Chapter Four

Recognition and Identification of Landslides

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The problems of recognition of landslides and identification of landslide types are as complex as are the materials and processes that cause them. As treated more fully in Chapter Three, the basic conditions that favor slides depend to a large extent on the character, stratigraphy and structure of the underlying rocks and soils, on the topography, climate and vegetation, and on surface and underground waters. All of these factors vary widely from place to place; their variations are reflected in differences in the rate and kind of landslide movements that result from their interaction.

Because so many variables are involved in the production of landslides, it is natural that many tools, theoretical and practical, must be used in recognizing and classifying them. The selection of methods and criteria for use in solution of a given problem is made with appreciation of the local conditions. Obviously, not all the available techniques are used on every job. One single factor may call for entirely different methods in determining the danger of landslides. Nevertheless, it is important to have all the methods in mind in case they are needed.

It is the purpose of this chapter to describe some of the techniques used in recognition and classification and to indicate their possible applications. One important method — photointerpretation — is treated separately in Chapter Five. The other approaches can be logically treated in two groups — the means of determining whether or not landslide movements have actually taken place or are likely to do so in the future, and the means of identifying the various types of landslides and their constituent parts. The application of these methods and criteria to the solution of landslide problems appears in succeeding chapters, particularly in Chapter Six.

Evidence for Actual or Potential Landslides

ENVIRONMENTAL FACTORS

A knowledge of the general setting is essential in the recognition of either potential or actual landslides. By setting is meant all the factors that make up the physical environment — geology, soils, topography, climate — for a difference in any single factor, such as climate, can have pronounced effect on the other factors, hence on the probability of slides.

Similar geologic and soil conditions tend to give rise to similar landslides — and recognition features — but only under constant climatic conditions. For example, in an arid region a mature topography developed on old inactive slumps is characterized by smooth, low rounded surfaces, known collectively as hummocky ground (see Fig. 33). Even though modified, the slump blocks are still discernible; the depressions between them are disconnected and there is no well-defined drainage system. In regions of heavy rainfall, however, and in the same amount of elapsed time, the topographic expression of identical geologic conditions is entirely different. The

Figure 33. Hummocky ground, one of the most easily applied criteria for recognizing landslides. In this slide, one mile south of Springdale, Utah, the hummocks are larger and more irregular than they are on many slides. (Photograph by H. E. Gregory, U. S. Geological Survey)

slopes of the hummocky ground are flatter and the depressions are filled with swamp mud and water, with some semblance of an integrated drainage system. This difference is, of course, due to the fact that landslide topography reaches maturity more rapidly in humid regions than it does in arid ones.

Knowledge of the general setting is best had by means of thorough personal acquaintance with the area and long-continued careful observations and analysis. Failing this method, and even accompanying it, much of the necessary background knowledge can be gained through study of available aerial photographs (see Chapter Five) and of topographic, geologic and soil maps. With these facilities the trained observer can obtain a great deal of information on the character of the slopes, of surface and subsurface drainage, and on the character and distribution of the different kinds of rocks and soils that cover them.

Only rarely do geologic or soil maps show landslides as such or describe their causes, nor do most of them show features in the detail that is necessary to answer specific problems. Such maps, however, as well as air photos, are of great assistance in giving background knowledge that is needed as a setting for detailed studies. Some of the useful facts that can be gleaned from maps of one kind or another, or from air photos, are as follows:

1. Rock and soil units and their characteristics.
2. Areal distribution of rock and soil units.
3. Sequence of rock and soil units. For example, a weak unit that could cause failure may not be exposed at the surface but may be plainly shown on a geologic cross-section or on a soil profile.

4. Character and distribution of folds, faults and joints in bedrock, all of which may seriously affect its susceptibility to sliding.
5. Location of volcanic cinder cones and similar features that offer special problems.
6. Drainage pattern — streams, lakes and swamps, all of which give indications of relative permeability of underlying materials.
7. Bowl-shaped headwater regions of creeks, which suggest landslide origins.
8. Terraces, slopes, and depressions.
9. Abnormally steep slopes, with mounds of possible landslide origin at their bases.
10. Scalloped escarpments that suggest landslide origins.
11. Anomalous constrictions in canyons, quite possibly caused by landslides.

Aerial photographs and geologic maps must be used with caution; they can be of great assistance in developing the setting for more detailed studies, but they seldom contain the detail that is required to answer specific questions. Many geologic formations throughout the country are labeled as troublemakers because they are susceptible to landsliding, yet no formation forms slides throughout the entire extent of its outcrop area. It is, thus, incorrect to give the entire formation a bad name. Slight differences in environmental factors or in facies within the formation can and do lead to stability as well as to instability. Moreover, slight differences within a formation may give rise to entirely different types of landslide. The Astoria formation of Oregon and Washington is a good case in point. It is composed of sandstone and siltstone that grade imperceptibly eastward from finer to coarser grain sizes. In the western portion of its area of outcrop the Astoria produces many deep-seated slump landslides; many of the higher hills are nothing more than remnants of slump blocks. Eastward, however, where the materials are somewhat coarser grained, the formation is characterized by debris slides that grade downward into flows. The practical difference to the engineer is that the fine-grained slump-forming materials will not stand up in fills, thus requiring road construction to be made entirely within cuts. On the other hand, the coarser materials that form debris slides farther east can be used successfully in fills if special precautions are taken in beginning them.

The example just given illustrates the fact that generalized geologic maps and descriptions have definite limitations, but this does not imply any lack of faith in their value as a tool for coping with landslide problems. Indeed, as the boundaries of the Astoria formation — and of other geologic units that present comparable problems — become better known, and the facies characteristics are mapped in greater detail, it is increasingly feasible to predict the kind and character of landslides that are likely to occur in any part of the formation.

The study of the environment of the area should give at least a general answer to a fundamental question: "Do landslides already exist along the proposed location?" If the answer is no, it may be taken as an indication that there are no regional factors that are themselves conducive toward landslides. If the answer is yes, it is probable that there are two or more regional factors which, acting together, may lead to landslides. For example, in the north-central part of Washington there is a great and widespread deposit of silt, called the Nespelem formation. When dry, as in small isolated hills or terrace remnants, this silt stands well in natural or artificial cuts. When wet by spring waters, however, the silt is very likely to slide. The conjunction of the two factors — silts and spring horizons — should be a danger signal to the engineer who is planning a highway or other structure in the area.

Studies of all existing landslides in the region are thus warranted in order to determine their geologic settings and their causes. If similar conditions are present along the proposed location it can be assumed that slides will occur there too.

POTENTIAL SLIDES

Even if the preliminary examination of the general environment has indicated that no landslide movements have yet taken place, it is still incumbent on the investigator to determine whether the ground to be disturbed by the proposed construction will prove reasonably stable. Man is not capable, nor is money available, to study in detail and to guarantee the stability of all the slopes along most proposed highways. As a general rule, the amount of investigation that is warranted is a function of the landslide susceptibility of the surrounding country. Too, it is a function of the degree of damage that might be expected to occur to persons or installations if a slide should occur. In other words, the more serious a landslide might be, the more detailed should be the search for potential slides.

After a knowledge of the general environment has been obtained, either by firsthand observation or by study of existing maps and air photos, the next essential step is to visit the site itself and examine its physical conditions. The whole site should first be studied from a distance, for a forest is more easily recognized than are the trees. Special attention should be given to the slopes, changes in slope, and their relationship to the different materials involved. Cracks and other evidences of motion, as well as all sources of water, should be noted. The structure of the underlying bedrock, as well as the depth of overburden, should be determined carefully.

Evidence of soil creep and of "stretching" of the ground surface, should also be sought. Stretching is here distinguished from soil creep because it indicates comparatively deep-seated movement, whereas soil creep is of superficial origin. The phenomenon of stretching is most commonly observed in noncohesive materials that do not form or retain minor cracks readily. The best evidence of stretching consists of small cracks that surround or touch some rigid body, such as a root or boulder, in otherwise homogeneous material; these cracks form because the tensional forces tend to concentrate at or near the rigid bodies.

