for slope movements of different types. Slope movements in Tertiary sedimentary rocks of the Oregon Coast Range include a high frequency (number per square kilometer per year) and low average volume of debris avalanches, high frequency of debris torrents down first- to fourth-order channels, and large, deep-seated slope movement features that may experience some of their movement in brief pulses lasting hours to days. Tertiary volcanic rocks in the Cascade Range have a lower frequency of debris avalanches and torrents and the large, deep-seated slope movements are mainly of the earthflow type that move slowly for prolonged periods (months) during the wet season. Further quantification of slope movement regimes will aid in planning land use and erosion control programs and in studying sediment production and landscape evolution.

INTRODUCTION

Japanese researchers have classified slope movements in Japan in a series of geologic divisions that have characteristic types of slope movement features (Yamaguchi, 1980). This geological approach to zoning slope movements and hazards is useful for grouping areas by common characteristics:
(1) engineering properties of materials, including primary and secondary features of mineralogy and fabric; (2) tectonics as they affect the history of uplift, potential for earthquakes, and disruption of rock materials; and (3) climate. These geologic and climatic characteristics of an area result in topography, and thickness and mechanical properties of the soil mantle distinctive to particular rock units. These relationships have been recognized and incorporated into a system for zoning prediction and mitigation of slope movement disasters in Japan, compiled by Dr. N. Oyagi (National Research Center for Disaster Prevention, Tsukuba, Japan).

Geologic zoning of slope movement regimes would be useful in the United States also. In western Oregon, for example, better zoning of slope movement conditions could be used for evaluating risk and liability and for preparing laws and rules to govern land use practices, mainly logging and road construction. The State of Oregon is now considering such laws and rules but without benefit of a systematic description of slope movement conditions in the State. Furthermore, description and analysis of broad-scale slope movement conditions in the area would be useful in analyzing sediment production and the history of landscape evolution. We are also interested in the amounts and geographic distribution of areas of the landscape experiencing various degrees and frequencies of disturbance by slope movement. This information would be useful in interpreting broad-scale patterns within forest and stream ecosystems.

Gaining a general undersanding of slope movement conditions in a region or a particular geologic unit is difficult, because in many cases research on slope movement has been concentrated on small areas with special problems of slope instability. To adequately analyze slope movement conditions, we need a rigorous, quantitative description of the slope movement regime for an area, based on a carefully designed sampling program. Characterization of the slope movement regime of an area should include: (1) rates and timing of movement by active, slow moving features; (2) recency of movement by inactive, large features; (3) frequency of occurrence of rapid slope movements; and (4) total area affected and size distribution (volume and area) of each type of slope movement. These characteristics can be defined in general terms, such as "active" or "inactive" for large features. More rigorous description is also possible, such as examining debris avalanche history in relation to land management history or the detailed mapping units of Wieczorek (1982) showing dates of last known movement for earthflow features. Because slope movement characteristics typically vary significantly from one geologic

