Chapter 4: Landslide Features and Their Relative Ages

This chapter describes measurable characteristics associated with landslides, morphological changes these components exhibit with time, and the landslide features found in the study area. These definitions and descriptions are used to distinguish relative ages of landslide features in the study area and thus identify the areas that are prone to future landslides.

Landslide Features

Features associated with landslides usually include scarps, tension cracks, shear zones, and toes (Figure 6). In many instances only a few of these features are present, but by mapping the distribution of these features, large landslides can often be delineated and the driving and resisting parts of these landslides can be identified which aid in developing a stability analysis for active and dormant slides (Baum and Fleming, 1991).

Extensional Features

Tension cracks and scarps are extensional features. Tension cracks can be found throughout a landslide and many landslide features initiate as tension cracks.

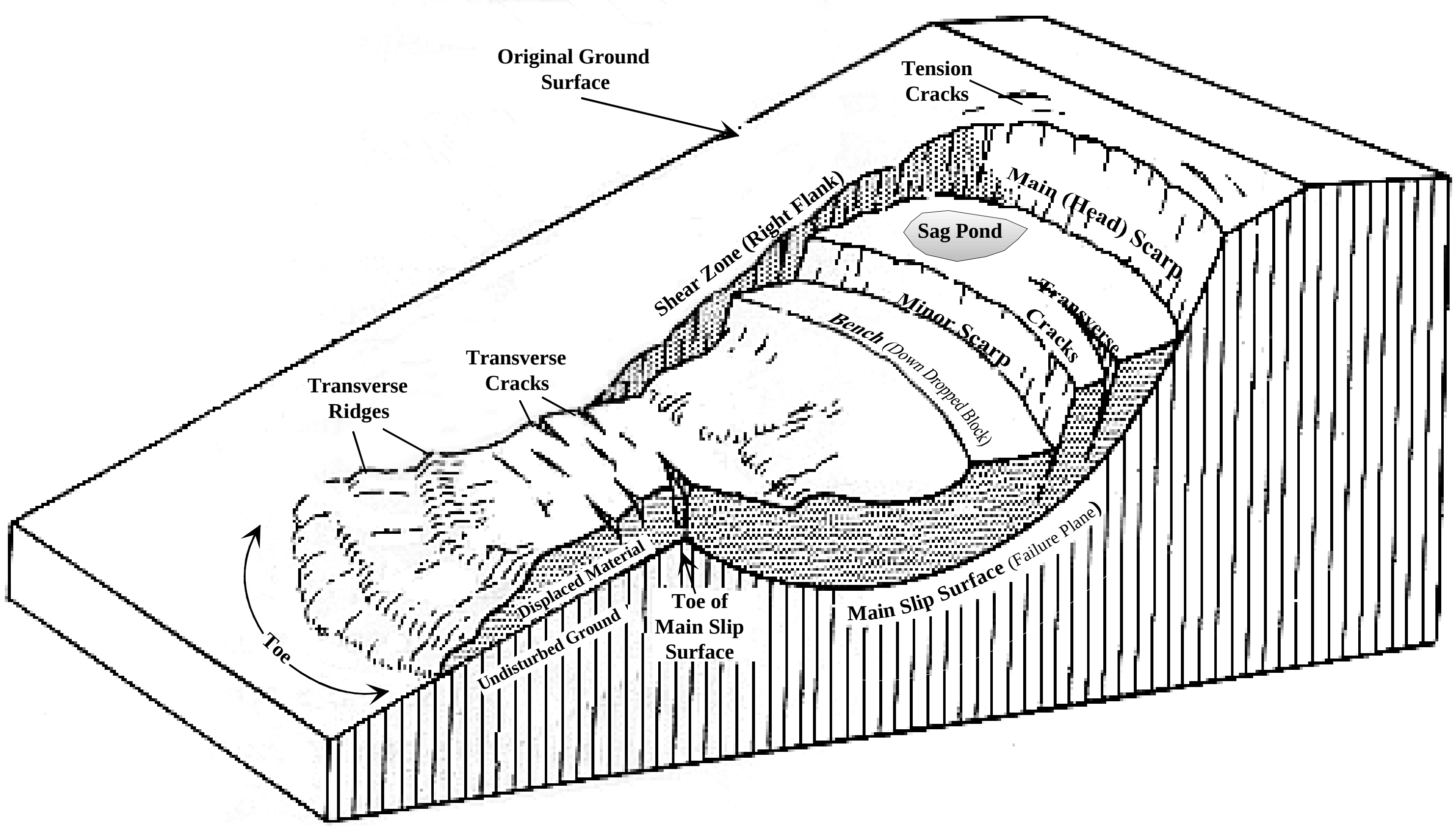


Figure 6: Block diagram of typical landslide, illustrating landslide features and their spatial relationships (after Cruden and Varnes, 1996).

Scarps are generally found near the top of a landslide, in the zone of extension and generally begin at the surface first as tension cracks, which develop into scarps. Early shear zones, located along the flanks of a landslide commonly appear at the surface first as en-echelon zones of tension cracks, and later develop into strike-slip faults. Toes can also have tension cracks on them, referred to as transverse cracks. Tension cracks are not only a precursor for future landslide features, but the pattern of tension cracks can also be used to define the local deformation and be used in a stability analysis for the surrounding area.

Tension cracks are open fractures in the ground that have rough and irregular surfaces (Fleming and Johnson, 1989). Movement is initially normal to the fracture, but lateral movement can occur later. These features are generally found above the head scarp and can be the first signs of movement (Figure 6) (Richards, 1982). Tension cracks can also be found along the flanks, outside the main landslide zone. Traverse cracks are located within the moving mass at the toe of the main slip surface (Cruden and Varnes, 1996).

