Tension fractures

Field evidence of movement downslope may be indicated by the presence of tension fractures or fissures in the overburden, or a roadbed, or bulges in the road. These features indicate there has been some downslope movement already at this site.

Fans/hummocky topography at slope base

Deposits of debris on the ground surface at the slope base, such as hummocky, irregular mounds or cones and fans with lobes or levees of coarse material, often with large logs incorporated in
debris on their surface, indicate past debris flow and debris torrent activity upslope.

Buried deposits

Buried deposits, often with wood layers incorporated in the material, can occur in fans. These layers provide evidence of past upslope landslide activity.

4) Bedrock Lithology and Structure

Rock type

The type of bedrock in an area can provide a qualitative indication of the overburden texture, clay mineral content, and relative cohesiveness. In many cases, the bedrock type is determined from a bedrock map; however, as these maps tend to be small scale and regional, the identification of a specific rock type is usually required in the field.

A simple classification of the common rock types is outlined on page 63. Actual rock identification requires basic knowledge of the differences between igneous, sedimentary, and metamorphic rocks, and some minimum experience with field identification.
ROCK IDENTIFICATION KEY

ROCK SPECIMEN

GLASSY

FINE GRAINED

MIXED FINE AND COARSE GRAINED

MEDIUM TO COARSE GRAINED

GRAINS EASILY DISTINGUISHED

FLOS WITH ACID

MARBLE

LARGE DISTINCT CRYSTALS

PORPHYRY

IN FINE GROUNDMASS

CONGLOMERATE

ANGULAR FRAGMENTS

IN FINE CEMENT

BREAKUP

NO FIZZ WITH ACID

GRANULAR AND TOUGH

INTERMEDIATE

ANDESITE

BASALT

GLASSY GRAINS

QUARTZITE

DULL

FELSITE

VIGOROUSLY

LIMESTONE

WITH DIFFICULTY OR

ONLY WITH ROCK POWDER

DOLOMITE

SPLITS EASILY INTO

THIN SMOOTH SHEETS

SLATE

DOES NOT

SPLIT EASILY

SHALE

NO LAYERS

SLIPPERY FEEL

GREEN TO BLACK

SERPENTINE

NO LAYERS OR BANDS

DISTINCT LAYERS OR BANDS

GRAINS INTERLOCKED

ROUNDED GRAINS CEMENTED TOGETHER

GRAINS INTERLOCKED

SAND SIZE

PIECE SIZE

CONGLOMERATE

MICACOUS

SPLITS EASILY

ALONG LAYERING

SCHIST

GRANULAR

DOES NOT

SPLIT EASILY

GNEISS

LIGHT

MOST GRAINS

LIGHT COLOUR

INTERMEDIATE

MANY DARK

GRAINS

QUARTZ DIORITE

FELDSPAR

QUARTZ AND FELDSPAR

QUARTZ

SYENITE

GRANITE

QUARTZITE

Rock classification chart. (Source: B.C. Energy Mines and Petroleum Resources.)
Structure

There are several structural and stratigraphic features that are useful indicators of potential landslide sites:

Attitude of beds

- **Beds of rock** that parallel or dip in the same direction as the slope can be an important contributor to rockfall from cliffs or overhangs, rock slides from steep slopes, or debris avalanches and flows from steep slopes overlain by shallow overburden.

- **Beds that dip** into the slope tend to produce benches and short cliffs which impede the development of large landslides and trap debris and sediment at intermediate locations on the slope.

Presence and degree of fractures, joints, and foliation

- **Fractures, joints, and foliation** (planar features associated with metamorphic rocks) refer to cracks in a mass of rock that can be of different intensity (few or numerous). The intensity of these structures can be quantified from measurements of the average spacing between features. Rocks that have numerous cracks (e.g., well-jointed), particularly those that dip downslope, can promote rockfall (from cliffs), rock slides and rock slumps on steep bedrock.
slopes, and debris avalanches and debris flows on steep slopes covered with thin overburden. The presence of these features in the rock creates local zones of weakness along which failures occur, as well as providing avenues for deep penetration of groundwater, with subsequent active pore-water pressure development along the planes.

