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Geology and Geomorphology of the H.J. Andrews Experimental Forest, Western Cascades, Oregon

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INTRODUCTION

In many areas of mountainous country, the development and productivity of forest ecosystems are closely linked with the geologic and geomorphic processes acting on the landscape. This is particularly true in areas such as the western Cascades of Oregon where erosion rates are naturally high, and deep-seated and shallow mass movements occur frequently. Furthermore, studies by Anderson (1954), Dyrness (1967), Fredriksen (1970), and others indicate that land management activities may substantially increase erosion, especially by road-related shallow soil mass movements. Increased fundamental knowledge of erosional processes is a prerequisite for sound management of unstable lands.

For this reason the U. S. Forest Service and the Coniferous Forest Biome of the International Biological Program have undertaken geology and geomorphology studies in the H. J. Andrews Experimental Forest in the western Cascade Range about 50 miles (80 km) east of Eugene, Oregon. The purpose of the work has been to collect information on bedrock and surficial geology which can be integrated with more detailed studies of erosion, soil genesis, and nutrient cycling. This paper summarizes the geologic and geomorphic histories of the Forest area and emphasizes the relationships between bedrock geology and mass wasting events.

GEOLOGY OF THE H. J. ANDREWS EXPERIMENTAL FOREST

A stratigraphic column and generalized bedrock geology map of the area are shown in figure 1. The Lookout Creek drainage which makes up the Forest is underlain exclusively by rocks of volcanic origin, including lava flows, ash flows, air fall tuffs, cinder beds, and water-worked tuffaceous sediments.

In this report, rock units are grouped following the designations used by Peck et al. (1964), who dated formations on the basis of paleobotany. A current project for potassium-argon dating of Cascade rocks (Dr. A. R. McBirney, University of Oregon, personal communication, 1974) may result in some major revisions in the stratigraphy and accepted ages of Western Cascade rock units.

The oldest rocks are included in the Oligocene to lower Miocene Little Butte Formation (fig. 1). The base of the section exposed in the Forest is located at the mouth of Lookout Creek. The rocks consist of massive, green, blocky breccias derived from mudflows and pumice-deficient pyroclastic flows. Higher in the section, pumice-bearing welded and nonwelded ash flows are dominant rock units. In several places within the section there are abundant waterworked volcanic sediments.

At several locations between 2,000-foot (610-m) and 2,500-foot (760-m) elevation, there are exposures of basaltic flow rock, often containing green mineralization and silica precipated in fractures. The limited lateral extent of the flows suggests that they occurred as intercanyon flows over a stream-dissected landscape. A further indication of significant topographic relief during late Little Butte time is the presence of several hundred feet (about 100 m) of tuffaceous siltstone and sandstone which accumulated with some plant matter in small lake basins (mapped in fig. 1).

In the western part of the mapped area, several dozen vertical dikes, ranging in composition from basalt to rhyolite, cut through the volcaniclastic country rock in a consistently northwesterly trend. The dikes appear to have served as local

