A Review of the Classification of Landslides of the Flow Type

OLDRICH HUNGR
Department of Earth and Ocean Sciences, University of British Columbia, 6339 Stores Road, Vancouver, B.C., V6T 1Z4, Canada

S. G. EVANS
Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, K1A 0E8, Canada

M. J. BOVIS
Department of Geography, University of British Columbia, 1984 West Mall, Vancouver, B.C., V6T 1Z2, Canada

J. N. HUTCHINSON
Department of Civil and Environmental Engineering, Imperial College of Science, Technology and Medicine, London SW7 2BU, England


ABSTRACT

As a result of the widespread use of the landslide classifications of Varnes (1978), and Hutchinson (1988), certain terms describing common types of flow-like mass movements have become entrenched in the language of engineering geology. Example terms include debris flow, debris avalanche and mudslide. Here, more precise definitions of the terms are proposed, which would allow the terms to be retained with their original meanings while making their application less ambiguous. A new division of landslide materials is proposed, based on genetic and morphological aspects rather than arbitrary grain-size limits. The basic material groups include sorted materials: gravel, sand, silt, and clay, unsorted materials: debris, earth and mud, peat and rock. Definitions are proposed for relatively slow non-liquefied sand or gravel flows, extremely rapid sand, silt or debris flow slides accompanied by liquefaction, clay flow slides involving extra-sensitive clays, peat flows, slow to rapid earth flows in non-sensitive plastic clays, debris flows which occur in steep established channels or gullies, mud flows considered as cohesive debris flows, debris floods involving massive sediment transport at limited discharges, debris avalanches which occur on open hill slopes and rock avalanches formed by large scale failures of bedrock.

INTRODUCTION

General

The landslide classifications of Varnes (1954, 1978) and Hutchinson (1968, 1988) are today the most widely accepted systems in the English-speaking world. Nevertheless, literature on engineering geology of landslides continues to be plagued by inconsistent terminology and ambiguous definitions of various landslide types. Cruden and Varnes (1996) proposed modifications to the Varnes classification, which introduce a multi-dimensional taxonomic framework. However, certain key terms defined in the older classifications and their equivalents in other languages have now achieved firm status in the vocabulary of both specialists and the public and are thus unlikely to disappear.

The aim of this contribution is to show that landslide phenomena can be usefully divided into a small number of classes, which preserve established concepts and at the same time bring out the most important attributes of landslide events. This can be achieved most easily without recourse to a taxonomic order. Furthermore, it is possible to show that the main classification systems in current use are conceptually related. Thus, many of the established terms may continue to be used, while the improved definitions facilitate “translation” between the two systems and those prevalent in other languages.

The discussion focuses on landslides of the flow type. The reason for this is firstly that this group of mass movements is very important as a natural hazard and secondly that the terminology of flows is the most poorly developed. The article adopts a North American perspective,
using the Varnes (1978) classification as a starting point. The discussion relates mainly to subaerial landslides. Although several of the terms under consideration can be applied to subaqueous events, the proposed classification will not serve as a substitute for established sedimentological schemes as reviewed, for example, by Postma (1986).

Approaches to Landslide Classification

A classification system can be taxonomic, employing a hierarchy of descriptors to form a branching structure. Alternatively, it can be a filing system, which places items into classes on the basis of various attributes (e.g., Hutchinson, 1968). A typological classification is particularly useful. This is based on selected attributes and is designed to present solutions to the problems at hand.

Given the uncertainties concerning process mechanisms in many landslide phenomena, taxonomy is difficult to achieve as shown in the following discussion. Since our preoccupation with landslides is usually motivated by the need to solve problems (i.e. to conduct hazard assessments), typological classification appears to be the most useful approach.

Conservatism is a very important attribute of classification. If language is to be an effective communication tool, care must be taken to preserve established terms. With prolonged use, brief but well-used terms acquire complex meanings which convey much information and facilitate connections between new observations and past experience. Both Hutchinson’s and Varnes’ classifications are based on earlier systems (e.g., Sharpe, 1938) and are thus tied to terminology which has developed in the engineering geology profession over the past century.