**Stratigraphy**

- Stratigraphy that promotes bedrock failures (rockfalls, rock slides, rock flows) includes massive beds overlying weaker beds, or the alternating of competent and incompetent layers. Examples include volcanic flows (hard, competent, impermeable) that overlie volcaniclastic rock (generally highly weathered, soft, incompetent), or interbedded sandstones (hard, competent) overlying altered shales and mudstone (soft, incompetent).

*Differential stratigraphy of Columbia River Gorge, Oregon*

**Tension Fractures**

- Tension fractures in rock appear as closely spaced linear cracks or fissures that parallel the rock surface. These fractures are generally caused by incipient slope movements or by expansion of the rock due to
removal of surface loads or lateral support (e.g., withdrawal of the weight of overlying glaciers), or differential temperature changes. These features are often difficult to identify on air photographs and their presence and influence on stability must be assessed in the field.

**Local terrain characteristics**

Local terrain features can also provide clues to potential landslides. Steep rock cliffs represent potential sites for rockfalls and rockslides. Cliffs and steep bedrock outcrops should be inspected for fresh or recent bedrock movement (usually a lighter tone than the surrounding weathered bedrock surface, as illustrated on the right, top). Terrain below and adjacent to the outcrop should be inspected for large isolated boulders or blocks of rock that rest on the overburden, or on talus deposits as illustrated on the right, bottom. Such boulders indicate past rockfall and rockslide activity. Recency of this activity can be judged by the freshness of the blocks and associated rock fragments, impact scars on trees, and relative size of lichens.

Lighter tone on rock face indicates recent activity

Talus at base of volcanic rock escarpment
5) Hydrology

Because groundwater is a primary factor in slope failures, indicators of wet or poor drainage sites on slopes are important features to note during a field inspection. Evidence of zones of periodic high soil moisture content and potential sites of active pore-water pressures during high rainfall periods may be indicated in the field by subsurface and surface features. These areas, once identified, represent potential areas of slope failure.

Subsurface Features of Poor Drainage Conditions

- **Mottles** are spots or blotches of different color (primarily reds and yellows) interspersed with the dominant soil color. Mottles (faint or distinct) present in the upper meter of soil generally indicate soil moisture in excess of field capacity for certain periods of the year.

- **Gleyed soils** (not the parent material) have wet/moist, gray B-horizons (indicating a strong reducing environment) overlain by a black, organic surface layer. Such soils remain wet for extended periods.
Soil drainage for a site can be estimated by the degree of oxidation or reduction evident in the soil profile. This is generally expressed as the relative amount of mottling or gleying indicated in the various soil horizons. The following table lists commonly used drainage classes and defining characteristics.

<table>
<thead>
<tr>
<th>Class</th>
<th>Soil characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapidly drained:</td>
<td>Soils are free from any evidence of gleying or mottling throughout the profile.</td>
</tr>
<tr>
<td></td>
<td>Common on steep slopes.</td>
</tr>
<tr>
<td>Well drained:</td>
<td>Soils are usually free of mottling in the upper 1 m, but may be mottled below this depth.</td>
</tr>
<tr>
<td>Moderately well drained:</td>
<td>Soils are faintly mottled in the lower part of the upper 1 m of soil (lower B-horizon).</td>
</tr>
<tr>
<td>Imperfectly drained:</td>
<td>Soils are distinctly mottled throughout the B-horizon.</td>
</tr>
<tr>
<td>Poor to very poorly drained:</td>
<td>Soils are usually strongly gleyed.</td>
</tr>
</tbody>
</table>

Surface features of poor drainage conditions

- **Vegetation** (see page 70)

- **Seepage** and concentrated subsurface drainage are indicated by springs, sag ponds, or moist areas on open slopes, and seepage sites along road cuts. The locations of these areas of concentrated subsurface flow should be noted on maps and profiles as potential sites of active, unstable ground.