In the study area, tension cracks, when present, were mostly found above scarp-like features and along the upper portions of the flanks of active landslides (Plate 3). Tension cracks found in the study area had openings from 5 to 30 centimeters wide (Figure 7). As observed by Sha Spady during the February 1996 failure of the Spady Landslide, a tension crack ranging in width from 5 to 30 centimeters appeared on the

Figure 7: Fresh tension crack located above head scarp of the Hilltop Avenue landslide, located at the dead end of Hilltop Avenue in the southwest section of the study area (8½ × 11 inch field notebook for scale).

Figure 8: Transverse cracks formed as a fill failure flows over the lesser disturbed natural stratigraphy. View looking down at west R & B Leasing landslide.

slope 24 hours prior to the first catastrophic failure of this landslide (Sha Spady, Property Owner, Newell Creek Canyon, Personal Communication, 1996).

Transverse cracks, although seldom found, were always located within the moving masses. On the R & B Leasing property, located on Morton Road (near Highway 213), one of the slides occurring in man-made fill had a series of transverse cracks where the fill flowed over a bench (Figure 8).

Scarps are steep exposures of the upper edge of slip surfaces marked by a sudden increase in slope angle, sometimes nearing vertical (Figure 6) (Cruden and Varnes, 1996). They generally first appear as tension cracks parallel to the slope contours and then develop into a scarp, concave downslope in map view. The head scarp is the upper edge of the main slip surface and is the uppermost scarp. Minor scarps are generally located within the moving mass and usually mark the beginning or end of a down dropped block or bench (Figure 6). These minor scarps appear morphologically similar to head scarps but are always located within the landslide and below the head scarp (Cruden and Varnes, 1996). Scarps are common within the extending portion of the landslide mass.

Among the features found in the study area resembling scarps, many of them associated with active landslides displayed a continuous, steep, bare soil escarpment, with a concave downslope shape in map view (Figure 9) (Plate 3). Other scarp-like

Figure 9: View looking up at head scarp of the Spady Landslide after the February 1996 failure displaying a continuous escarpment of bare soil with a concave downslope shape. This is typical of a fresh head scarp on an active landslide (plane table survey rod = 15 ft).

features only displayed the steep, concave downslope escarpment, which remained vegetated with plants like water-loving vegetation and displaced trees. At the extreme, some scarp-like features only displayed a moderately steep escarpment that may or may not be continuous.