Hutchinson’s (1988) classification is essentially nontaxonomic, with only the most basic kinematic patterns set out as the principal attribute. Varnes’ (1978) classification is weakly taxonomic. Its tabular layout has six lines representing movement mechanisms and three columns for material type (Table 1). Velocity of movement is the third dimension (Table 2, based on Cruden and Varnes, 1996). Within this framework, one or two-word key terms such as “debris avalanche” complete the classification and subsume all other attributes such as moisture content, magnitude range, geometry, or physical setting. The following section explores the three taxonomic dimensions, as used in Varnes’ classification of “flows,” with the aim of showing that even a weak taxonomic order is difficult to impose.

CLASSIFICATION CRITERIA

Movement Mechanisms

Previous schemes for landslide classification have included terms such as flow or slide, which presume a knowledge of movement mechanisms. For example, in the scheme of Varnes (1978), all slope movements involving significant internal distortion of a moving mass would be classed as flows. However, it is often difficult to determine whether internal distortion or boundary sliding is dominant in a given case. Hence, Hutchinson (1988) refers to the whole group as “debris movements of flow-like form,” thus avoiding any commitment to a specific kinematic model.

As an example of the ambiguity involved in using movement mechanism as a classification attribute, Varnes’s earth flows are known as “mudslides” in Hutchinson’s classification. Numerous field observations have shown that such landslides move predominantly by sliding along discrete shear surfaces, not by distributed flow (e.g., Hutchinson, 1970; Brunsden, 1984, Figure 1). The existence of distributed straining is often evidenced only by streamlines, bulges, lobes and similar large-scale flow-like features in the morphology of the deposits.

In a narrower sense, “flow” can also be understood as the motion of a fluid material over a rigid bed. In this case, there is a difference between the mechanical character of the flowing mass and that of the underlying bed material. By contrast, distortional movements such as “Sackung” (gravitational sagging) or soil creep may exhibit little difference in character between the deforming material and its substrate and, in many cases, no clearly identifiable strain or displacement discontinuity. Such

<table>
<thead>
<tr>
<th>Rate of Movement</th>
<th>Bedrock</th>
<th>Debris (&lt;80% Sand and Finer)</th>
<th>Earth (&gt;80% Sand and Finer)</th>
</tr>
</thead>
</table>
| rapid and higher (>1.5 m/day) | rock flow (creep, slope sagging) | debris flow  
debris avalanche | wet sand and silty flow  
rapid earth flow  
loess flow  
dry sand flow |
| less then rapid (<1.5 m/day) | solifluction 
soil creep  
block stream | earth flow | |
Classification of Landslides

Table 2. Landslide velocity scale (Cruden and Varnes, 1996).

<table>
<thead>
<tr>
<th>Velocity class</th>
<th>Description</th>
<th>Velocity (m/sec)</th>
<th>Typical velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Extremely Rapid</td>
<td>5</td>
<td>5 m/sec</td>
</tr>
<tr>
<td>6</td>
<td>Very Rapid</td>
<td>0.05</td>
<td>3 m/min</td>
</tr>
<tr>
<td>5</td>
<td>Rapid</td>
<td>$5 \times 10^{-4}$</td>
<td>1.8 m/hr</td>
</tr>
<tr>
<td>4</td>
<td>Moderate</td>
<td>$5 \times 10^{-6}$</td>
<td>13 m/month</td>
</tr>
<tr>
<td>3</td>
<td>Slow</td>
<td>$5 \times 10^{-8}$</td>
<td>1.6 m/year</td>
</tr>
<tr>
<td>2</td>
<td>Very Slow</td>
<td>$5 \times 10^{-10}$</td>
<td>16 mm/year</td>
</tr>
<tr>
<td>1</td>
<td>Extremely Slow</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

movement types are excluded from the flow category in this article.

A flow-like landslide often begins as a slide, forming a rupture surface, but then continues moving over a long distance. The term “landslide source volume,” or simply “landslide source” is defined here as the volume between the rupture surface and the pre-slide ground surface. It is the volume of initial movement, from which the landslide mass issues onto a flow path (J. King, personal communication).