For recognition of a potential landslide condition where bedrock is hidden, a preliminary but adequate field investigation of the soil, coupled with shear measurements in the laboratory, is perhaps the best means available. Such a combined field and laboratory investigation, backed by at least general knowledge of the underlying rocks, should reveal the soil profile and ground water conditions along a proposed route even where surface features alone do not provide sufficient warning. It must be remembered, however, that there are some rather severe limitations on the applicability of shear measurements to landslide problems; these are further discussed in Chapter Nine.

Potential slides of the rockfall and soilfall type can commonly be foreseen simply by recognizing geologic conditions that are likely to produce overhanging or oversteepened cliffs. Some of the geologic settings that fall in this category are as follows:

1. Massive lava flow underlain by strongly fractured flow or by poorly consolidated volcanic tuffs.
2. Lava flow underlain by easily erodible sandstone.
3. Sandstone or limestone underlain by coal seams or by relatively soft shale.
4. Cliff subject to erosion by waves or running water at its base.
5. Frozen ground or rock subject to local thawing by lake or running water.
6. Firm cohesive or partly consolidated soil underlain by noncohesive soil or fine sand that will be easily eroded by wind or water, by excessive drying, or by seepage pressures from within the slope if it is exposed during construction.

All of the foregoing geologic situations involve a stronger unit over a weaker one. Too often the weak unit is more or less completely obscured by talus or other debris from the stronger layer. This is a point which serves to emphasize the need for thorough field examination.

Effect of Proposed Construction

Many landslides are caused by man's upsetting the natural causes of erosion. This is another way of saying that consideration of the effect of proposed or future construction itself cannot be neglected in the search for dangers of potential landslides. Any cut or fill will change the local stress conditions; it is, therefore, necessary to analyze the possible effects of the stress readjustments to future cuts or fills, whether natural or manmade, and to evaluate the effect of modifying the erosional process that was in operation.

For instance, construction of jetties or groins along Lake Michigan and many other lake and ocean shores disturbs the normal processes of beach erosion and formation, especially in places where there is an interruption of littoral drift of beach sand that protects adjacent bluffs. The location of a scenic highway skirting such a bluff is, then, contingent on future plans for jetty construction along the beaches (see Fig. 4).

A similar problem is encountered when a highway is constructed in a region where adjacent lands may be irrigated in the future. In such a case, it is well to consider the probable results of a rising water table, for such a change in ground water conditions may detrimentally affect a cut or fill section of a highway or of a bluff above the new road. As a concrete example, the Washington State Highway Commission in 1955 was confronted with a $600,000 relocation job, plus purchase of water rights, because the initial instability of the region below Grand Coulee Dam had been aggravated by local irrigation projects.

The effect of water on silts in reservoir banks is well-known, as is the effect of drainage of silts during reservoir drawdown. Dams also affect the regions below them, and can set up potential landslide conditions there. If the materials in the valley walls below the dam are at the critical point of stability a change in the regional water table may trigger the sensitive materials. A dam also retards the normal movement of the river's load; the river bed downstream becomes starved for material, which leads to excessive scour, deepening of the channel and undermining of the banks.

If the engineer keeps proposed or future construction in mind, and evaluates the effect which this construction may have on the soil profile, the underlying rock, and ground water conditions, he will go a long way toward recognizing a potential landslide problem and will be able to make plans to avoid or to stabilize the sensitive mass. Typical situations that should be looked for in this connection are as follows:

1. Restriction of ground water flow by sidehill fill.
2. Overloading of relatively weak underlying soil layer by fill.
3. Overloading of sloping bedding planes by heavy sidehill fill.
4. Oversteepening of cuts in unstable rock or soil.
5. Removal, by cut, of thick mantle of pervious soil if the latter is a natural restraining blanket over a softer core.
6. Increase in seepage pressure by cut or fill that changes direction or character of ground water flow.
7. Exposure, by cut, of stiff fissured clay that may soften when exposed to surface water.
8. Removal of mantle of wet soil by sidehill cut; such a cut may remove toe support, causing soil above cut to slide along its contact with stable bedrock.
9. Increase in hydrostatic head below surface of a cut in silt or permeable clay if surface is allowed to freeze or to become covered with impervious slough material.

Figure 34. Early signs of impending debris slide, highway along Clear Creek, Colo. Displacement of fence, upbulge of pavement, and distress in bridge abutments (see also Figure 35) all gave early indications of movement at the toe of an incipient slide. In several places, now covered by patching, the centerline stripe was offset along cracks. (Photograph by D. J. Varnes, U. S. Geological Survey)

ACTUAL SLIDES

The term landslide, by definition, implies that movement has taken place, hence an analysis of the kind and amount of movement becomes a key to the nature of an active slide. Similarly, prediction of the kind of movement that may take place in the future is prerequisite to the analysis of potential slides.

Quite commonly the first visible sign of ground movement is recorded by settlement of the roadway or, depending on the road's location within the moving mass, an upbulge of the pavement. In some cases it is possible to find evidence of landslide movement that has not yet affected the highway but that may do so in time. Thus, minor failure in an embankment, material that falls on the roadway from an upper slope, or even the progressive failure of the region below a fill may well presage a larger landslide that will endanger the road itself. Other evidences of movement are to be found in broken pipe or power lines, spalling or other signs of distress in concrete structures, closure of expansion joints in bridge plates or rigid pavements (see Figs. 34 and 35), or loss of alignment of building foundations. In many cases, arcuate cracks and minor scarps in the soil give advance notice of serious failure (see Fig. 38).

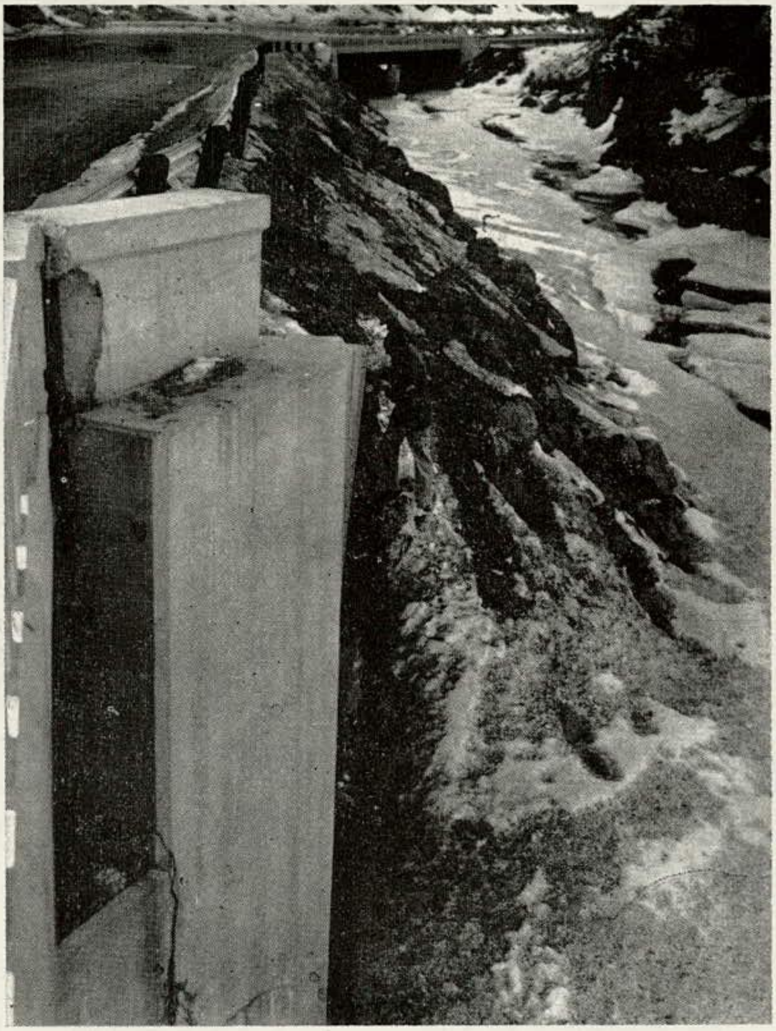

Figure 35. Distress in bridge abutment indicates incipient slide. Right-hand wing wall of bridge shown in lower center of Figure 34. In addition to offset of the wing wall shown here, rockers beneath bridge girders were tipped. (Photograph by D. J. Varnes, U. S. Geological Survey)

The chief evidences of movement in the various parts of each type of landslide are summarized in Table 1 and in the section on "Identification of Landslide Types." Most of these evidences are self-explanatory and require no further explanation. The facts that can be deduced from a study of surface cracks are so important in recognizing and classifying slides that they deserve a few words separately.