The measured vertical offset of scarps ranged from 0.2 to 18 meters throughout the study area. Between many of these scarp-like features and minor scarps, a down dropped bench could be found. Sag ponds commonly formed on top of these benches and when dry, they appear as local depressions.

Shear Features

The most prominent features associated with landslides are the shear zones forming the flanks of the landslide. These zones separate the moving mass from the surrounding stationary slope (Figure 6). Shear zones are also present within a landslide. Flank shear zone surfaces may show slickensides on the bare surfaces, indicating horizontal shearing (Fleming and Johnson, 1989). As the landslide is beginning to move, the shear zones usually first show up as en-echelon tension cracks which develop into a shear zone (Fleming and Johnson, 1989).

In the study area, the shear zones were easily identified on active slides by the change from a predominantly vegetated area off of the slide to a predominantly non-vegetated area. When vegetation was present everywhere, a dramatic change in the

Figure 10: Change in vegetation size, from large (older) trees in the foreground (left side of picture) to smaller (younger) trees in the background (on landslide), divided by a shear zone marked by a small gully. This slide is located in the northern portion between Newell Creek and Highway 213.

size or age of the vegetation helped to distinguish shear zones (Figure 10). Other shear zones sometimes appeared as erosional gullies in the direction of the slope.

Shortening Features

Shortening features of landslides are toes, transverse ridges, and snouts. The snout is the furthest downslope extent of the slide, however toe-like features may also be found within a slide mass referred to as transverse ridges (Figure 6). These shorting features consist of a linear to concave upslope ridge of disturbed soil/debris that is sometimes thrust over undisturbed ground (Cruden and Varnes, 1996).

Landslide toes in the study area generally exhibited an oversteepened slope, with a concave upslope shape in map view. These toes are composed of displaced material. Many of the larger landslide toes have smaller failures located on them. Many of these toes structures parallel a creek, and in some cases, the creeks formed a new path around the toe. For example, the toe of the Waitkowicz landslide, at the corner of Eluria Street and Pearl Street, and the toe of the inactive-mature slide (Highway 213-Morton Road landslide) on the western side of Morton Road, both have diverted streams, forming a new path around their toes.

Transverse ridges, like toes, are thrusts of soil/debris located within the landslide mass. These ridges appear as linear to concave upslope features in map view (Cruden and Varnes, 1996).

Transverse ridges were found at many landslides in the study area. These ridges, paralleling the slope contours, located within the moving mass appeared as thrusts of displaced material (Figure 6). Many times a local depression, sometimes filled with water, was located directly behind these ridges. The Mountain View landslide has five of these local depressions, located behind transverse ridges, and three of them are filled with water all year and are called sag ponds (Easterbrook, 1993).

Associated Features

In areas of instability, environmental changes associated with landslides are sometimes easier to identify than landslide morphological features. These non-morphological features appear as a direct result of the formation of landslide features and therefore can be indirect indicators of past movement. Three of these non-morphological features are vegetation which has responded to ground movement, specific hydrological conditions, and channels filled with debris flow deposits.

Vegetation's response to landsliding is a widely documented subject and is important in that it can help identify instability and hydrologic conditions of a slope (Richards, 1982; Wieczorek, 1984; McCalpin, 1974). In the Pacific Northwest, the presence of large conifers such as Douglas firs and cedars generally indicates stable conditions; many of these trees are hundreds of years old. The presence of young deciduous trees, such as alders, oaks, and maples, on the other hand, can indicate unstable conditions because these types of trees are generally the first to reinhabit areas with removed vegetation (Scott Burns, PSU Geology Department, personal communication, 1996). The presence of trees of the same size may also indicate instability. In cases when landslides fail catastrophically, causing the complete loss of all vegetation, the revegetation of these landslide surfaces occurs fairly uniformly. This generally results in the growth of similar-aged trees and, hence, size (McCalpin, 1974). Vegetation that may indicate the hydrological conditions on a slope, such as the presence of a spring or seep, includes small water-loving plants such as Horse Tails and Skunk Cabbage.