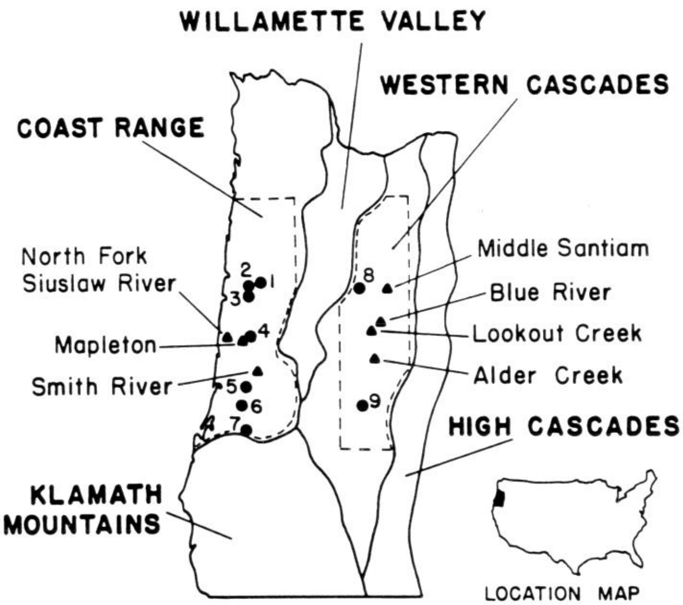

Figure 1. Map of physiographic units, slope movement study areas, areas surveyed for lakes dammed by slope movements (outlined with dashed line), and those lakes (1. Trembly, 2. Drift I, 3. Drift II, 4. Triangle, 5. Wassen, 6. Loon, 7. Sitkum, 8. Moose, 9. Windfall, 10. Fish).

terrane to another, geologic units can form natural strata for sampling.

Thorough descriptions of the slope movement regime for areas in the United States are rare. We can, however, begin to compile such descriptions by using existing inventories of debris avalanches and by interpreting maps of large-scale slope movement features. In this paper we characterize and contrast the slope movement regimes of two areas in western Oregon from available data. We give examples of the strong control of geology on slope movement processes and of the approaches to defining and interpreting slope movement regimes. A sampling program designed to provide a general description of the slope movement conditions in a geologic unit was not used in collection of these data, so the distinctions between areas can be considered only qualitative. Finally, we consider approaches to compiling a quantitative description of the slope movement regime of an area.

STUDY AREAS

Western Oregon can be broadly divided into four physiographic provinces: Coast Range, Cascade Range, Klamath Mountains, and Willamette Valley (Fig. 1). A variety of bedrock types are present in each of these areas. In this paper we focus on sedimentary rocks of the south-central Coast Range and volcanic rocks of the western Cascades Range.

The central part of the southern half of the Coast Range in western Oregon is underlain by Tertiary turbidite sandstone beds up to 4 m thick with thin interbeds of mudstone and siltstone. These rocks are broadly folded and generally dip less than 15°. The topography ranges from gentle hills to areas with short, steep (33-36°) slopes mantled with thin soils. Average annual precipitation ranges from 1500 to more than 2000 mm, falling mainly between October and April. Forestry centered on native Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) is the dominant land use.

The western Cascades are underlain by a complex mixture of Tertiary volcanic rocks, including materials originating as lava flows, lahars, pyroclastic flows, and water-reworked volcanic deposits. Alteration of these rocks has been widespread, resulting in formation of clay minerals and amorphous materials. Topography varies from gentle, hummocky slopes to steep, rock cliffs. Average annual precipitation is about 1000 mm in the southern half of the range and more than 2500 mm in much of the northern half, falling as rain and snow during the fall and winter. Production of Douglas-fir and other tree species is the dominant land use.

SLOPE MOVEMENT CHARACTERISTICS IN THE WESTERN CASCADE RANGE

Debris Avalanches

Several detailed inventories of debris avalanches have been conducted by compiling a record of all debris avalanches in a selected area over a known period from aerial photographs and field surveys (Swanson et al., 1981). These data can then be summarized in terms of frequency of debris avalanches (number per square kilometer per year) and soil transfer rate (cubic meters of soil transported per square kilometer per year). Three studies that used similar detailed field investigations report occurrence of debris avalanches in the central western Cascade Range (Table 1, Fig. 1). The observed frequencies of debris avalanches, average volume, and soil transfer rates for forested areas fall within moderately restricted ranges (Table 1). Here we report values for forested areas only because frequency and size of debris avalanches vary among forest, clearcut, and roaded areas; and land use practices can vary between areas. Consequently, analysis of inherent slope stability of an area and comparison between areas are best based on slope movement under forested conditions. The minimum size of debris avalanche sampled was 75 m^3.