Significance of Cracks

The ability to recognize small cracks and displacements in the surface soils and to understand their meaning is one that deserves cultivation because it can produce accurate knowledge of the cause and character of movement that is prerequisite to correction. The significance of tiny cracks around boulders or roots as evidence of "stretching" of the ground surface has already been mentioned.

Surface cracks are not, as is commonly assumed by some, necessarily normal to the direction of ground movement. For example, cracks near the head of a slump are indeed normal to the direction of horizontal movement, but the cracks along its flank are nearly parallel to it.

Small *en echelon* cracks commonly develop in the surface soil before other signs of rupture take place; they are, thus, particularly valuable tools in the recognition of potential or incipient slides. They result from a force couple in which the angle between the direction of motion and that of the cracks is a function of the location within the landslide area. It follows that for many cases a map of the *en echelon* cracks will delineate the slide accurately, even though no other visible movement has taken place (see Fig. 36). Figure 37 shows an actual set of *en echelon* cracks.

In addition to indicating incipient or actual movement, cracks in the surface soils are locally useful in helping to determine the type of slide with which one is dealing. For example, in a slump the walls of cracks are slightly curved in the vertical plane and are concave toward the direction of movement; if the rotating slump block has an appreciable vertical offset the curved cracks wedge shut in depth. In block glides, on the other hand, the cracks are nearly equal in width from top to bottom and do not wedge out in depth. This is because failure in a block glide begins with tension at the base of the block and progresses upward toward the surface. Block glide can be distinguished from lateral spreading by the presence of a few major breaks in the upper parts of a block glide (see Fig. 38) whereas lateral spreading is characterized by a maze of intersecting cracks.

Cracks in block glides of cohesive soils are commonly almost vertical, regardless of the dip of the slip-plane, whereas in block glides of rock the inclination of the cracks depends on the joint systems in the rock.

One of the most helpful applications of a study of cracks lies in the distinction between incipient block glides and slumps. If the outline of the crack pattern is horseshoe-shaped in plan, with or without concentric cracks within it, a slump is almost certainly indicated. If, on the other hand, most of the surface cracks are essentially parallel to the slope or cliff face, a block glide is probably in the making. In either case, additional cracks may develop as major movement gets under way, but these will generally conform to the earlier crack pattern (see Figs. 18 and 19).

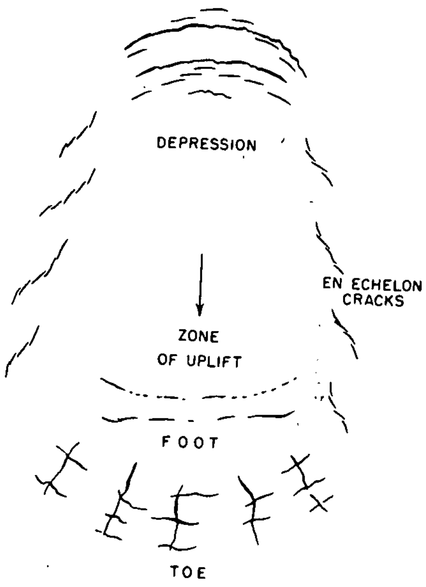

Figure 36. Tension cracks as typically developed in a slump slide in cohesive materials. (Based on Terzaghi and Peck, Fig. 151, 1948)

Hidden Landslides

Among the most difficult kinds of slides to recognize and guard against are old landslides that have been cov-

FEATURES THAT AID RECOGNITION OF

Kind of Material	Type of Motion	Stable Parts Surrounding the Slide		
		Crown	Main Scarp	Flanks
Falling: **Rockfall**	Rock	Loose rock; probable cracks behind scarp; irregular shape controlled by local joint system	Usually almost vertical; irregular, bare, fresh. Usually consists of joint or fault surfaces	Mostly bare edges of rock
Soilfall	Soil	Cracks behind scarp	Nearly vertical, fresh, active, spalling on surface	Often nearly vertical
Sliding: **Slump**	Soil	Numerous cracks, most of them curved concave toward slide	Steep, bare, concave toward slide, commonly high. May show striae and furrows on surface running from crown to head. Upper part of scarp may be vertical	Striae on flank scarps h strong vertical compon near head, strong horizon component near foot. Hei of flank scarp decrea toward foot. Flank of sl may be higher than origi ground surface between f and toe. *En echelon* cra outline slide in early stag
	Rock	Cracks tend to follow fracture pattern in original rock	As above	As above
Block glide	Rock or Soil	Most cracks are nearly vertical and tend to follow contour of slope	Nearly vertical in upper part, nearly plane and gently to steeply inclined in lower part	Flank scarps very low, cra vertical. Flank cracks usua diverge downhill
Rockslide	Rock	Loose rock, cracks between blocks	Usually stepped according to the spacing of joints or bedding planes. Surface irregular in upper part, and gently to steeply inclined in lower part; may be nearly planar or composed of rock chutes	Irregular
Flowing: **Dry** **Rock fragment flow**	Rock	Same as rockfall	Same as rockfall	Same as rockfall
Sand run	Soil	No cracks	Funnel-shaped at angle of repose	Continuous curve into ma scarp
Wet **Debris avalanche** **Debris flow**	Soil	Few cracks	Upper part typically serrate or V-shaped. Long and narrow Bare, commonly striated	Steep, irregular in upper pa Levees may be built up alo lower parts of flanks
Earthflow	Soil	May be a few cracks	Concave toward slide. In some types scarp is nearly circular, slide issuing through a narrow orifice	Curved, steep sides
Sand or silt flow	Soil	Few cracks	Steep, concave toward slide, may be variety of shapes in outline — nearly straight, gentle arc, circular, or bottle-shaped	Commonly flanks converge direction of movement

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E OR RECENTLY ACTIVE LANDSLIDES

Parts That Have Moved

Head	Body	Foot	Toe
lly no well-defined head. Fallen terial forms a heap of rock xt to scarp.	Irregular surface of jumbled rock, sloping away from scarp. If very large, and if trees or material of contrasting color are included, the material may show direction of movement radial from scarp. May contain depressions	Foot commonly buried. If visible, the foot generally shows evidence of reason for failure, such as underlying weak rock or banks undercut by water	Irregular pile of debris or talus if small. If the rockfall is large, the toe may have a rounded outline and consist of a broad, curved transverse ridge
lly no well-defined head. Fallen terial forms a heap next to rp	Irregular	As above	Irregular
nants of land surface flatter n original slope or even tilted o hill creating depressions at ot of main scarp in which rimeter ponds form. Trans- rse cracks, minor scarps, gra- ns, and fault blocks. Attitude bedding differs from surround- area. Trees lean uphill.	Original slump blocks generally broken into smaller masses; longitudinal cracks, pressure ridges, occasional overthrusting. Commonly develops a small pond just above foot	Transverse pressure ridges and cracks commonly develop over the foot; zone of uplift, absence of large individual blocks, trees lean downhill	Often a zone of earthflow, lobate form, material rolled over and buried; trees lie flat or at various angles mixed into toe material
bove	As above, but material does not break up as much or deform plastically	As above	Little or no earthflow. Toe often nearly straight and close to foot. Toe may have steep front
tively undisturbed. No rota- n	Body usually composed of a single or a few units, undisturbed except for common tension cracks. Cracks show little or no vertical displacement	No foot, no zone of uplift	Plowing or overriding of ground surface
blocks of rock	Rough surface of many blocks. Some blocks may be in approximately their original attitude, but lower down, if movement was slow translation	Usually no true foot	Accumulation of rock fragments
head	Irregular surface of jumbled rock fragments sloping down from source region and generally extending far out on valley floor. Shows lobate transverse ridges and valleys	No foot	Composed of tongues. May override low ridges in valley
lly no head	Conical heap of sand, equal in volume to head region	No foot	
be no head	Wet to very wet. Large blocks may be pushed along in a matrix of finer material. Flow lines. Follows drainage lines and can make sharp turns. Very long compared to breadth	Foot absent or buried in debris	Spreads laterally in lobes. Dry toe may have a steep front a few feet high.
monly consists of a slump ock	Broken into many small pieces. Wet. Shows flow structure	No foot	Spreading, lobate. See above under "slump"
rally under water	Spreads out on underwater floor	No foot	Spreading, lobate