Unstable soils can also be identified by the presence of vegetation which has been disturbed in some manner (Richards, 1982). Disturbed trees, for example, are usually leaning in an upslope or downslope direction (sometimes referred to as a drunken forest) or can be lying on the ground.

Specific hydrologic conditions associated with landslides, such as water seeps, springs, and sag ponds are also associated features that can indicate instability. When these associated features are related to landslides, seeps and springs are generally located at the bottom of the head scarp, below minor scarps, and below the toe and usually mark where there is a vertical change in conductivity (Richards, 1982). Sag ponds are usually located on top of a down-dropped bench or just below the head scarp, and, when dry, appear as a local depression. As mentioned above, water-loving vegetation present can be an excellent indicator of these hydrologic conditions.

Debris flows are rapid flows of saturated earth/debris mixed with water. They have the consistency of wet concrete and can flow with a plastic behavior forming steep fronts and marginal levees (Easterbrook, 1993).

In the study area, these debris flow deposits appeared as creek channels filled with soil and debris with marginal levees of displaced material (Figure 11). These debris flows also have steep thrusts (toe compressional features) where the material flowed around a corner or where the material came to a stop (snouts). In one case (March, 1997 failure of the Spady Landslide, located at the end of Alden Street), a debris flow traveled the length of the creek (approximately 60 m) and into the merging creek, where it blocked the merging creek, damming it and ponding water up the merging creeks valley to an estimated depth of two meters (Figure 12 and Plate 3).

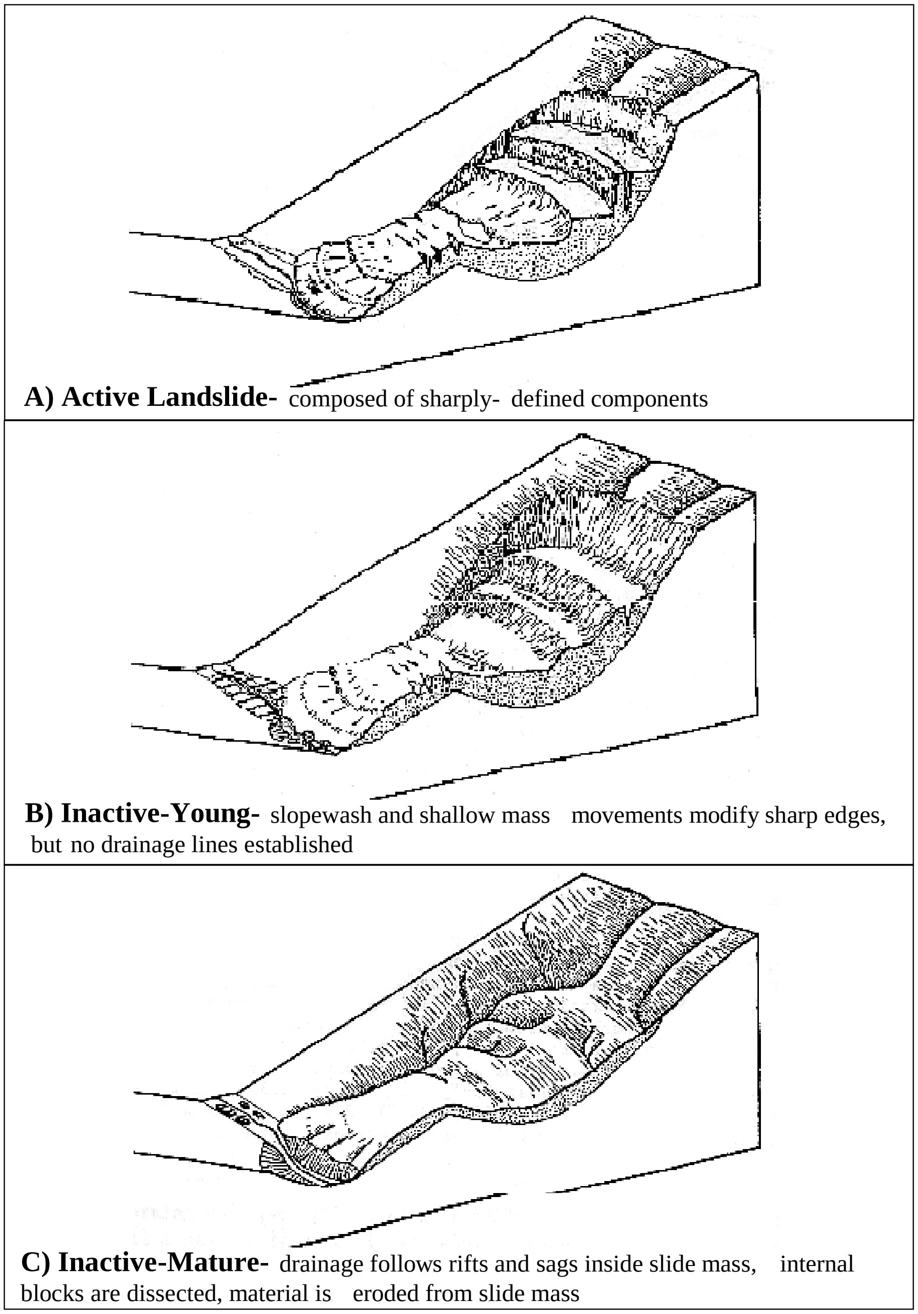
Morphological Changes of Landslide Features with Time