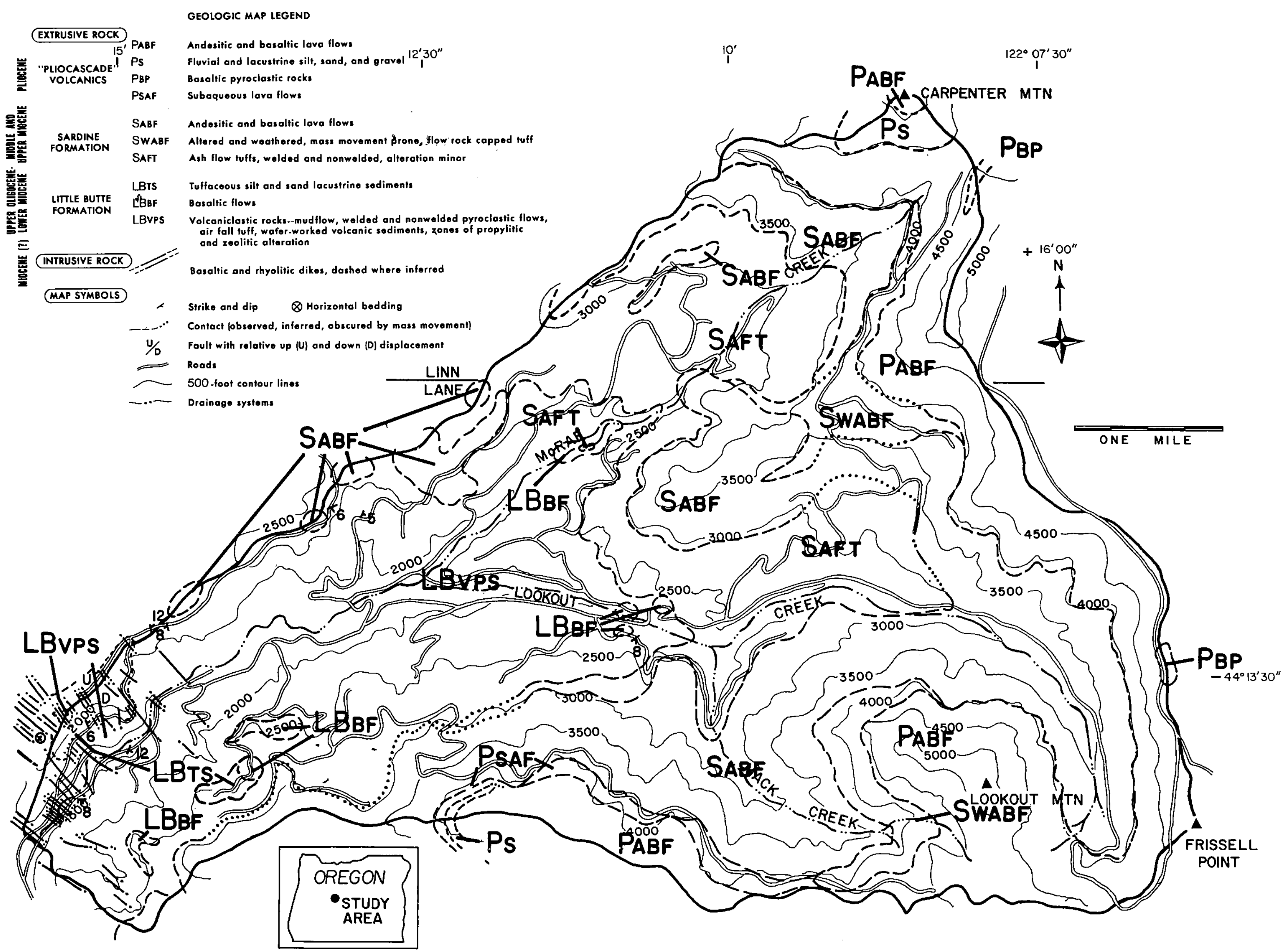

Figure 1.--Geologic map, H. J. Andrews Experimental Forest.

feeders for some of the ash flows and lava flows of the Little Butte and the overlying Sardine Formations.

Capping the Little Butte clastic and flow rocks are two units of the Sardine Formation, dated as middle- to late-Miocene by Peck et al. (1964). The Little Butte-Sardine contact, though difficult to trace through the forest cover, varies in elevation from about 2,500 to 3,000 feet (760 to 915 m), indicating that there was more than 500 feet (150 m) of relief on the pre-Sardine landscape. The lower Sardine unit contains welded and nonwelded ash flows which are notably less altered than underlying rocks of similar lithology mapped as Little Butte. Basalt and andesite lava flows make up the bulk of the upper Sardine unit. The contact between the units is complicated by the interstratification of lava flows and ash flows.

In several locations the uppermost Sardine age flows appear to have been deeply weathered during a long hiatus before eruptive activity began again.

Andesitic and basaltic lava flows, cinder beds, and sediments which overlie the Sardine have been informally designated "Pliocascade" by Dr. E. M. Taylor (Oregon State University, personal communication, 1973). In the Forest area, Pliocene volcanism commenced with pyroclastic eruptions in the vicinity of Lookout Mountain and Frissell Point. Several distinct cinder cones were constructed and possibly served as vents for lavas which flowed to the north and west. In the area of what is now Lookout Ridge, lavas flowed westward into a lake or partially dammed river system, resulting in the formation of pillow lavas and amber-colored, glassy breccias produced by quenching. Some fluvial and lacustrine sediments are interbedded with the flows.

Several flows within the "Pliocascade" sequence have been dated by potassium-argon methods at 6.1 ± 0.1 and 3.9 ± 0.1 million years in age (E. M. Taylor, Oregon State University, personal communication, and A. R. McBirney, University of Oregon, personal communication, 1974). Since that time the area of the present High Cascade Mountains immediately east of the Forest was downdropped along a series of north-south trending, high angle normal faults. Displacement took place in a zone of parallel, north-south faults which extends from Frissel Point eastward to the McKenzie River where it disappears beneath the cover of younger High Cascade lavas. When High Cascade volcanism began about 2.0 to 2.5 million years ago (E. M. Taylor, Oregon State University, personal communication), the Forest area had been sufficiently uplifted that no High Cascade lava flows spilled into the Lookout Creek drainage.

GEOMORPHOLOGY OF THE H. J. ANDREWS EXPERIMENTAL FOREST

Geomorphic development of the modern Lookout Creek drainage probably began about 4 million years ago, during the close of Pliocene volcanic activity. River gravel and quiet water sediments beneath "Pliocascade" lavas near the tops of Lookout Ridge and Carpenter Mountain indicate that the early and middle Pliocene geography bore little resemblance to the modern landscape. Late Pliocene volcanism flooded the pre-"Pliocascade" landscape, filling in stream valleys and essentially setting the stage for development of the Lookout Creek drainage during Quaternary time.

Glacial, fluvial, and mass wasting

processes have all had important roles in shaping the present morphology of Lookout Creek valley. Rapid erosion of the steep terrain has erased much of the record of the early geomorphic history of the area. However, landforms and surficial deposits which date back as much as several tens of thousands of years leave a clear record of recent actions of glacial, alluvial, and mass movement processes in the valley.

We will first briefly summarize the glacial and fluvial histories of the area and then describe mass movement processes, which deserve special emphasis from the viewpoint of land management.