- **Shallow linear depressions** oriented up- and down-slope. 

[Headwater portion of a shallow linear depression]
downslope represent old landsli
deslide scars or surface erosion
channels and identify concen-
trated surface and subsurface
flow. Such features are poten-
tial sites for debris avalanches
and debris flows.

- **Curved depressions** and
swales identify local areas of
slump and earthflow failure
and are sites of deep subsur-
face water concentration.

Quantitative drainage indicators

Site-specific hydrologic tests that are useful in the identification
and analysis of landslide hazards may be available from other
sources or may be obtained by specialists with the required
expertise and field experience. Such tests and measurements go
beyond the objectives of this manual, but are listed below to
provide the user with background information on their value and
meaning for stability hazard analysis.

| HYDRAULIC CONDUCTIVITY | The process of water
movement in and through slope materials. This is quan-
tifiable in the field and in the laboratory using pumping
tests and permeameters. Low hydraulic conductivities
mean rapid storm-generated saturation and a high
probability of active pore-water pressure, which pro-
duces highly unstable conditions on steep slopes. |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PORE-WATER PRESSURE</td>
<td>A measure of the pressure produced by the head of water in a saturated soil and transferred to the base of the soil through the pore water. This is quantifiable in the field by the measurement of free water surface level in the soil. Pore-water pressure is a key factor in failure of a steep slope soil, and operates primarily by reducing the weight component of soil shear strength.</td>
</tr>
</tbody>
</table>
6) Vegetation

The presence of hydrophytes (water-loving plants) is often a reliable indicator of excessive wet areas on hillslopes. Areas undergoing active movement are also frequently indicated by stressed vegetation or by certain types of disturbance vegetation.

**Presence of water-loving plants**

Water-loving plants indicate high groundwater levels and impeded drainage. In the Pacific Northwest, the presence of these plants on steep slopes overlain by shallow overburden represents sites of potential debris avalanche and debris flow activity. Such plants in hillslope depressions developed in deep soils and weathered bedrock represent areas of potential accelerated creep and earthflow movement. The table on pages 72-73 outlines some of the more common water-loving plants, their major identifying characteristics, and an illustrated example for field identification.

**Stressed vegetation indicators of active movement**

- **Jackstrawed trees** (trees tilted in various directions) and split trees (trees split up the middle) are indicators of active ground movement. They can occur on slump blocks and around headwall sites of newly active slumps and earthflows. The presence of **curved tree trunks** bent downslope may indicate an area undergoing active creep modification, but such an assessment must be used with caution. Snow creep in an area of commonly heavy annual snow accumulation can produce the same type of curvature. Trees tipped downslope on steep gradient sites with shallow soil, may indicate recent mechanical shifting of materials and a
potential for slope failure. Past landslides that in many instances have been revegetated can be identified by several factors:

- **Differences** between successional species growing in recent landslide scars (e.g., alder) and species growing in the surrounding forest (e.g., spruce-hemlock).

- **Uniform age** of dominant forest cover in old landslide scars, compared to the uneven-age old-growth cover of the surrounding forest. These features are discernible from air photographs and from field traverses.

- **Windthrown trees** on hillslope areas commonly indicate poor drainage or shallow soils, or both, and may define sites of actual or potential failure. Windthrown areas are identifiable from air photographs.
• **Shrub**, or rarely, small tree up to 8 m tall.

• **Branches** - twigs hairless to finely hairy, smooth, reddish brown.

• **Leaves**, egg-shaped to elliptic, sharp-pointed at tip (a); finely double toothed, shallowly lobed, leaves yellowish-green on both sides, usually shiny and smooth above, hairy in vein axils below, petioles usually glabrous, young leaves sticky beneath, buds sessile and pointed.