It quickly became obvious that the geomorphic features being recorded during the field mapping portion of this study were not all the same age. Hence, these features were divided into three categories, using the descriptions from McCalpin (1974): active, inactive-young, and inactive-mature (Figure 13 and Table 3).

In the study area, it is common for large inactive-mature landslides to have smaller active or inactive-young slides located on the steep head scarps or toes due to undercutting of the toe by a stream. In order to define morphological changes with time, one must start with a description of these changes (Table 3) (McCalpin, 1974).

Figure 11: View down the debris flow filled channel below the Spady Landslide after the first failure (February 1996), displaying marginal levees and creek channel filled with soil/debris. It is approximately 15 meters wide and extends for approximately 60 meters beyond the large, downed tree in foreground.

Figure 12: Ponded channel caused by debris flow from the second failure (March 1997) of the Spady Landslide.



A) Active Landslide- composed of sharply- defined components

B) Inactive-Young- slopewash and shallow mass movements modify sharp edges, but no drainage lines established

C) Inactive-Mature- drainage follows rifts and sags inside slide mass, internal blocks are dissected, material is eroded from slide mass

Figure 13: Block diagram of idealized landslide features displaying morphological changes with time: A) Active, B) Inactive-Young, and C) Inactive-Mature Features (after McCalpin, 1974).

Table 3: Description of morphological feature changes with time (after McCalpin, 1974).

Age Class	Head Scarp	Internal Morphology and Drainage	Vegetation	Toe	Estimated Absolute Age
Active	Sharp, Unvegetated	Undrained Depressions, Lakes, Hummocky Topography, Angular Internal Blocks Separated by Unvegetated Cracks	Absent or Sparse on Scarps and Internal Scarps, Tilted "jack-strawed" Trees Common	Forces Axial Drainage to Opposite Side of Valley, Dams Drainage, Covers Modern Flood Plain, Not Modified by Streams	Activity Within Historic Time, Less Than 100 years old
Inactive-Young	Sharp to Smooth, Partly Vegetated	Undrained and Drained Depressions, Ponds and Marshes, Internal Cracks Vegetated	Younger than Adjacent Terrain or Different Type or Density	Same as Above, But May be Modified by Modern Channel	100 - 5000 years old
Inactive-Mature	Smooth, Dissected, Vegetated	No Drainage Depressions, But Smooth Rolling Topography, Shear Zones Become Drainage	Same Age as Adjacent Terrain, But May be Different Density	Cut by Modern Flood Plain, Stream Not Constricted	5000 - 10,000 years old