Groupings Based on Material Properties

The second major variable used in previous classifications is material type. Varnes’ (1978) distinction between “debris” and “earth” materials is based on the percentage content of coarse material. “Earth” has less than 20 percent of gravel and coarser clasts (grain diameter greater than 2 mm) while “debris” has more. Cruden and Varnes (1996) retained the same convention.

Although apparently simple, this criterion is not easy to apply. It cannot be applied at all in preliminary studies, where landslides are described from aerial photography or reconnaissance. Even during fieldwork, the average grain-size distribution of a deposit often cannot easily be estimated, because of lateral and vertical non-homogeneity of many landslides, combined with difficulty of access and lack of exposures.

Furthermore, poorly-sorted materials can be fully supported by a clayey matrix with coarse-grain content as high as 65 percent by volume (Rodine and Johnson, 1976). Therefore, the limit of 20 percent content of coarse clasts may have little significance with respect to mechanical behavior. For example, Holtz and Ellis (1968) showed that adding up to 35 percent by weight of gravel to a well-graded clayey soil resulted in no measurable change in either the effective friction angle or cohesion.

For the purposes of an engineering-geological landslide classification, it may be useful to replace grain-size criteria by genetic concepts. One group may contain sorted fine-grained deposits (sand, silt or clay) produced by fluvial, lacustrine, marine, eolian or volcanic processes (e.g., ash fall), or sorted anthropogenic deposits (e.g., mine tailings). Flows in such materials could be referred to using the specific textural or genetic label of the soil involved, such as sand, clay, loess or talus. The presence of sorting is implicit in the geomorphic process responsible for the origin of the deposit. This can be determined by geomorphological techniques in the field, or by remote sensing, without the need to impose arbitrary textural criteria.

The term “earth” is useful in connection with the well-established North American term earth flow (Varnes, 1978), which must be distinguished from the equally well-established term debris flow. Earth flow involves the products of weathering of stiff clays and clay-rich rocks such as mudstones, shales and certain metamorphic rocks. Weathering produces a clayey colluvium with a consistency closer to the Plastic than the Liquid Limit. The Liquidity Index is variable, on account of non-homogeneity of earth flow material (Hutchinson, 1970, 1988), but reported values are generally below 0.5 (Keefer and
Johnson, 1983; Bovis, unpublished data). These low-sensitivity clay-rich materials of intermediate consistency produce slow to rapid sliding movements along distinct slickensided shear surfaces. Many typical earth flows contain large percentages of gravel and coarser particles, albeit often in a friable form (Figure 2 and Hutchinson, 1988).

However, not all clayey colluvium forms earth flows. Clay slopes under arid climatic conditions produce liquid, extremely rapid debris flows, also referred to as mud flows (e.g., Bull, 1964). The term “mud flow” appears to have been coined by Blackwelder (1928), in connection with similar clay-rich debris flows. Geologically, the term “mud” refers to liquid or semi-liquid clayey material. Rapid mixing of the originally stiff or dry clayey matrix with surface water is required to raise the water content to, or above the Liquid Limit. Dispersive smectitic clays may be particularly prone to such a process (e.g., Sherard et al., 1972).

Many debris flows of volcanic origin also involve clayey debris. Scott and others (1992) suggested the term “cohesive debris flows” for those with matrix clay content of more than 3 to 5 percent. Depending on the activity of the clay fraction, this corresponds to a Plasticity Index of 3–15 percent.

It is proposed here to use the term “mud” for soft, remoulded clayey soils whose matrix (sand and finer) is significantly plastic (Plasticity Index > 5 percent) and whose Liquidity Index during motion is greater than 0.5. However, these criteria may not easily be applied quantitatively in field studies for lack of textural and consistency data, as well as the variability of the indices within a given landslide deposit.

“Debris” can be defined as loose unsorted material of low plasticity such as that produced by mass wasting processes (colluvium), weathering (residual soil), glacier transport (till or ice contact deposits), explosive volcanism (granular pyroclastic deposits) or unsorted anthropogenic waste, such as mine spoil. Debris may also contain a significant proportion of organic material, including logs, tree stumps and organic mulch (e.g., Swanston, 1974).