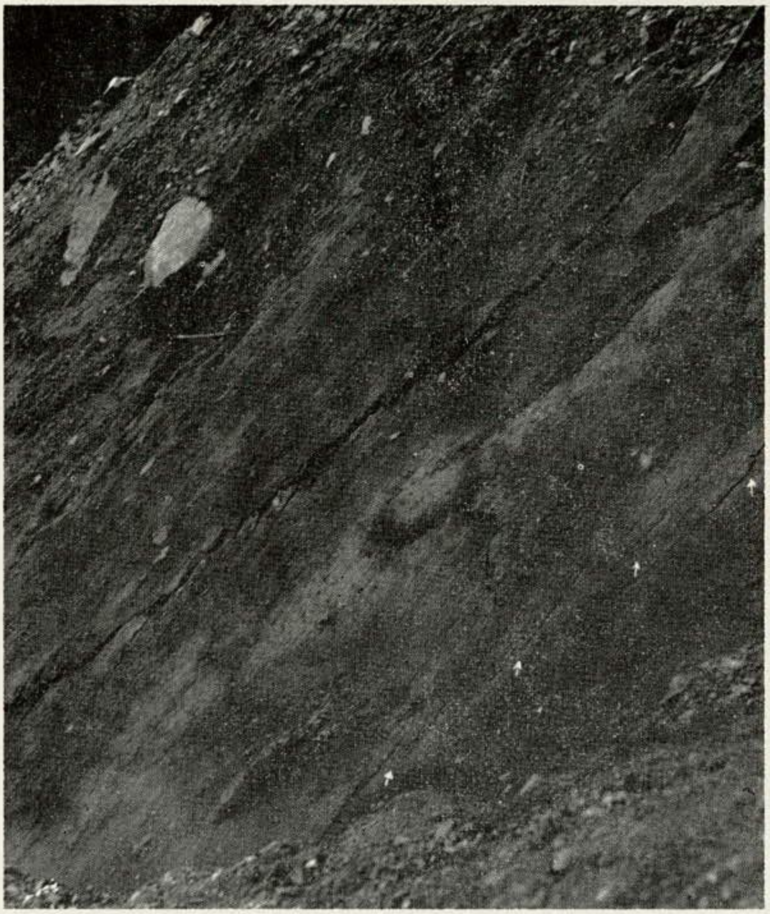

Figure 37. Minor en echelon cracks in soil reflect nearby landslide of major proportions, White Pass, Wash. The soil, only about one foot thick, covers a contact between diorite above and shale beneath. The first system of en echelon cracks has sheared through to form a single irregular fracture; a second line of en echelon cracks (indicated by white arrows) is developing below the first. (Courtesy Washington Department of Highways)

ered by glacial till or other more recent sediments. In such cases as the two examples mentioned hereafter it is probably impossible to predict, in detail, the existence of old buried slides or the effect that they may have on new construction work that happens to expose them. One who knows the recent geologic history of the region intimately, however, may well be able to make some controlled guesses as to the probable existence of such slides, and even as to where they are most likely to be found.

One example is shown in Figure 39. The unstable body of soft shale and chalk shown is clearly related to a fault in the bedrock, but it also has the characteristics of a surface landslide. Since this slide took place, the area was covered by two or more layers of loess, which completely obscured the evidence of the landslide until the rising waters of the lake undercut the bank and exposed the old slide.

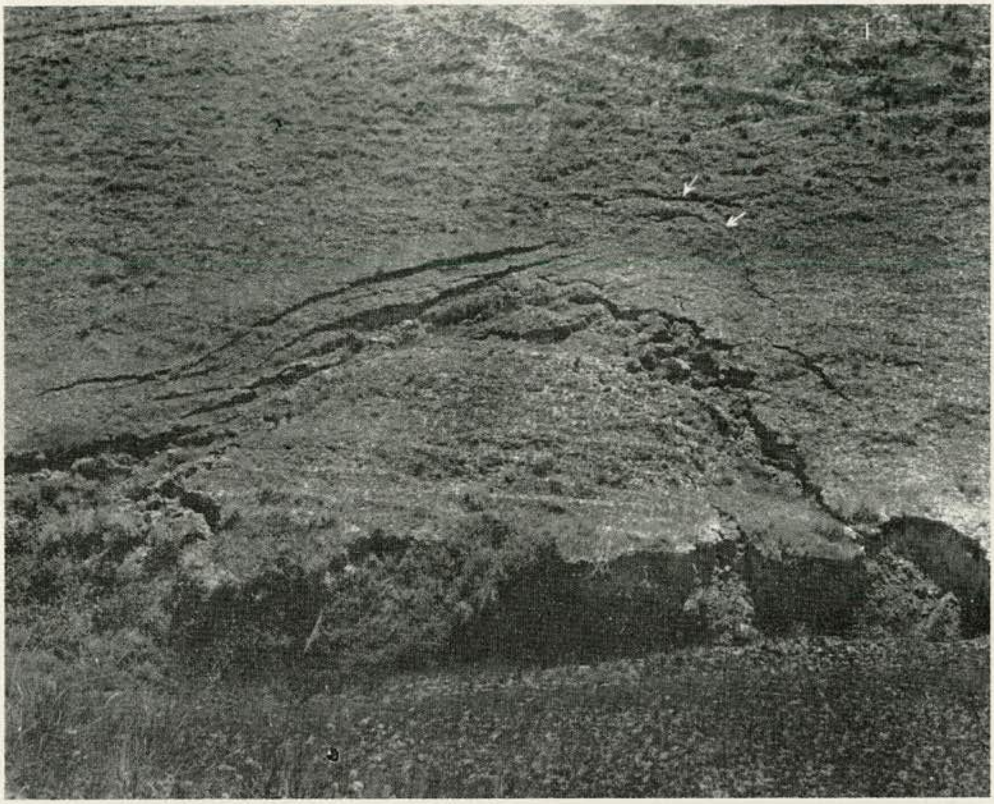

Figure 38. Block glide in cohesive materials, near Portage, Mont. The slide, in alluvium, colluvium and a little wind-deposited silt, is moving out over the surface of an alluvium-filled stream channel with little or no rotation of the block and without developing a zone of uplift at the foot. Note the parallel step scarps along the main scarp and the drag effects along the flanks, both characteristic of block glides. The arrows indicate overbreak cracks that develop after the main scarp is formed; possibly because of the abrupt break in slope, these are more sharply curved than are those above most slump slides. (Photograph by E. K. Maughan, U. S. Geological Survey)

A second example is shown in Figure 40. This landslide, which blocked a major highway near Snoqualmie Pass in the Cascade Mountains, was one of the most disastrous that has ever occurred in Washington. The valley wall, composed of strongly fractured graywacke, was cut to a steep angle by a valley glacier. Retreat of the ice removed lateral support from the rock and resulted in a slump failure that sheared through the fractured graywacke along a typical slump circular arc. Later, readvance of the ice removed projecting material along the valley wall and covered the landslide remnants with a 10-foot thick plaster of glacial till. The resulting slope appeared harmless enough before construction, but soon after the till and some of the rock had been removed it was found that major movement was taking place. Examination showed that the excavation was in the foot region of the old slump. Unloading of the foot caused one-half million yards of rock to cascade down the slope.