Active Features

For planning purposes, any landslide that has undergone historic (about 100 years for the western U.S.) movement is considered active or as having the potential for renewed movement (McCalpin, 1974). This category also includes landslides which are currently moving. Landslides in this active category typically possess fresh, unmodified morphologic features (Figure 13A). The head scarp is fresh, often jagged, steep (approaching 90°), unvegetated, and shows the original irregularities of the break. Closed depressions or sag ponds, often containing water are common on the down-dropped blocks. Pre-slide drainages are truncated and development of internal, marginal drainage channels have not begun. The slide toe may interfere with the modern valley, forming ponds upstream of the slide-toe dam (McCalpin, 1974).

Active features found in the study area contained the most pronounced morphological changes to the slope. These are best represented on a map and include the following (Plate 3, detailed map of the Spady Landslide):

1) sharp unvegetated, continuous scarps (Figure 9),

2) sharp unvegetated, shear zones, most with cracks extending outward and parallel to the main shear and some with slickensided surfaces,

3) sharp, open tension cracks above the main head scarp (Figure 7),

4) unmodified toes of debris, some with ponds upstream (Figure 12). Some toes entered the valley and became debris flows displaying marginal levees (Figure 11), and

5) internal down-dropped blocks, separated by minor scarps, with active springs and sag ponds on the scarps and blocks, and lobes of saturated flow material.

Inactive-Young Features

Landslides that have not moved within historic time will have more subdued features than active landslides (McCalpin, 1974). Figure 13B shows the morphological change of original sharp features to softened features of an inactive-young landslide. Scarps become smoother (decrease in slope angle) due to erosion and begin to be vegetated. Internal depressions begin to fill with locally derived sediments and may appear as soggy areas. Marginal gullies begin to develop along the newly developed topographic boundaries. The slide toe is trimmed back from stream bank erosion, which may trigger smaller debris slides and slumps along the margin of the toe (McCalpin, 1974).

Inactive-young features found in the study area were slightly harder to identify than active features. The inactive-young features found in the study area include the following:

1) slightly rounded, partly revegetated scarps,
2) shear zones partly revegetated, no visible fresh cracks extending outward and parallel to shear, shear zone becoming or is a gully,
3) internal vegetation is younger, different type, or different density than surrounding areas (Figure 10),

4) toes are revegetated and some have active landslides occurring on the oversteepened slope due to stream bank erosion, and

5) internal down-dropped blocks are rounded, but sag ponds and springs are still prevalent, with some of the sag ponds being dry or moist depressions.

Inactive-Mature Features

The mature landslide is a transition from a mass-movement dominated landform to a fluvial-dominated landform (Figure 13C) (McCalpin, 1974). The scarps appear as moderate changes in slope angle and are rounded and thickly revegetated. Many times, smaller landslides occur on these modified scarps. Tributaries of the marginal drainages extend themselves into the slide mass. The toes appear as oversteepened ridges paralleling the slope contours. The stream may make a gentle but unmistakable swing to the opposite side of the valley from the toe (McCalpin, 1974).

Inactive-mature features were the most difficult to identify in the study area. These features are subdued and poorly defined, but an accurate topographic base map aided in their identification. The following includes the inactive-mature features found in the study area:

1) smooth, non-continuous, completely revegetated scarps (some of these scarps had smaller, more recent landslides occurring on them),

2) shear zones appeared as small gullies and tributary creeks,

3) toes being revegetated and commonly having smaller more recent landslides occurring on them, and

4) rolling topography (hummocky), some sag ponds still present, but mostly dry or moist depressions.

These landslide features, as defined and illustrated above, change with time and form the basis for developing a model for the causes of landslides and the factors they relate to possible reactivation.