In Figure 3, matrix compositions of earth flows, debris flows and mud flows from several areas in the world are compared. Debris flows typically contain less than 30 percent silt and finer particles. On this basis, they can be distinguished from earth flows. However, mud flows cannot be distinguished from earth flows on a textural basis. A comparison of colloidal indices leads to a similar conclusion: Earth flows have clay contents ranging between 10 and 70 percent, averaging 40 percent and Plasticity Indices of 10 to 60, averaging about 35 percent (based on data in Keefer and Johnson, 1983). Debris flows are usually non-plastic or weakly plastic. However, some mud flows derived from volcanic sources may have clay contents and Plasticity Indices of more than 10 percent (Jordan, 1994). Mud flows derived from montmorillonitic shales may have clay contents exceeding 50 percent (Bull, 1964).

Given this situation, the distinction between “debris” and “earth” should not be based solely on grain-size distribution, but should instead be derived from the context of each landslide class. Specifically, earth flow and mud flow may involve material of similar texture, but are

![Figure 2. Earth flow material derived from Cretaceous shale and sandstone, Liard River, northwestern British Columbia. Note the high percentage of gravel and coarser particles. The clipboard is 8.5 in. (216 mm) wide.](image)

![Figure 3. Textural composition of the matrix material in debris flows and earth flows: gravel, 2–18 mm; sand, 0.074–2 mm; silt and clay, < 0.074 mm. Data from Bovis (unpublished), Bull (1964), Pierson (1980), Keefer and Johnson (1983), Hutchinson (1988), Takahashi (1991), Major and Pierson (1992), Scott and others (1992), and Jordan (1994).](image)
Classification of Landslides

Table 3. Material involved in landslides of the flow type.

<table>
<thead>
<tr>
<th>Origin</th>
<th>Character</th>
<th>Condition¹</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>SORTED (marine, lacustrine,</td>
<td>Non-cohesive</td>
<td>Dry or Saturated</td>
<td>- Gravel</td>
</tr>
<tr>
<td>fluvial, eluvial,</td>
<td>(Plastic Limit &lt; 5%)</td>
<td></td>
<td>- Sand</td>
</tr>
<tr>
<td>volcanic, anthropogenic)</td>
<td>Cohesive</td>
<td>- Plastic (I&lt;sub&gt;c&lt;/sub&gt; &lt; 0.5)</td>
<td>- Clay</td>
</tr>
<tr>
<td></td>
<td>(Plastic Limit &gt; 5%)</td>
<td>- Liquid (I&lt;sub&gt;c&lt;/sub&gt; &gt; 0.5)</td>
<td>- Sensitive Clay</td>
</tr>
<tr>
<td>UNSORTED (residual, colluvial,</td>
<td>Non-cohesive</td>
<td>Dry or Saturated</td>
<td>- Debris²</td>
</tr>
<tr>
<td>glacial, volcanic,</td>
<td>(Plastic Limit &lt; 5%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>anthropogenic)</td>
<td>Cohesive</td>
<td>- Plastic (I&lt;sub&gt;c&lt;/sub&gt; &lt; 0.5)</td>
<td>- Earth</td>
</tr>
<tr>
<td></td>
<td>(Plastic Limit &lt; 5%)</td>
<td>- Liquid (I&lt;sub&gt;c&lt;/sub&gt; &gt; 0.5)</td>
<td>- Mud</td>
</tr>
<tr>
<td>PEAT</td>
<td>Organic</td>
<td>Saturated</td>
<td>- Peat</td>
</tr>
<tr>
<td>ROCK</td>
<td>Fragmented</td>
<td>Dry or Saturated</td>
<td>- Rock</td>
</tr>
</tbody>
</table>

¹ Related to the material found in the vicinity of the rupture surface at the time of failure, if it can be determined. In many cases, the material condition must be deduced from the behavior of the landslide, especially velocity.
² Debris may contain a considerable proportion of organic material.

significantly different in other ways, particularly in the velocity of movement and the average water content.

It is proposed here to reserve a special category, rock avalanche, for fragmented rock which originates as intact rock mass at the source of the landslide, but disaggregates in the course of failure. A certain difficulty exists in separating uncemented granular pyroclastic deposits (debris) from cemented or welded pyroclastic breccias (rock). The distinction between rock avalanches, debris avalanches, and flow slides from volcanic sources will therefore remain gradational and subjective.