Identification of Landslide Types

Once it has been established that land movement has taken place, or is still going on, the next essential step is to

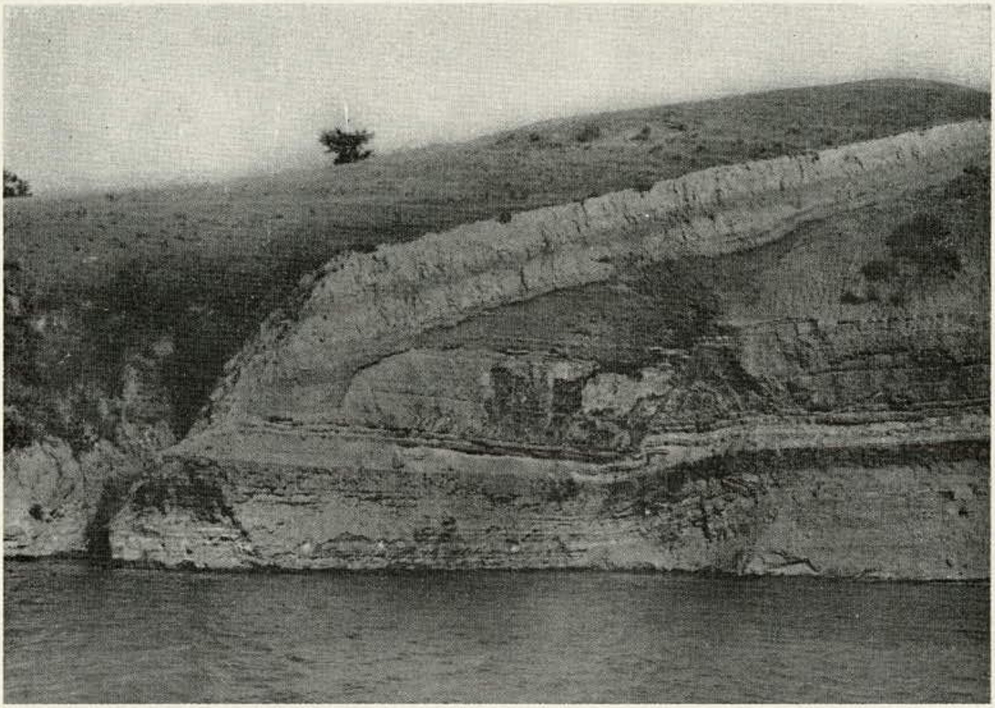

Figure 39. Hidden landslide exposed when overburden of loess was removed by bank-cutting along lake shore, Fort Randall Reservoir, S. Dak. The buried soil profiles indicate two periods of loess deposition after faulting and landsliding took place in the underlying shale and chalk of Cretaceous age. All surface evidence of the landsliding was obliterated by the loess until the lake waters cut a new face. (Photograph by C. F. Erskine, U. S. Geological Survey)

identify the type of landslide. One would not apply the same corrective procedure to a rockfall as to a block glide, nor to a flow and a slump. If maximum benefit is to be had from the preventive or corrective measures finally employed, therefore, it is imperative to learn to recognize the kind of slide that exists. Table 1 summarizes the surface features of various parts of active slides as they aid in identification of the different types. Further generalizations are given in the following paragraphs.

It is important to observe that landslides may change in character and that they are usually complex, frequently changing their physical characteristics, as well as their marks of identification as time goes on. For instance, a landslide examined a year after its occurrence may have changed remarkably from the conditions immediately following the original movement. Certainly, if a landslide developed as a slump slide and over a period of time turned into a flow, the original report on the nature of the slide would be invalid as a basis for planning a correction of the slide at the later date. The identification of the type of slide should be made at the same time it is to be corrected. Even if the landslide that started as a slump but later changed to a flow is corrected as a flow, this does not necessarily mean that the adjoining area, which may be still a slump block, or yet another area that has not moved at all, should require the same kind of correction. Each slide must be classified according to its own characteristics at the time it is to be corrected. If this is not done, time may destroy the value of the identification

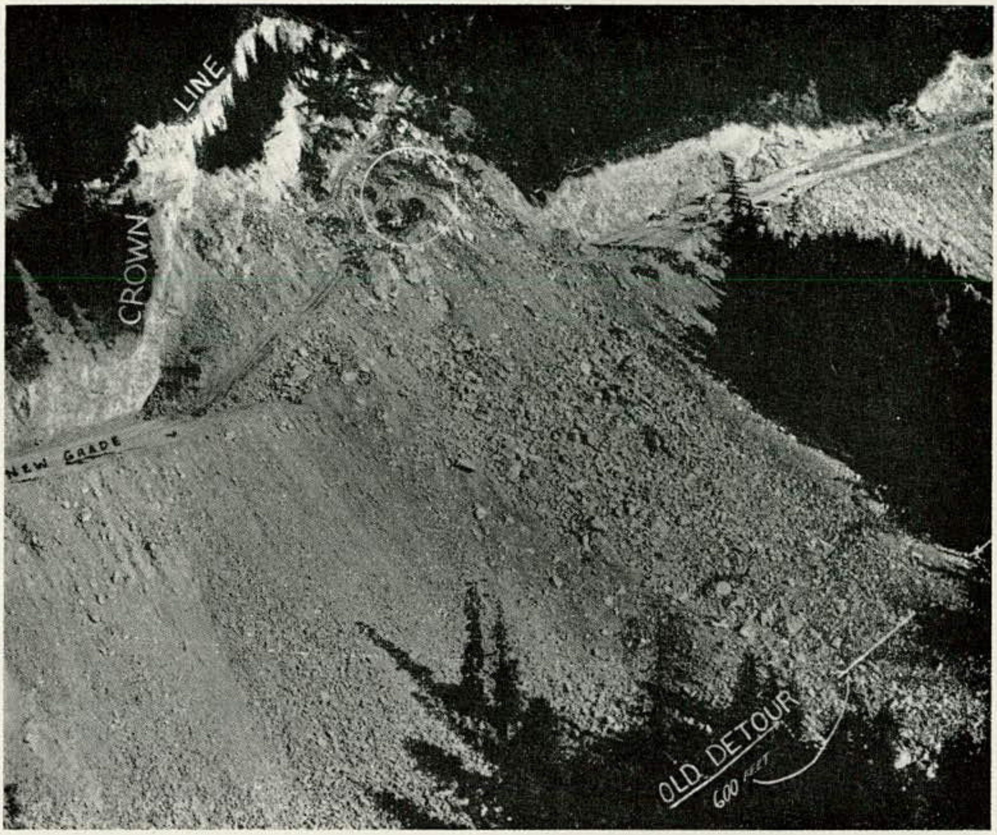

Figure 40. Originally hidden slump block after reactivation by construction; Snoqualmie Pass, Wash., August 13, 1953. After the slide began, and to facilitate removal of unstable material, further movement was deliberately induced by pumping water into the mass. Because the cut slope was more than 160 feet high, the front of the slide moved as a rockfall avalanche, the complete slide taking place in a few seconds. For scale, note 2 1/2-yard power shovel and two bulldozers in circled area. (Photograph courtesy of Pacific Builders and Engineers, Inc.)

work and a corrective procedure based on the previous characteristics of the slide is likely to be the wrong one.