• **Catkins** arising from buds of the current season.

• **Rhizome**, extensively creeping and branched, dark-felted, tuber-bearing; fertile and sterile stems not alike, annual, erect.

• **Fertile stem** - (a) unbranched, usually thick and succulent, brownish to whitish, soon withering; sheaths with 8-12 large, brown, pointed teeth.

• **Sterile stem** - (b) solitary or clustered, green slender, much branched with about 12 sharp lance-shaped brownish teeth; branch sheaths (c) closest to the stem are large and obvious, while others are slightly flaring, somewhat appressed, and 4-6 toothed; branches numerous in dense, regular shorts, ascending or spreading, mostly unbranched, 3-4 angled; central cavity present.

• **Cones** - (d) long-stalked, blunt-tipped.
Devil’s club

- **Shrub**, deciduous, 1-3 m tall, with thick stems armed with numerous yellowish spines (a).
- **Leaves** shallowly, palmately 7-9 lobed, broad, twice serrated, "mapleleaf" like, with numerous spines present on underside.
- **Flowers** in an elongated cluster to 25 cm long composed of several smaller clusters.
- **Fruit** considerably flattened bright red berries (b); little is known about their edibility, not recommended.

Cow-parsnip

- **Herb**, very large, hairy, single-stemmed perennial from stout taproot or cluster of fibrous roots, 1-3 m tall; stems hollow.
- **Leaves** once ternate, with broad distinctly petiolate, coarsely toothed and palmately lobed leaflets, 10-30 cm long and wide, asymmetrical.
- **Flowers** (a) with 5-10 deciduous narrow bracts beneath compound inflorescence, bractlets below secondary flower stems similar to bracts; flowers white.
- **Fruit** (b) egg-shaped to heart-shaped, with or without hairs.

Skunk cabbage

- **Herb**, perennial with short, fleshy, erect underground stems.
- **Leaves** large, 30-130 cm long and 10-70 cm wide, simple, oblong-oval, glossy green, with a skunk-like odor.
- **Flowers** on spadix (a), yellowish green; spathe (b), large, yellow.
2.4 PART C: STABILITY HAZARD ASSESSMENT

An assessment flow chart is shown on pages 76-77 to guide the quantitative assessment or characterization of unstable or potentially unstable slopes on forested lands. Following the steps in the chart, one can assess the relative potential of landslide initiation (hazard) and the type of landslide that may occur on different types of terrain, based on the data obtained from the review of office sources and field observations. These steps are described below:

Part A: Evidence of past landslide activity

Assess evidence of past landslide activity by reviewing the categories designated in Part A of the assessment chart on page 76.

If YES → the potential landslide hazard is identified on the chart.

In most instances, the user should seek the expertise of a specialist for further analysis of the problem, assessment of risk, and recommendations for control and correction.

If NO → proceed to Part B on page 77.

Part B: No evidence of past landslide activity

DETERMINE THE TYPE OF MATERIAL on the site, unconsolidated or bedrock. If unconsolidated, refer to Section 2.4.1; if bedrock, refer to 2.4.2.
Proceed along the appropriate part of the chart according to the physical characteristics detailed. Most of these variables have been defined in previous sections and sufficient data should be available on the data sheets (pages 22 and 42-43).

2.4.1 Unconsolidated Materials

**STEP ONE: Determine material type and texture**

**Fine-textured materials (cohesive materials)**

- **predominantly** made up of sand, silt, and clay;
- **or** made up of more than 20% clay;
- **or** made up of clays that swell upon wetting (e.g., smectite and montmorillonite clays);
- **or** consisting of layers or lenses of alternating fine and coarse textured materials.

Include: tills predominantly derived from fine-textured bedrock (e.g., shale) or sediments (e.g., glaciolacustrine silts and clays); windblown silts; colluvium and weathered bedrock (residual overburden) derived from fine-textured bedrock (e.g., mudstone); silt/clay lake sediments and ocean bottom sediments.