A proposed scheme for the classification of materials involved in flows is shown in Table 3. The first level of distinction between sorted and unsorted soil and fragmented rock, can be achieved using geomorphological techniques, which can identify the likely character of deposits based on genesis. At the second level, the distinction between cohesive and non-cohesive materials may also be derived from geomorphological analysis, augmented by field observations and, perhaps, laboratory testing. At the third level, the distinctions between saturated versus dry, and liquid versus plastic, can often only be derived by inference from the observed landslide behavior, since the condition of the material in the vicinity of the rupture surface during motion may be very difficult to ascertain. Extremely high velocity and long runout on slopes flatter than the effective dynamic friction angle often signifies the presence of saturation and excess pore-pressure.

Movement Velocity

The velocity of landslide movement is a function of time and space and can rarely be mapped in detail. Reported velocities are usually random observations at a point and at a given moment. However, given the wide spectrum of speeds, such observations are still useful.

Examples of velocity observations from various sources are shown in Figure 4, sorted according to the key terms suggested later in this paper. Most of these numbers represent point observations or maximum values at randomly chosen locations and are not necessarily maxima for any given event. All of the data represent fully developed velocities, recorded outside the acceleration/deceleration phases of the given events. A clear distinction can be made between extremely rapid processes such as debris flow, mud flow and debris avalanche and a slow process such as earth flow.

Other Attributes

Many other dimensions can be used to classify mass movements (e.g., Coates, 1977; Hutchinson, 1988; and Cruden and Varnes, 1996). Several of special importance include event volume, water content, relationship between natural water content and plasticity indices (“liquidity”), the presence of mechanisms capable of creating excess pore-pressures during failure, the existence of an established channel or path and the role of free-flowing water. All of these attributes are used in the definitions of flow types presented below, although organizing them strictly in a taxonomic manner is not possible.

DEFINITIONS OF CLASSES

Flow-Like Mass Movements: In the kinematic category of “flows,” Varnes (1978) defined 11 key terms, as listed in Table 1. The most important among these terms are: debris flow, debris avalanche, rapid earth flow and earth
flow. Blong (1973) argued that distinguishing between these processes on morphological grounds was difficult to achieve. New definitions are now proposed here which do not stray too far from the original meanings imparted by Varnes (1978), but bring out distinctions of practical importance.

In the following paragraphs, a definition of each term is first given, then each landslide characteristic used in the definition is explained further. Two important landslide types not addressed by Varnes (1978): mud flow and debris flood, are also defined. The term rock avalanche, which Varnes (1978) included under “complex” landslides, is also considered as it is closely related to other phenomena under discussion. The material definitions are based on Table 3 and the key criteria involved in each definition are summarized in Table 4.

**Dry (or Non-Liquefied) Sand (Silt, Gravel, Debris) Flow:** “Dry (or non-liquefied) sand (silt, gravel or debris) flow is a flow-like movement of loose dry or moist, sorted or unsorted granular material, without significant excess pore-pressure.”

In the absence of excess pore-pressures, granular materials tend to fail by shallow planar sliding, followed by a flow-like movement and distributed straining at the critical void ratio. The initial movement may be triggered by sliding at or slightly above the angle of repose, or by a block fall from a steep exposure or cliff. Dry landslides of this type tend to be small in volume and limited in velocity, although the latter depends on the steepness and length of the slope. Their motion can be analysed using frictional models with the effective dynamic friction angle of the material (Hungr, 1995).

**Dry sand flow** is a fundamental process in the migration of sand dunes (Figure 5). Unsorted debris of colluvial, volcanic or other origin can also flow in a dry condition. Dry talus flow (usually slow to very rapid) is important in the shaping of talus cones (Evans and Hungr, 1993). Dry silt flows are sometimes triggered by the collapse of steep silt scarps or cliffs (Figure 6). These may be relatively mobile, given the large amount of energy imparted by the initiating block fall (Evans and Buchanan, 1975). The motion of the flow in Figure 6 has been simulated successfully using a frictional model with no pore-pressure and a friction angle of 28° (Hungr, unpublished).