Glacial History

Numerous landforms and surficial deposits record a history of glaciation within the Forest. Cirques were developed on north and northeast aspects where ridges exceed about 4,500 feet (1,370 m) in elevation. The flatter parts of the cirque floors are covered with patches of compacted till which is probably of latest Wisconsin age. This estimate is based on the oxidation of the deposits to a depth of less than 3 feet (1 m), which is comparable with the weathering of latest Wisconsin till identified in the McKenzie River valley by Taylor (1968). More extensive, pre-latest Wisconsin till and fluvioglacial outwash are recognized by greater depths of weathering. Remnants of these deposits occur along Lookout Creek to a point at least 0.6 mile (1 km) below its confluence with Mack Creek and down McRae Creek valley to an elevation of about 2,500 feet (760 m). The preserved glacial material has a patchy distribution as a result of erosion from hill-slope areas and fluvial reworking along the valley floor.

There are also indications that movement of glaciers into the mouth of Blue River formed an ice-dammed lake which flooded the lower kilometer of the Lookout Creek valley. Swanson and James interpret exposures of fine-grained, lacustrine sediments in the banks of lower Blue River and Lookout Creek as having accumulated in such a depositional environment.

Alluvial History

Fluvial processes have constructed terraces and numerous small alluvial fans along the valley bottoms of Lookout Creek and some of its major tributaries. Geomorphic units forming the valley floor along the lower 2-1/2 miles (4 km) of Lookout Creek include the modern channel, a vegetated flood plain, and a terrace surface 15 to 25 feet (5 to 8 m) above the active channel. In places on the terrace surface there are patches of volcanic ash from the eruption of Mount Mazama (correlation based on petrographic characteristics). Wood fragments associated with the ash have been dated by radiocarbon methods at about 7,000 years before present (b.p.) (Kittleman 1973). This indicates that the terrace surface had been abandoned as a flood plain by that time, and since then Lookout Creek has been actively downcutting. In addition, alluvial fans have been constructed onto the terrace surface from the mouths of tributary streams beginning more than 7,000 years b.p. (Swanson and James (1975) present a detailed discussion of fan and terrace stratigraphy.)

At a point about 3 miles (5 km) upstream from the mouth of Lookout Creek, the character of landforms on the valley floor changes markedly. Downstream the valley bottom is narrow, generally 300 to 1,000 feet (90 to 305 m) wide, and the terrace is a prominent landform. Upstream to a point about half a mile (1 km) below

Mack Creek, alluvial deposits extend from 1,000 to 1,300 feet (305 to 395 m) across the valley floor and have a definite asymmetry with thickest deposits occurring on the south side.

Two factors account for the contrasting characteristics of the upstream and downstream valley segments. The point of transition is located at the base of a massive earthflow (shown in figures 2 and 3), which has raised local baselevel by dumping large quantities of sediment into the stream. Consequently, the upstream portion of the Lookout Creek aggraded, constructing a broad flood plain. In addition, greater influx of sediment from the large tributary watersheds on the south side of the valley resulted in formation of a wedge of sedimentary deposits along the southern margin of the valley.

The history of these landforms began with alluviation of the valley in response to glacial and mass movement processes operating in the large watersheds on the north face of Lookout Ridge. Most of this sedimentation occurred during latest Wisconsin deglaciation and earlier, probably more than 10,000 years b.p. Subsequently, Lookout Creek began to exhume its channel, and in places the stream has now cut down through as much as 60 feet (20 m) of the fill. This transition from aggradational to degradational fluvial regimens in early to middle Holocene time has also been documented in lower Blue River (see footnote 1) and in the Willamette Valley (Balster and Parsons 1968).

The timing of movement of the massive earthflow is difficult to determine. Mazama ash was collected in some closed depressions on the landslide terrain, indicating that the mass movement topography had begun to develop more than 7,000 years b.p. However, the steep, actively eroding, 130-foot-high (40-m-high) cliffs at the toe of the earthflow (location "X" on figure 2) and the shallowness of stream incision on the earthflow terrain suggest that movement has probably continued until quite recently and portions of the area may still be active today.

Another example of the interaction of earthflows and streams is discussed in the following section and sketched in figure 4. These situations emphasize the close interrelationships among fluvial, mass movement, and glacial processes.

Deep-Seated Mass Movement History

Massive, deep-seated earth failures have had an important part in forming the present Lookout Creek landscape. Most of the landslide areas mapped in the Forest (fig. 2) may be classed as slump-earthflow types (Varnes 1958). Such events involve the simple downward sliding of massive slices or blocks of material in the upper part of a failure zone; in the lower portion of the moving mass, transport takes place mainly by a flowage mechanism. Some of the smaller failures are rotational slumps in which the failing mass rotates on a curved sliding surface with only minor disruption of the moving block.

Slump-earthflow areas and simple rotational slumps were identified in the field and aerial photographs on the basis of three groups of criteria: (1) large-scale topographic features such as anomalous drainage patterns; (2) small-scale topographic features, mainly hummocky ground, scarps, and poorly drained depressions; and (3) vegetation disturbed by ground movement.