FALLS

Rockfalls and soilfalls are best recognized by the accumulation of material that is not derived from the underlying slope and that is foreign to normal processes of erosion. In most cases this material consists of blocks of rock or earth scattered over the surface or forming a talus slope. If undercutting by lake or stream waters has caused the fall, the rate of failure is proportional to the ability of the water to remove the fallen material. Thus a fast-moving stream may remove material almost as fast as it falls, thus removing the evidence but encouraging continuous further falls. On the other hand a lake, or some parts of an ocean shore, must depend only on wave action to disintegrate and remove the fallen material, hence the evidence tends to remain in sight but continued falls tend to be inhibited.

Most of the material yielded by a rockfall is necessarily close to the steep slopes from which it came. but some may bound down the slope and come to rest far from its present source.

If the rockfall or soilfall is active or very recent its parent cliff is commonly marked by a fresh irregular scar. This scar lacks the horseshoe shape that is characteristic of slumps; instead, the irregularity of its surface is controlled by the joints and bedding planes of the parent material (see Figs. 41 and 42).

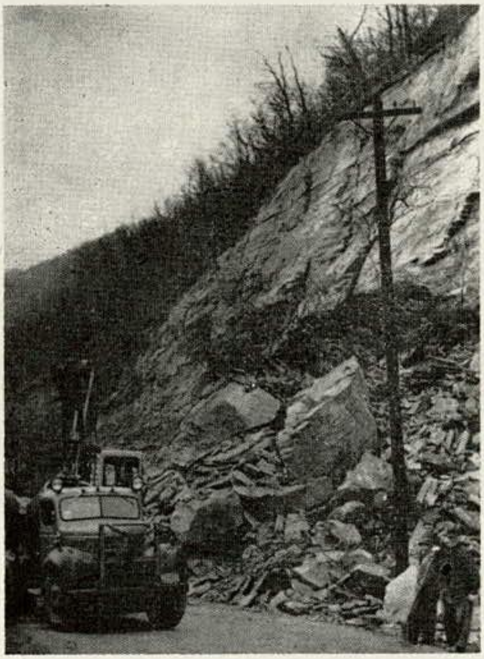

Figure 41. Rockslide-rockfall along Route 105 in Pennsylvania. Beds nearly flat; slide controlled by joints dipping at steep angle toward road. (Photograph by Pennsylvania Department of Highways)

Some idea of the intensity and state of activity of a rockfall can be inferred from the presence or absence of vegetation on the scarp and by the damage done to trees by the falling rocks. In active areas, the trees are scarred and debarked or there is evidence of healed wounds. If the rockfall is severe or long-continued, conifers and other long-lived trees are absent; their places may or may not be taken by aspen or other fast-growing species. Many rockfalls follow chutes or dry canyons that can usually be differentiated from normal watercourses or paths cut by snow avalanches (see Fig. 42).

Some soilfalls exhibit most of the characteristics of rockfalls; others proceed by mere spalling of the surface; but even this activity, if long continued, can lead to removal of considerable quantities of material. Any rockfall or earthfall may, of course, presage major landslide movement in the near future.

SLIDES

Slides, as distinct from falls and flows, are characterized by a host of features that are observable at the surface. These features are related to the kind of material in which the slide occurs, as well as to the amount and direction of motion.

Slumps are characterized by rotation of the block or blocks of which they are composed, whereas block glides are marked by lateral separation with but little vertical displacement and by vertical, rather than concave, cracks. Lateral spreading with few if any cracks, on the other hand, is characteristic of earthflows. One form of lateral spreading, in which a plastic layer is squeezed out by the weight of an overlying rigid layer, is here termed a "piston slide." In this type, a part of the upper layer may drop vertically, without rotation, into the space left by removal of the plastic layer.

Rockslides are generally easy to recognize because they are composed wholly of rock, boulders, or rock fragments. Individual fragments may be very large and may move great distances from their source. Most rockslides are controlled by the spacing of joints and bedding planes in the original rock. There is particular danger of forming a rockslide of serious proportions if construction is undertaken in an area marked by a system of strongly developed joints or by bedding planes that dip steeply outward toward the natural slope. This is especially so if the natural slope angle is steeper than

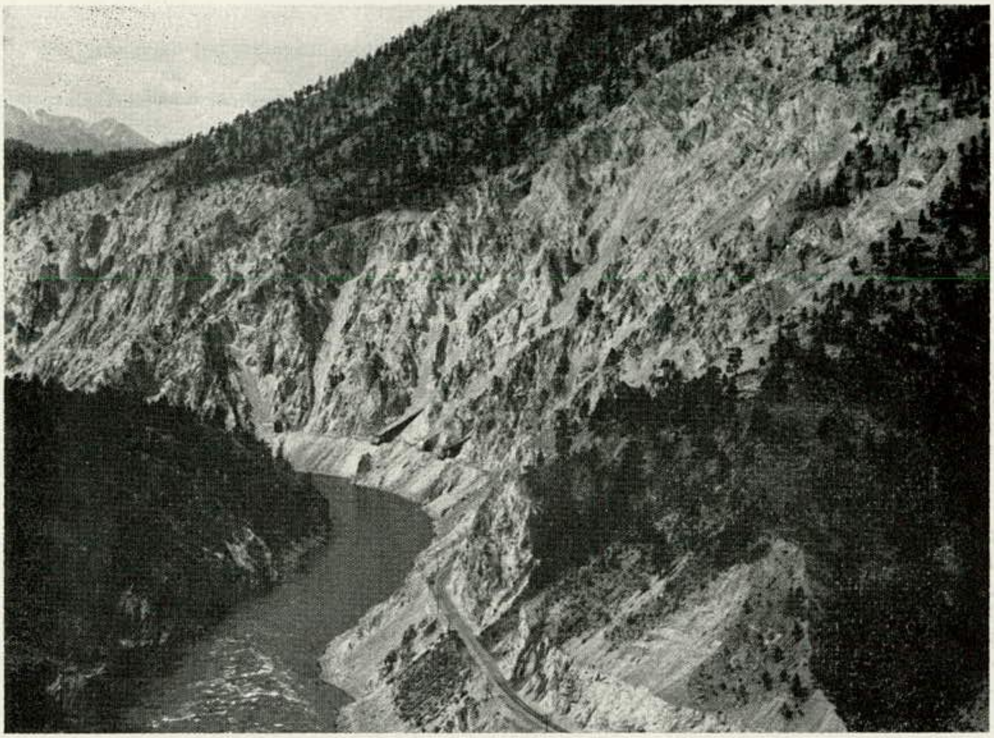

Figure 42. Rockfall and rockslide near Skihist, British Columbia, on Canadian National Railroad. Note the bare active slopes, the closely spaced jointing of the rocks, the rock chutes, and the absence of water. This picture also shows one method of protection against landslides — falling debris from above is by-passed over the tracks by means of wooden and concrete sheds. (Photograph by F. O. Jones, U. S. Geological Survey)

the angle of repose of the broken rock. Water is seldom an important factor in causing rockslides (see Fig. 42), although in some instances it helps to weaken bedding or joint planes that would otherwise offer high frictional resistance. Any seepage that is apparent after a rockslide has taken place is most likely to be seen in the scarp region or, perhaps, in the slide material itself.

Slumps rarely form from solid, hard rocks, although special combinations of factors have been known to produce them. Slumps are widespread, however, in sands, silts and clays and in the weaker bedded rocks. There they can be readily identified from surface indications, though only after considerable movement has taken place.

The head region of a slump is characterized by steep escarpments and by visible offsets between separate blocks of material (Fig. 16). The highest escarpment is commonly just below the crown; because the crests of the flanks are lower than the crown they can be recognized as flanks even if the escarpment on one of them happens to be larger than the one below the crown. If the landslide is active, or has been active recently, the scarp is bare of vegetation and may be marked by striations or grooves that indicate the direction of movement that has taken place. At the head, the striations tend to reflect downward movement, whereas striations along the flanks may be nearly horizontal. If the slump is compound, its several horseshoe-shaped scarps will appear as a scalloped edge in plan view (see Fig. 32).