Features of Large Slope Movements

Two studies report results of detailed mapping of landforms created by large slope movements in the central western Cascades (Fig. 1). In the Lookout Creek basin, Swanson and James (1975) identify 3.3% of the basin in active slumps and earthflows and 9% of the area in inactive features. Active areas are those with fresh scarps and tension cracks,

Table 1. Debris avalanche frequency, average volume, and soil transfer rate for forested areas

Site	Area Sampled (km^2)	Period Sampled (yr)	Frequency (events km^{-2} yr^{-1})	Average Volume of Soil (m^3)	Transfer Rate (m^3 km^{-2} yr^{-1})
Cascade Range					
Blue River (Marion, 1981)	48.5	34	.012	3120	37
Lookout Creek (Swanson and Dyrness, 1975)	50.1	25	.025	1460	36
Alder Creek (Morrison, 1975)	12.3	25	.023	1990	45
Coast Range					
Mapleton (Ketcheson, 1977)	4.4	15	0.58	31	18
Mapleton (Swanson et al., 1981)	5.2	15	0.53	61	32
Smith River (Pierson, 1977)	126	15	0.060	270	16

indicating movement within the past few years, and vegetation disturbed by slope movement at any time within the life of the forest, which is up to 500 years old in the study area. Inactive areas have broad scale landforms produced by slope movement, but they lack vegetation and microtopography indicative of recent movement. Using similar criteria in mapping a part of the Middle Santiam area (Fig. 1), Hicks (1982) found 15% of of the area in active slumps and earthflows and 7% inactive. This area is noted for its abundance of earthflows, parts of which have been moving at 10+ m/yr.

The timing and rates of movement of large slope movement features in the Cascade Range have been documented by direct measurements on four earthflows and informal observations of many other features. Active earthflows appear to move every year (our longest period of direct measurement is 10 yr), and movement may persist for 6 to 12 months of the year. At the four sites of direct monitoring, movement during an individual storm each year has been only a minor part of the total annual movement. The maximum measured annual rate of movement has been 18 m/yr in the lower part of the Jude Creek earthflow in the Middle Santiam area (Fig. 1). The most common rates of movement of active earthflows in the western Cascades appear to be a meter per year or less.

Investigation of aerial photographs since 1946 shows that several large debris avalanches, each up to 1 hectare in area, have occurred in the central western Cascades; however, we know of no very rapid movement of areas of 5 ha or more.

Lakes dammed by slope movements are quite rare in the Cascade Range; we have identified only two in a 12000 km^2 area (bounded by latitudes 43°N and 45°N, and longitudes 122° and 122°45'). Both are small (4-ha Moose Lake, 1-ha lake on Windfall Creek) (Fig. 1) and become dry during the dry summer period. Existence of a lake dammed by slope movement indicates slope movement sufficiently fast and voluminous that fluvial erosion could not keep pace with debris supplied by the slope movement. In general in the western Cascades slow encroachment of slopes into channels locally raises the base level, but formation of a lake is prevented by rapid erosion of the toe of the slope and deposition of sediment upstream of channel constrictions.

There has been little dendrochronologic analysis of large slope movement features in the Cascades; however, we have examined tree-ring records on many stumps where trees were cut and removed from active earthflow areas. We have noted a consistent lack of development of discrete episodes of eccentric tree-ring growth indicative of periods of tilting of the trees, as described by Shroder (1978). This may be a result of earthflow movement persisting year after year, rather than occurring only in years of particularly heavy precipitation.

SLOPE MOVEMENT CHARACTERISTICS IN THE COAST RANGE

Debris Avalanches

Two studies of debris avalanches have been done in the area of sedimentary rocks in the

Coast Range by use of comparable, detailed field investigations (Ketcheson, 1977; Swanson et al., 1981). This work centers on steep, highly dissected slopes in the Mapleton area which is known for its high level of slope instability. This area exhibits a high frequency of debris avalanches with small average volume of soil transported, based on a sample of features larger than 7.5 m^3 sampled in forested areas (Table 1). This minimum size of sampled debris avalanches is only 10% of the smallest debris avalanches sampled in the Cascade studies. These minimum values for sizes of debris avalanches sampled are, however, reasonable for the respective sites, because debris avalanches between 7.5 and 75 m^3 are common in the Coast Range study sites, but rare in the Cascade Range areas studied.