In some of the larger areas of earthflow activity (greater than several hundred

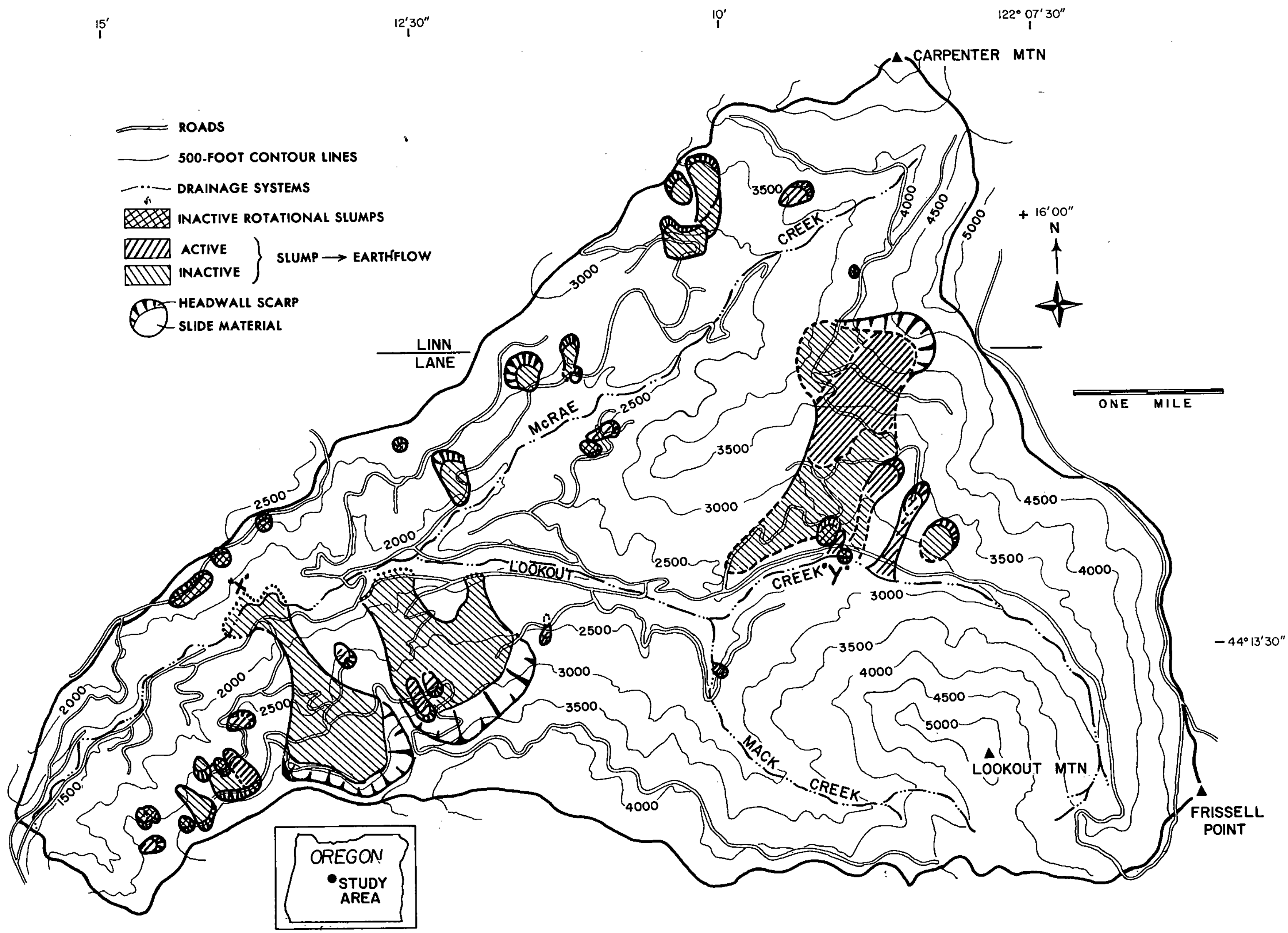

Figure 2.--Deep-seated mass movements, H. J. Andrews Experimental Forest. Location "X" shows toe of large earthflow and location "Y" marks the earthflow sketched in figure 4; both features are discussed in the text.