Undrained depressions and perimeter lakes, bounded upward by the main scarp, characterize the head regions of many slumps; even if internal drainage prevents such ponds from holding water for long periods their depressions may be evident. In humid regions the head area may remain greener than surrounding areas because of the swampy conditions. In the San Juan region of southwestern Colorado, for instance, groves of aspen trees are commonly good indications of wet ground conditions, hence of slides and unstable ground. In northern West Virginia the swampy areas in the head remain green during the winter, whereas the well-drained toe areas are brown.

The tension cracks near the head of a slump are generally concentric and parallel to the main scarp. Many such cracks are obscured by rubble or other noncohesive materials, but even so they may be indicated by evidence of surface "stretching," by lines of rock fragments that have been displaced, or even by blades of grass that have been pulled down into the cracks by sand or other loose surface material as it sifted into them.

The head region of a slump, or of a block glide with surficial slump characteristics, may also be recognized by the presence of slump grabens which have experienced some rotation (Fig. 43). These are depressed fault blocks of soil or rock, caused in part by decrease in curvature of the shear plane. This produces tension and ultimate failure in the main slump block because of lack of support on its uphill side.

The amount and direction of rotation that any slump block has undergone can usually be ascertained by determining the slope of its surface as compared with that of the original slope. Comparison of the dip and strike of bedded material within the slump block with the original attitude of the unslumped material is an even more exact and more foolproof method of determining the amount of rotation, because erosional alteration of the surfaces may give an erroneous impression. In a general way the amount of rotation is a measure of the amount of displacement.

The part just above the foot of a slump is a zone of compression. The slumped material is confined by the foot and by the flanks of the main scarp so that it is compressed by the load upslide into the bottom part of the bowl-shaped surface of rupture. In this region, therefore, there are no open cracks.

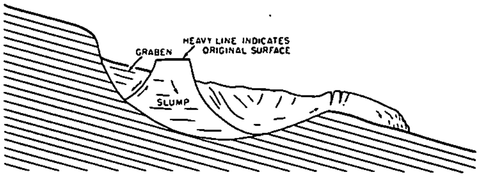

Figure 43. Graben on a slump slide. The rotation of a slump block is uphill, resulting in a flattening of the original ground surface; whereas the graben block, which breaks off from the slump block, rotates downhill. Grabens do not form if the slump block has sheared on a surface that approaches the arc of a circle; instead, they form on slump blocks that slide over a principal surface of rupture having a marked decrease in its curvature, causing a greater horizontal movement for each foot of vertical offset in the center portion of the slide than in the head region.

The foot region is marked by a zone of tension and uplift because the slumped material is required to stretch over the foot before it passes further downhill. This stretching destroys any remaining slump blocks because of the change in direction of forces. The small blocks and fragments that result tend to weather to rounded forms, producing hummocky ground. It is also in the foot zone that pavement uplifts and cracks, so disconcerting to the motorist and highway engineer, are most likely to take place.

Seeps, springs, and marshy conditions commonly mark the foot and toe of a slump. Moreover, trees tend to be tilted downhill, rather than uphill as they near the head (see Figs. 44 and 46). This is because there is a tendency for the surface material to roll over (see Figs. 29 and 43) as it moves downhill on the original slope surface, tilting trees and grass and even burying trees and other material that fall before it.

The approximate age of some slumps can be inferred by study of the bent trees. If older trees are bent but younger ones are straight, for instance, it is probable that the slide has not moved during the life of the younger trees. On the other hand, the sizes of the tree trunks at the points where the bends occur give a running history of the rotation.

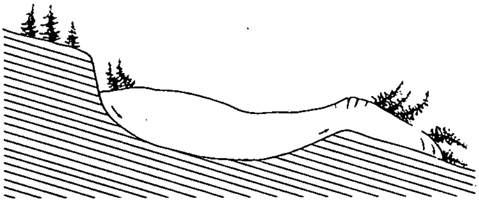

Figure 44. General orientation of trees on a slump landslide. Because of rotation, the trees on the blocks are bowed uphill, a result of the tree tops tending to grow vertically while the stump portion changes with the rotating land surface. Contrast the head and the toe region, and compare with Figure 46.

Just below the foot of a slump the ground is commonly marked by long transverse ridges, separated from one another by open tension cracks. These cracks seldom remain open for long, and they do not form scarps or other evidence of displacement, for the material is no longer confined but spreads out laterally and develops radial cracks at the toe.

Rockslides. — Rockslides can be distinguished from block glides and slumps by their size, shape and makeup. They commonly occur only on steep slopes and most of them are single, rather than multiple. They are composed of numerous small block units with random rotation, mixed in a matrix of finer-grained material. Most of them are wet, and large rock fragments tend to float on or in the matrix. Rockslides have no definite surface of rupture that is concave upward, as do slumps, and they do not move as unrotated multiple units like block glides. Many rockslides are thinner than either slumps or block glides because they are commonly restricted to the weathered zone in bedrock or to surficial talus. The shape of its shear zone, therefore, conforms with the unweathered bedrock surface and is not controlled to any large extent by joints or bedding planes in the bedrock. Many talus slopes produce rockslides by failure within the body of talus.

FLOWS

Dry flows are not difficult to recognize after they have taken place, but it is virtually impossible to predict them in advance. They are commonly very rapid and short-lived. Dry flows are rarely composed of rock fragments, more commonly of uniformly sized silt or sand. They exhibit no cracks above the main scarp and flow lines in them are poorly developed or nonexistent. Except for sand runs, they have no well-defined foot.

If rock fragments are set in motion by free fall, their inertia may cause them to act like a fluid and to flow a mile or more out into a valley. Dry loess may be set in motion by earthquake or other external vibrations, become fluid, and flow down a slope. Sand runs also behave somewhat as fluids, but in the latter part of their course the sand particles are more likely to slide than to flow.

Wet flows occur when fine-grained soils, with or without coarser debris, become mobilized by an excess of water. Most of them behave like wet concrete in a chute, with differences due to water content, but the flow of some wet silts and fine sands is triggered by shocks. "Quick" or sensitive clays may be liquefied by the leaching of salts or by other causes that are not completely understood.

Wet flows are generally characterized by greath length, by their generally even gradient and surface, by the absence of tension cracks, and by the lack of blocky units and minor scarps. If tension cracks are present, they are bowed in the direction of movement (see Fig. 45), showing the effect of movement of wetter material in depth beneath the drier crust. An older flow that has had time to dry