**Coarse textured materials (non-cohesive materials)**

- made up of sand and/or gravel, rubble and rock fragments with low to moderate amounts of silt (<20%) and little to minor clay (40%).

Include: the weathered surface of most basal tills, ablation tills; mixed sand and gravel fluvial, glaciofluvial and shoreline deposits; colluvium and weathered bedrock (residual soils) derived from medium- to coarse-textured bedrock.
Part A: EVIDENCE OF LANDSLIDES (check appropriate boxes)

1. Recent landslides occur in the area

2. Tension fractures
   - arcuate depressions
   - numerous springs
   - split trees
   - eneselon benches
   - bulges in road
   - sag ponds

3. Partially vegetated strips
   - linear patches of even-age timber
   - downslope deposits of debris
   - buried landslide deposits
   - debris-filled gullies

4. Deep gullies and canyons
   - gully gradient >22°, >40%
   - organic/inorganic debris in channels
   - debris piles at mouth
   - raw, exposed gully side-walls

5. Talus/scattered boulders at slope base (fresh, recent)
   - cliff face with fresh exposed rock

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HIGH LANDSLIDE HAZARD

MODERATE-HIGH HAZARD: active movement, primarily creep, slumping and earthflows

MODERATE-HIGH HAZARD: recent activity, primarily debris avalanches, debris flows, or debris torrents

MODERATE-HIGH HAZARD: recent and continuing activity, primarily debris flows and debris torrents

MODERATE-HIGH HAZARD: recent and probably continuing rock slide and/or rockfall activity
**STEP TWO: Determine the shape of coarse particles**

Coarse-textured colluvial and residual materials can further be separated by their dominant particle shape into two general categories:

- Angular
- Rounded

**STEP THREE: Determine average depth of materials**

Depth refers to the thickness of surficial materials measured perpendicular to the slope and is divided into two categories for purposes of the assessment.

- Shallow: <3 m
- Deep: >3 m

**STEP FOUR: Calculate average gradient of the failure surface in the area of potential initiation**

Gradient is measured in degrees or percent.

For shallow, coarse-textured materials, critical gradient can be approximated by the hillslope gradient. Categories for materials with rounded versus angular coarse fragments are:
For fine-textured, deep materials, an estimate of the critical failure surface gradient must be made based on apparent size of rotational blocks; "daylighted" failure surfaces in road cuts and along stream channel; other soils or geologic report; and drill log information. Two general categories are recognized:

- **10-30° (18-58%):** low to moderate
- **>30° (>58%):** steep

**STEP FIVE: Determine surface configuration**

Surface configuration refers to the general shape of the hillslope along the potential path of failure and material transport. Surface configuration is an important indicator of the stability and probable hazard from failures in shallow, coarse-textured materials. Two classes of surface configuration or shape of the slope are recognized:

- **Irregular:** (broken or step-like)
- **Uniform:** (smooth with few surface irregularities)
STEP SIX: Establish drainage conditions

The relative amount of moisture available within the overburden, and the length of time it remains, can have significant influence on hillslope stability in all types of materials.

Two classes of drainage are recognized:

- **Wet:** Materials that have mottled or gleyed profiles in the upper meter and an impervious layer at shallow depth;
  or whose drainage has been classified in soils reports as moderately well, imperfectly, or poorly drained;
  or the presence of water-loving plants at several locations on the slope;
  or of springs;
  or of numerous seepage sites or local ponding;
  or of numerous shallow incipient drainage depressions on the slope.

- **Dry:** Materials that are free from any evidence of mottles or gleying in the upper meter and with no impervious layer at shallow depth;
  or whose drainage has been classified in soils reports as rapidly or well drained;
  or the lack of water-loving plants on the slope;
  or of springs or seepage sites;
  or of incipient drainage depressions on the slope.