Pierson's (1977) inventory of debris avalanches in the Smith River area in the Coast Range (Fig. 1) was based mainly on analysis of aerial photographs and did not involve the same detailed field sampling methods used in the studies of Ketcheson (1977) and Swanson et al. (1981). He reports higher average volume of soil transport by debris avalanches and lower frequency. This may reflect both an inability to see smaller debris avalanche scars in aerial photographs and natural variation in slope movement characteristics within a single geologic terrane. Assuming that only 59% of debris avalanches were visible on aerial photographs, Pierson did attempt to correct his value for debris avalanche frequency by adjusting his calculations, which he estimated from his studies in the area.

Features of Large Slope Movements

Evidence of large (greater than one-half hectare) slope movements is widespread in the Coast Range. Evidence includes slumps and areas of block glide on bedding planes, but there has been little effort to map them in detail on an extensive basis. The only estimate of the proportion of sedimentary rock landscape in landforms created by large slope movements in the Coast Range comes from the work of J. D. Graham (U.S. Army Corps of Engineers, personal communication) who has mapped features of large slope movements for 5% to 10% of a 110-km^2 area in the North Fork Siuslaw River basin.

The timing and rates of movement of these features are very poorly documented, but several lines of evidence suggest that at least some of these areas have experienced brief periods of rapid movement. Measurement of movement of the Wilhelm and Condon slides in the basin of the North Fork of the Siuslaw River (Fig. 1) reveals that pulses of movement have occurred for hours to a few months, based on the time between resurvey of fixed monuments. Extensiometers at these sites record movement for periods of hours to a few days.

Large, rapid slope movements of 20 to 100 m or more have also been reported in the area over the past 10 years, most notably the 20 ha Drift Creek Slide (Location 2-3, Fig. 1) and an unnamed slide of about 5 ha located about 6 km to the northwest of the Drift Creek Slide. Neither slide was observed directly, but their movement was heard and was viewed shortly afterward. Movement of up to 8 m occurred over a few years preceding the Drift Creek Slide, but catastrophic failure occurred in a period of minutes to perhaps an hour or more.

The Drift Creek Slide and other large rapid slides have dammed rivers and have formed seven lakes in a 13000 km^2 area of the Coast Range, bounded approximately by latitudes 43°N and 45°N and longitudes 123°15' and 124°15' (Fig. 1). Four of these slope movements formed lakes with greater than 50-ha surface area, the largest being 112-ha Triangle Lake.

Dendrochronologic evidence also points to a history of brief episodes of movement followed by periods of little movement. In samples of tilted trees growing on the Wilhelm and Condon Slides, J. D. Graham (U.S. Army Corps of Engineers, personal communication) observed abrupt development of eccentric growth of tree rings during wet periods in 1950-1958, 1964-1965, and 1971. This suggests that slope movement and tilting of trees accelerated during these periods, after which movement tilting of the trees was greatly reduced and tree-ring growth returned to a more concentric pattern.

CONTRASTS BETWEEN THE COAST AND THE CASCADE RANGES

Based on the available data, debris avalanches in sedimentary rocks of the south-central Coast Range are much more frequent and of smaller average volume than debris avalanches in the western Cascades. The rates of soil transfer by debris avalanches are, however, quite similar between the two areas. The higher frequency and lower average volume of debris avalanches in the Coast Range may result from the effect of highly dissected, steep slopes providing many sites where debris avalanches can occur, but debris avalanches at these sites have very limited widths and depths, so the volume of soil moved is small.

Although available data are inadequate to document patterns conclusively, large slope movement features appear to cover a higher percentage of the landscape in the Cascade Range. We attribute this to widespread occurrence of hydrothermally altered volcaniclastic rocks in the western Cascades which have resulted in development of numerous large-scale slope failures. The movement characteristics also appear to differ between the two areas. Earthflows in the Cascades experience more prolonged periods of within-year and between-year movement, probably in response to a greater abundance of clay and amorphous materials in zones of failure. These materials deform slowly and plastically. The siltstones and mudstones that occupy failure planes of many of the large slope movements in the Coast Range fail in a more catastrophic manner. Because large, slow-moving slope movement features are widespread in the western Cascades, they form important sites for occurrence of debris avalanches (Swanson and Fredriksen, 1982). In the Coast Range 0-order channels, following ıe terminology of Tsukamoto et al. (1982), ꞓe the dominant sites for initiation of ebris avalanches.