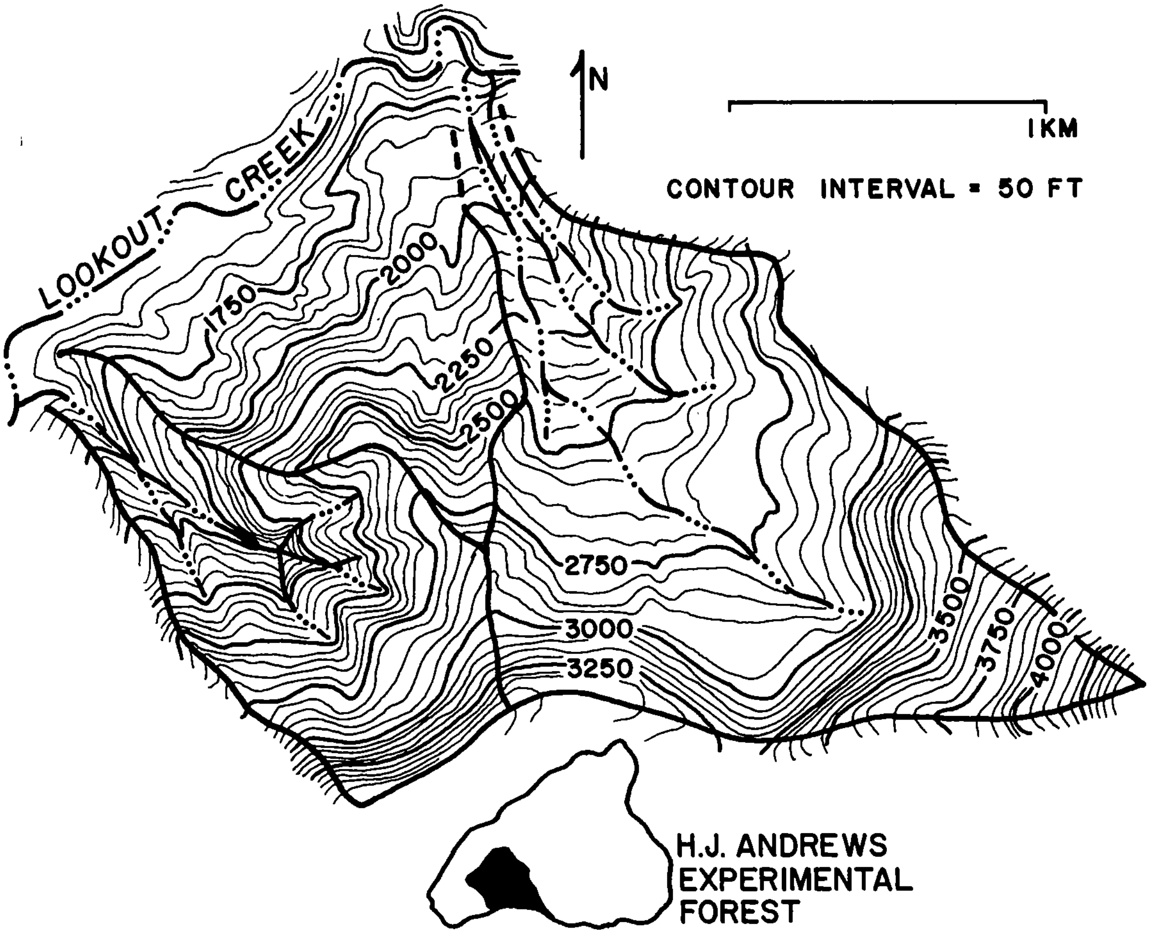

Figure 3.--Topographic map showing contrasting topography between experimental watershed #3 (Fredriksen 1970) on left, which has been deeply dissected by stream erosion and the watershed on right which has undergone deep-seated failure, filling the lower part of the drainage with mass movement material.

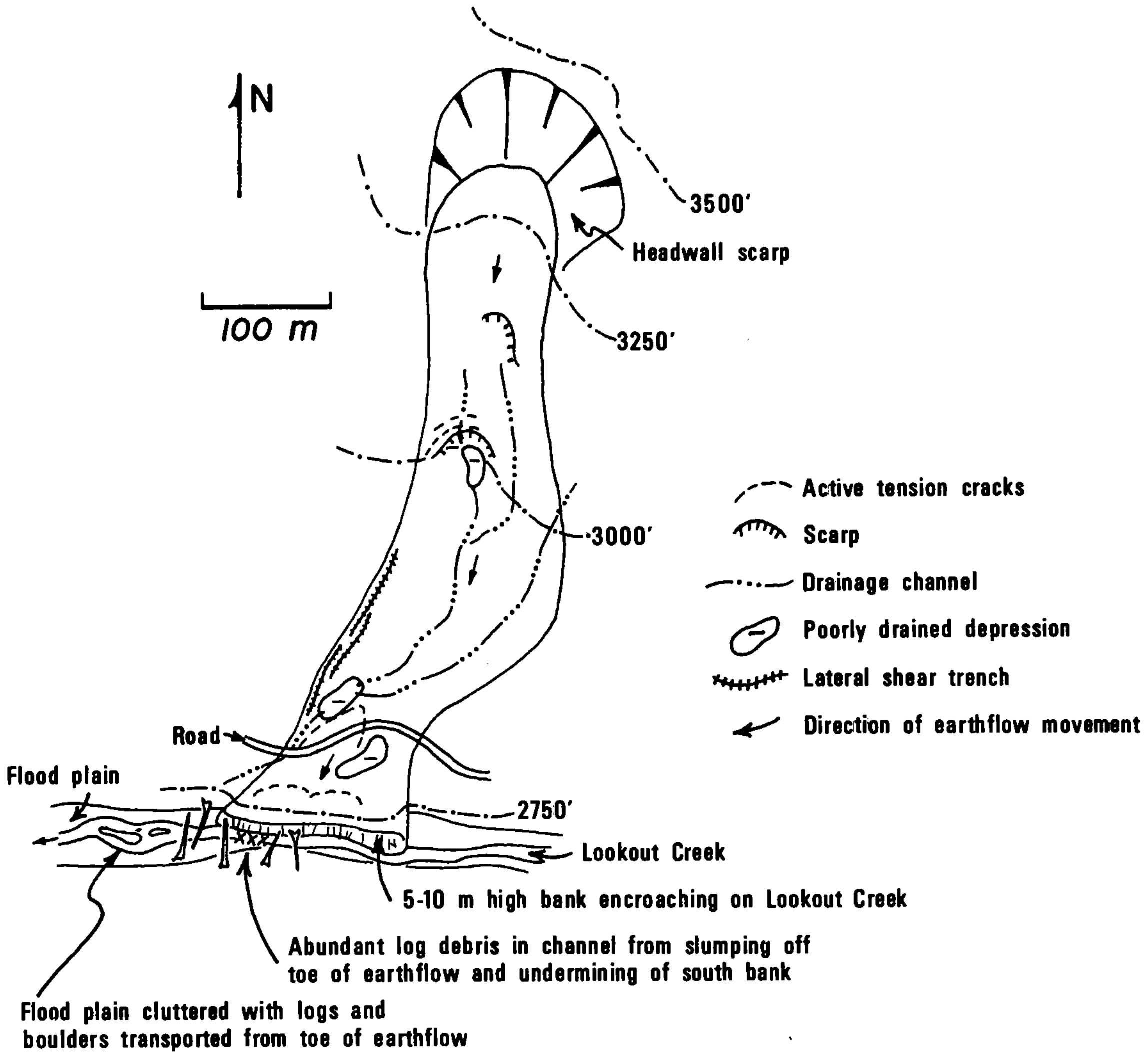

Figure 4.--Sketch map of active slump-earthflow (location "Y" in figure 2), showing surface features and impact on Lookout Creek.