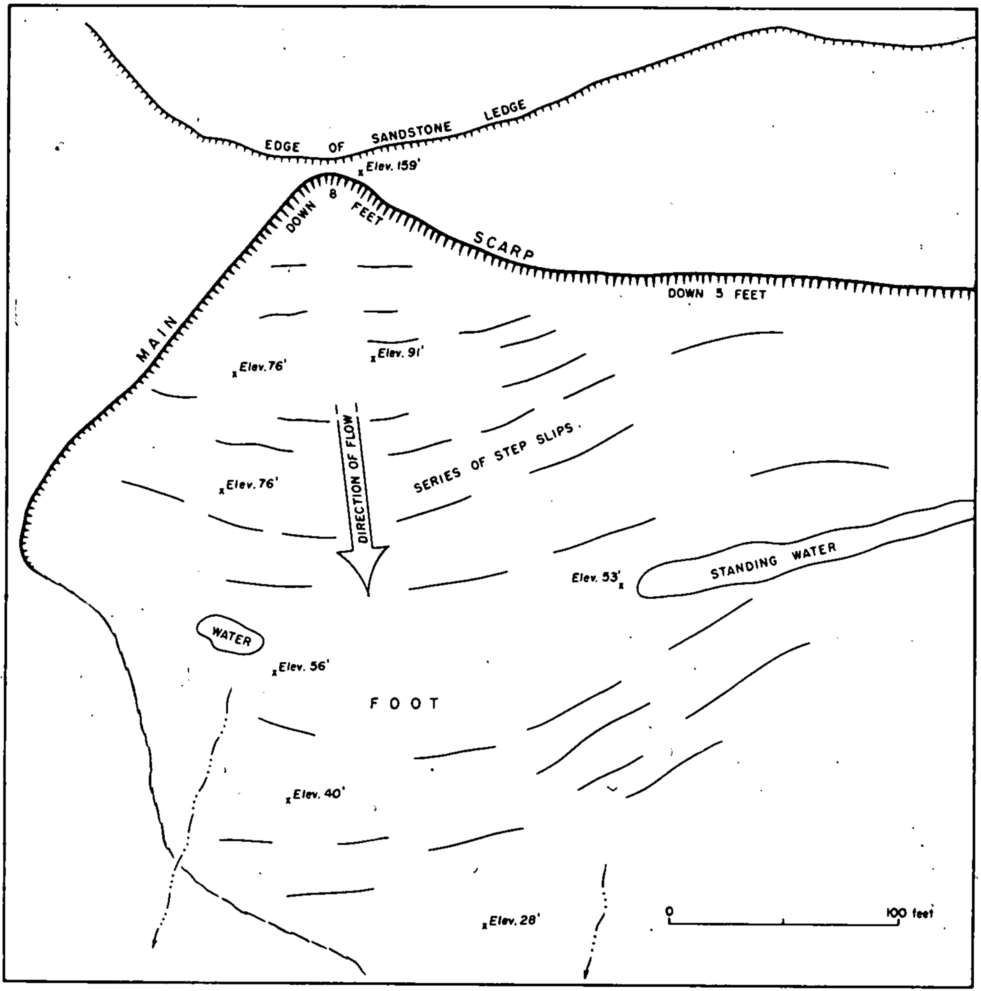

Figure 45. Crack pattern in slump that indicates flowage in depth beneath harder material at surface. Broken pipes from reservoir at top of hill dumped a large amount of water into an old slide and reactivated it. Horseshoe-shaped scarp is imperfect, differentiating it from that of a true slump. The greatest movement is near the center of the slide, as indicated by arrangement of cracks and of standing water. The fact that cracks are convex outward is indicative of flow movement in depth. South side of Reservoir Hill, Dunbar, W. Va. (From drawings supplied by Robert C. Lafferty, Consulting Geologist)

may show large shrinkage cracks or flow lines. In many cases the main scarp area is emptied by removal of all flow material and resembles a glacial cirque in some degree. In other cases there may be imperceptible gradation downward from soil creep to mudflow.

The rate of flow is dependent on the total amount of material that feeds the slide; the accumulated debris imposes a hydrostatic head on the entire mass below it and tends to maintain a constant rate of movement. The flow is under pressure everywhere from the material above it; consequently, the mass shows few if any cracks over the foot. Flows can and do make sharp turns and move around any firmly fixed obstacles that

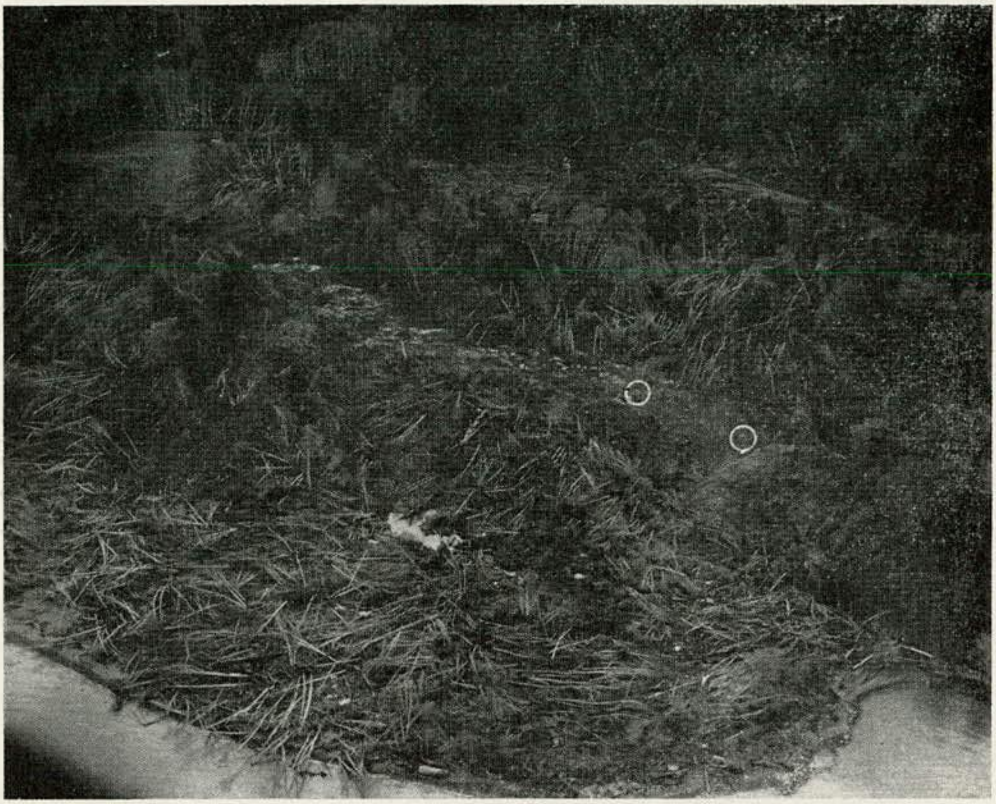

Figure 46. Random orientation of fallen trees on slump slide; Twin, Wash., March 1953. Destruction of 3,100 feet of State Highway 9-A took place in a few minutes. The highway, whose remnants appear as white specks, moved more than 600 feet downhill as the toe of the slide pushed out into the Straits of Juan de Fuca. Failure took place along steeply dipping shale beds that were undercut by the sea. White circles enclose telephone poles. (Photograph courtesy U. S. Coast Guard, Port Angeles, Wash.)

appear in their path. If the flow is very wet and moves on rapidly, it may leave "high water marks" of debris on trees or other objects; along its sides it may leave ridges of debris called torrent levees.

Conclusion

All landslide investigations must start with recognition of a distressed condition in the natural or artificial slope or of the dangers that are involved in readjustment of those stress conditions by construction work. The evidence for distressed conditions that may be present, or that may be induced, lies chiefly in evidence of movements, minor or major, that have already taken place or of geologic, soil and hydrologic conditions that are likely to cause movement in the future.

Once the fact of land movement, actual or potential, has been established, the next essential step is to identify the type of landslide. One would not apply the same corrective procedure to a rockfall as to a block glide, any more than one would attempt to prevent a slide without knowing the kind of slide he expects. If maximum benefit is to be had from the preventive or corrective measures finally employed, therefore, it is imperative to learn to recognize the kind of slide that exists or that is to be expected.

This chapter attempts to isolate certain specific characteristics that will prove that there has been, or will be, movement and that will help identify the type of landslide that is involved. Landslides are not simple, however, and more than one kind of motion is involved in many of them. Despite the complexity of a given slide or its associated geologic conditions, most of the facts in the foregoing paragraphs can be applied beneficially. The knowledge so gained will help limit the problem, serve as a guide to the drilling program, and restrict the choice of preventive or corrective procedures that may be applied.

It must be recognized, of course, that most of the criteria mentioned throughout this chapter must be qualified. Compare, for instance, the statement that "the trees in the head region of a slump slide lean uphill whereas those near the toe lean downhill or lie flat" with the situation shown in Figure 46. There, thousands of trees, which were felled by a slump slide in a matter of minutes, lean in all directions. Even here a careful frequency count would show the foregoing statement to be true; but without such a count the leaning trees provide no evidence as to their places on the slide or their relations to the individual slump blocks.

Reference

Terzaghi, Karl, and Peck, R. B., "Soil Mechanics in Engineering Practice." John Wiley & Sons, New York, N. Y., fig. 151, p. 354, 1948.