ıPPROACHES TO CHARACTERIZING SLOPE MOVEMENT ꝒEGIMES

Description of the slope movement regime of an area depends on the objectives of the work. We envision a basic description including the area in active and inactive large slope movement features, their rates and timing of movement, and the frequency and size distribution of small, rapid slope failures. These data can be collected by mapping the large features and compiling an inventory of small, rapid failures occurring over specific areas and periods of time (Swanson et al., 1981). This sampling program should be stratified by geologic units, and possibly by variation within these units, such as considering degree of hydrothermal alteration in volcanic terranes like the western Cascade Range. On Federal and industry lands in many areas of western Oregon, soils and landforms have been mapped with units down to 2 ha in size, providing a ready basis for fine-scale stratification for sampling slope movements.

REFERENCES

Hicks, B. A. (1982). Geology, geomorphology, and dynamics of mass movement in parts of the Middle Santiam River drainage, western Cascades, Oregon. Oregon State University, Corvallis, Oregon. 170 p. M.S. thesis.

Ketcheson, G. L. (1977). Hydrologic factors and environmental impacts of mass soil movements in the Oregon Coast Range. Oregon State University, Corvallis, Oregon. 93 p. M.S. thesis.

Marion, D. A. (1981). Landslide occurrence in the Blue River drainage, Oregon. Oregon State University, Corvallis, Oregon. 114 p. M.S. thesis.

Morrison, P. H. (1975). Ecological and geomorphological consequences of mass movements in the Alder Creek watershed and implications for forest land management. Oregon State University, Corvallis, Oregon. 102 p. B.A. thesis.

Pierson, T. C. (1977). Factors controlling debris-flow initiation on forested hillslopes in the Oregon Coast Range. University of Washington, Seattle, Washington. 166 p. Ph.D. thesis.

Shroder, J. F., Jr. (1978). Dendrogeomorphological analysis of mass movement on Table Cliffs Plateau, Utah. Quaternary Research 9:168-185.

Swanson, F. J., Dyrness, C. T. (1975). Impact of clearcutting and road construction on soil erosion by landslides in the western Cascade Range, Oregon. Geology 3(7): 393-396.

Swanson, F. J., Fredriksen, R. L. (1982). Sediment routing and budgets: Implications for judging impacts of forestry practices. In: Swanson, F. J., Janda, R. J., Dunne, T., Swanston, D. N., eds. Sediment budgets and routing in forest drainage basins. U.S. Department of Agriculture, Forest Service Research Paper PNW-141. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. 129-137.

Swanson, F. J., James, M. E. (1975). Geology and geomorphology of the H. J. Andrews Experimenal Forest, western Cascades, Oregon. U.S. Department of Agriculture, Forest Service Research Paper PNW-188, 14 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Swanson, F. J., Swanson, M. M., Woods, C. (1981). Analysis of debris-avalanche erosion in steep forest lands: An example from Mapleton, Oregon, U.S.A. In: Erosion and sediment transport in Pacific Rim Steeplands. IAHS Publ. No. 132, 67-75.

Tsukamoto, Y., Ohta, T., Noguchi, H. (1982). Hydrological and geomorphological studies of debris slides on forested hillslopes in Japan. IAHS Publ. No. 137, 89-98.

Wieczorek, G. F. (1982). Map showing recently active and dormant landslides near La Honda, Central Santa Cruz Mountains, California. U.S. Department of the Interior, Geological Survey Map MF-1422.

Yamaguchi, S. (ed). (1980). Landslides in Japan. Japan Society of Landslides, 44 p.