acres or about 100 ha), earth movement has produced large, bowl-shaped drainages; hummocky topography in the central and lower portions of watersheds; poorly developed drainage systems, including sets of small parallel streams; and temporary blockage or diversion of the mainstream channel at the foot of the watershed. All of these features are observed in the watershed shown in figure 3. The distinctive characteristics of the disrupted watershed are especially evident when contrasted with the adjacent, deeply incised drainage to the west. Practically the entire area of the watershed on the east has undergone massive deep-seated earthflow, creating a steep headwall scarp across the top of the drainage and completely burying and reshaping the former topography of the lower 70 percent of the basin below an elevation of 3,000 feet (915 m).

Zaruba and Mencl (1969), Varnes (1958), and others offer excellent descriptions of the smaller scale surface characteristics of mass movement areas. The most common features in the study area include poorly drained depressions (ponds or skunk cabbage (*Lysichitum americanum*) and cedar (*Thuja plicata*) bogs); arcuate, concave downslope scarps, and hummocky topography. Figure 4 shows examples of surface morphological features on an active earthflow encroaching on a section of Lookout Creek.

The character of vegetation also is an excellent indication of active earth movement at unstable sites. The presence of "jackstrawed," or tipped and bowed, trees is commonly interpreted as the result of land movement churning the ground and tilting of trees on the ground surface. However, it is necessary to use care in vegetation study because trees may also have irregular growth form resulting from snow creep, change in canopy structure due to blowdown, wind tilting, other trees falling or rolling against them, and other factors. In analysis of vegetation it is also important to note that some species tend to be more stable than others; e.g., Douglas-fir (*Pseudotsuga menziesii*) is more windfirm than western redcedar (*Thuja plicata*). Some stands have mixed growth forms with older trees (greater than 200 years in age) being "jackstrawed," while intermixed younger timber (less than 100 years old, for example) is not. These circumstances may result from a period of recent stability or from earth movement so slow that tree form is affected only on the longer time scale.

For presently inactive mass movement areas, four criteria may be used to estimate the time elapsed since the last substantial movement took place: (1) the landforms which define the movement area are extensively dissected by postslide erosion, (2) slide material is overlain by glacial deposits showing no indication of having been moved by the slide, (3) slightly reworked beds of Mazama ash have collected in closed depressions on a slide topography which is pre-ash in age, and (4) the vegetation shows no sign of having been bowed and tilted by earth movement. These criteria are ranked in order of decreasing minimum time period of stability, ranging from several tens of thousands of years for criterion 1 to several centuries for criterion 4. Mass movement areas noted as "Active" in figure 2 exhibit tilted and bowed trees and in some cases freshly exposed slippage planes.

The rates of earthflow movements in the western Cascades have not been documented in any detail. However, preliminary observation suggests that movement rates vary from zero in presently stable areas to more than 1 yard per year (1 m/yr) for very active flows. The higher rates have been registered by downslope movement of segments of roads and the encroachment of flows over roads.

As slow-moving, deep-seated failure takes place, there is a general decrease in relief over the surface of the sliding mass. This results in increased stability until a stable configuration is reached and movement slows or stops. Movement may start again during later periods of very heavy precipitation either as single storms or as long-term changes in precipitation patterns over several years. Movement may also be reactivated by changes in distribution of mass in the failure area due to the single or combined effects of road construction, stream erosion, or small-scale mass movements. These processes account for some of the complexity of earthflow terrains which include both presently active and long stable areas, e.g., the very large mass movement area in the east-central portion of figure 2.

Comparison of figures 1 and 2 demonstrates the strong control which bedrock geology has on deep-seated mass movements. The principal failure zone of many of the failures, especially the larger ones, is near the contact where lava flows and welded ash flow beds cap volcaniclastic rock. In fact, much of the length of the contact zone in the west half of Lookout Ridge lies along the headwalls of mappable mass movement areas. In higher elevation areas underlain exclusively by lava flows, there is no evidence of extensive mass movement. Below the contact zone there are a few small, scattered, deep-seated failures which occur entirely within volcaniclastic bedrock.

The tendency for landslides to have headwall scarps at the contact zone is related to the capping effect of the flow rocks in the headwaters of small watersheds. The underlying volcaniclastic rocks are much more susceptible to erosion by mass soil movements (Dyrness 1967) and stream cutting. The greater resistance of the capping flow rocks to these erosional processes prevents the establishment of a stable slope profile. In moist, temperate regions these circumstances commonly result in the development of deep-seated rotational slumps and earthflows.

Shallow Soil Mass Movement History

In this study, as in Dyrness (1967), shallow soil mass movements are classed as those events in which more than 100 cubic yards (76 m^3) of mainly soil, colluvial, and, possibly, vegetative material is transported rapidly downslope. From a land management viewpoint these events pose the major erosion problem in the western Cascades. Shallow mass wasting damages roads, removes soil from tree-growing sites, and may lead to degradation of water quality and the stream habitat.

Dyrness (1967) offers an excellent description of the types and occurrences of 47 shallow mass movements which took place in the Forest as a result of severe storms in December 1964 and January 1965. The recorded events include slumps, small earthflows, debris slides, avalanches, and torrents. Dyrness observed that the mass movements occurred mainly on green volcaniclastic rocks and on soils derived from them, on slopes between 45 and 90 percent, at elevations between 2,300 and 2,600 feet (700-790 m), and in association with logging roads.

We have compiled data for an additional 50 events which took place in other winters since about 1950, when timber harvest and roadbuilding began in the Forest. Information was gathered from written U.S. Forest Service records made between the early 1950's and early 1960's, conversations with R. L. Fredriksen and C. T. Dyrness (both with Pacific Northwest Forest and Range Experiment Station), sets of aerial photographs taken in 1959, 1967, and 1972, and our own field observations.

All shallow soil mass movements known to have occurred since about 1950 are shown in figure 5. Analysis of the combined data for all shallow failures reinforces the general conclusions of Dyrness (1967) based on the 1964-65 winter events alone.

Critical comparison of maps of bedrock geology and deep-seated and shallow mass movements (figs. 1, 2, and 5) reveals some additional relationships between bedrock and surficial geology. As in the case of deep-seated failures, shallow mass movements tend to occur in volcaniclastic rock terrains, especially in the contact zone where flow rocks cap clastics. Several factors contribute to the instability of this geologic setting. At elevations above the contact zone the bedrock is relatively impermeable and, in places, highly jointed; soils are shallow and stony. As a result, waters move rapidly downward into the marginally stable ground below the contact. Rapid influx of water during heavy storms produces high pore water pressures and an increased probability of mass movement.

The common occurrence of deep-seated failures in the contact zone has resulted in the accumulation of poorly consolidated, potentially unstable mass movement deposits in many areas at elevations below 3,000 feet (915 m). In several cases active deep-seated earthflows are directly responsible for the instability of areas subject to recurring shallow mass movements. For example, the active earthflows encroaching on upper Lookout Creek (location "Y" in fig. 2) have caused numerous small streambank slumps. In another case a small, active earthflow near the headwaters of a drainage appears to have triggered repeated debris torrents down the kilometer-long channel draining the watershed.

Dyrness (1967) has shown that a major geological factor determining the occurrence of shallow mass movements is the high content of expendable clays in soils derived from volcaniclastic rocks. He noted that green colored breccias are particularly failure-prone, and Paeth (1970) found that they contain abundant zeolites which weather readily to unstable montmorillonite. Both the green coloration and the assemblage of easily weathered minerals in the breccias have been produced by several geological processes: (1) propylitic alteration involving the formation of albite, chlorite, pyrite, and other minerals by reaction with hot water circulated during the cooling of shallow intrusive bodies, (2) hydrothermal development of zeolites by circulating hot solutions or gases which may be heated either at depth or near the surface as fresh lava and ash flows cool, (3) burial metamorphism in which burial leads to increased temperature and pressure conditions and the formation of new minerals. With further study of these forms of low-grade metamorphism in the western Cascades, it will be possible to better predict the locations of unstable ground on the basis of regional geology.

LAND MANAGEMENT IMPLICATIONS

The close relationships between geology and landscape stability established in this and earlier studies in the Forest should be considered in management planning for forest lands in the western Cascades. Potentially unstable areas may be recognized by (1) presence of altered

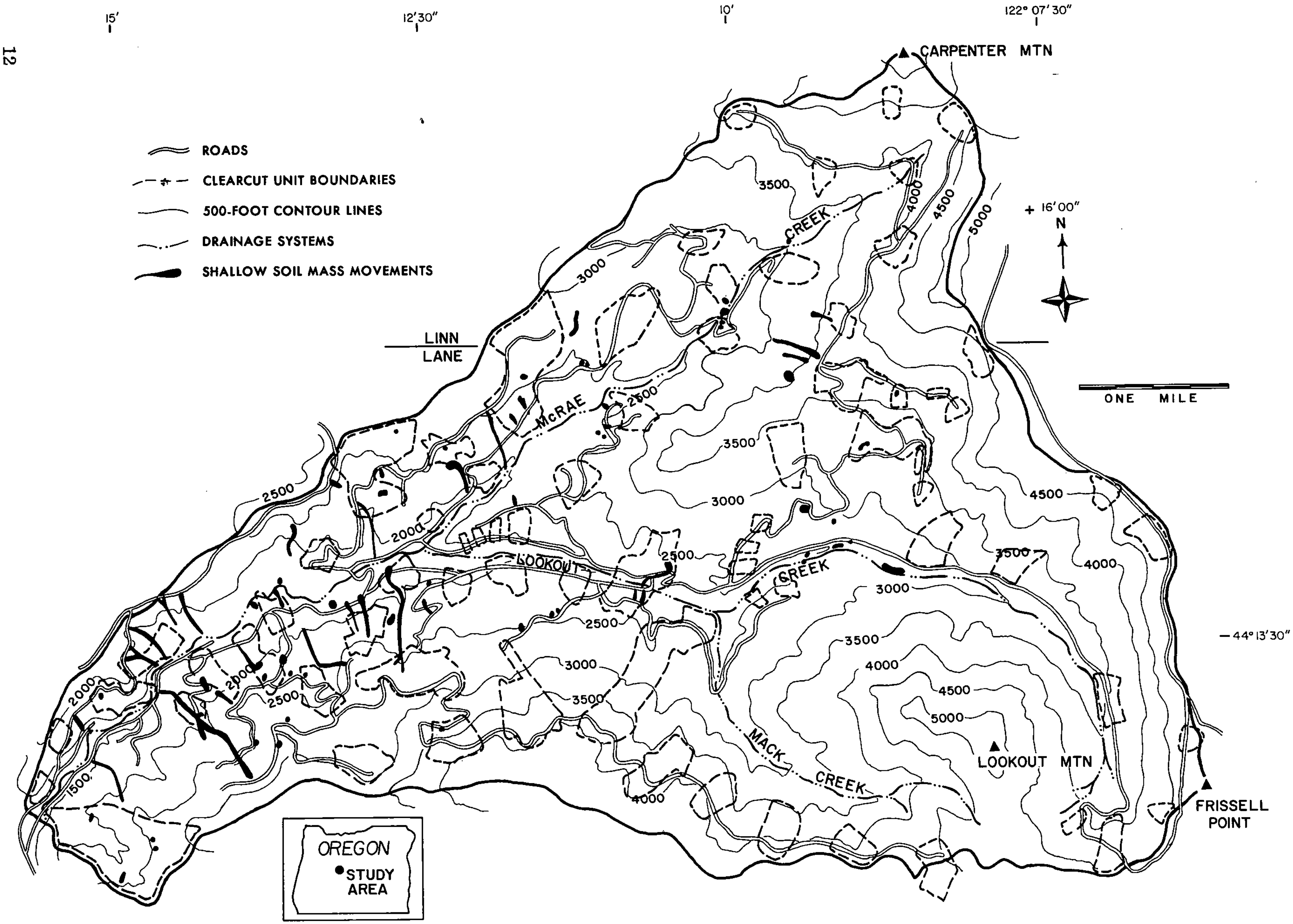

Figure 5.--Shallow soil mass movements, H. J. Andrews Experimental Forest.

volcaniclastic rocks, (2) proximity to contact zones where lava flows or other relatively competent rocks overlie volcaniclastic rocks, or (3) evidence of past history of instability in the area. Areas of past and presently active instability should be identified from aerial photographs, field inspection of topography and vegetation, and even topographic maps.

Judicious use of land stability information in road placement, design, construction, and maintenance will help to minimize the types of accelerated erosion in the area documented by Dyrness (1967) and Fredriksen (1970).

CONCLUSIONS

The geologic history of the H. J. Andrews Experimental Forest area has been one of distinct phases of volcanism interspersed with periods dominated by weathering, erosion, and the reworking of volcanic material. Paleobotanical evidence suggests that the earliest rocks, mainly mudflow and pyroclastic flow units, were erupted in late Oligocene to early Miocene time. Younger eruptive activity poured out basaltic and andesitic flows as recently as about 4 million years b. p.

Glacial, alluvial, and mass movement processes have formed the modern Lookout Creek landscape since late Pliocene time. Glaciation has formed cirques on north- and northeast-facing ridges higher than 4,500 feet (1,370 m), and glacial deposits are found along Lookout and McRae Creeks down to elevations of about 2,200 and 2,500 feet (670 and 760 m), respectively. Latest Wisconsin ice appears to have been mainly restricted to cirques and elevations above 3,800 feet (1,155 m).

Alluvial processes have constructed a modern flood plain and a terrace on which numerous small alluvial fans have accumulated from tributary watersheds. About 3 miles (5 km) from the mouth of Lookout Creek, a massive earthflow encroached on the channel during Holocene time, resulting in the development of a very broad flood plain for about 2.8 miles (4.5 km) upstream. The section of the valley above the earthflow is also characterized by a thick wedge of sediment along the south side of the valley. This deposit accumulated before mid-Holocene time as a result of high sedimentation rates from the large glaciated and slide-prone watersheds forming the southern valley wall.

Mapping of mass movements in this study and by Dyrness (1967) has demonstrated that bedrock geology exercises significant influence on the occurrence of deep and shallow mass movements in the western Cascades. Both occur predominantly in areas underlain by volcaniclastic rocks which weather readily to deep, clay-rich soils. Landscape stability problems tend to be most severe where a contact zone of lava flow over volcaniclastic rocks occurs in the steep headwall or midbasin regions of watersheds. The capping effects of the more resistant flow rocks leads to development of critical slopes on the unstable volcaniclastic rocks. As instability is enhanced by the downcutting of streams, earthflows, slumps, and shallow soil mass movements occur. These processes are presently playing major roles in shaping those small watersheds within the Lookout Creek drainage which are in part underlain by clastic rocks.

Recognition of the various types of active or potentially active areas of the landscape is important in planning the development of any area. Landscape stability may be evaluated on the basis of several important criteria, including topography, general bedrock geology, and vegetation types and conditions. These factors can be examined by using aerial photographs, topographic maps, and field observations.

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