Non-liquefied saturated sand or gravel flows transport sediment on relatively coarse and steep delta fronts or on channel bottom dunes, with limited mobility. Such relatively small and benign subaqueous mass movements must be clearly separated from subaqueous debris flows and flow slides (Terzaghi, 1957).

**Sand (Silt, Debris, Weak Rock) Flow Slide:** “Sand (silt, debris, weak rock) flow slide is a very rapid to extremely rapid flow of sorted or unsorted granular material on moderate slopes, involving excess pore-pressure or liquefaction of material originating from the landslide source.”

Full or partial liquefaction of loose saturated granular material due to internal collapse during initial failure produces highly mobile, dangerous landslides. The presence of this process is of such importance that it should be reflected in the name of the landslide type. The term flow slide, introduced by Casagrande (1936) and re-defined by Hutchinson (1992a, 1992b), is suitable for this purpose.

Sand or silt flows involving significant pore-pressures tend to occur in certain well-defined geological settings. These include submerged deposits of loose deltaic sand (Andresen and Bjerrum, 1968), accumulations of lacustrine silt (Stanton, 1898), or loess (Dijkstra et al., 1994). The latter, loess flow slides, are among the most destructive landslide types ever observed (Close and McCormick, 1922). Sorted or unsorted loose man-made fills such as hydraulic fills (Casagrande, 1936), and mine tailings (Blight, 1997) or waste deposits (Dawson et al., 1998) fall into the same category. One of the most destructive landslides in British history, the Aberfan colliery waste flow slide of 1966, was of this type (Bishop et al., 1969).

In each case, a collapsive internal structure exists, causing a significant portion of the material to maintain a moisture content in excess of the liquefaction limit. After an initial deformation, or as a result of earthquake shaking, the metastable structure collapses and the material liquefies, with a dramatic reduction in strength. The pore-pressure in the liquefied zone increases to approximately the total stress, reducing effective stress to a very small value (Bishop, 1973; Dawson et al., 1998).

Flow slides in non-plastic materials may be fully saturated with liquefaction affecting the full thickness of the material, as is the case with subaqueous loose sand flow slides. Silt, loess and man-made fill flow slides may be largely unsaturated. In such cases, liquefaction may be confined to a thin saturated basal layer and the surface, or even much of the body of the flow, may appear dry.
### Classification of Landslides

<table>
<thead>
<tr>
<th>Material</th>
<th>Water Content</th>
<th>Special Condition</th>
<th>Velocity</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silt, Sand, Gravel, Debris</td>
<td>dry, moist or saturated</td>
<td>- no excess pore-pressure, - limited volume</td>
<td>various</td>
<td>Non-liquefied sand (silt, gravel, debris) flow</td>
</tr>
<tr>
<td>Silt, Sand, Debris, Weak rock</td>
<td>saturated at rupture</td>
<td>- liquefiable material, - constant water</td>
<td>Ex. Rapid</td>
<td>Sand (silt, debris, rock) flow slide</td>
</tr>
<tr>
<td>Sensitive clay</td>
<td>at or above liquid limit</td>
<td>- liquefaction in situ, - constant water content</td>
<td>Ex. Rapid</td>
<td>Clay flow slide</td>
</tr>
<tr>
<td>Peat</td>
<td>saturated</td>
<td>- excess pore-pressure</td>
<td>Slow to very rapid</td>
<td>Peat flow</td>
</tr>
<tr>
<td>Clay or Earth</td>
<td>near plastic limit</td>
<td>- slow movements, - plug flow (sliding)</td>
<td>&lt; Rapid</td>
<td>Earth flow</td>
</tr>
<tr>
<td>Debris</td>
<td>saturated</td>
<td>- established channel, - increased water content</td>
<td>Ex. Rapid</td>
<td>Debris flow</td>
</tr>
<tr>
<td>Mud</td>
<td>at or above liquid limit</td>
<td>- fine-grained debris flow</td>
<td>&gt; Very rapid</td>
<td>Mud flow</td>
</tr>
<tr>
<td>Debris</td>
<td>free water present</td>
<td>- flood</td>
<td>Ex. Rapid</td>
<td>Debris flood</td>
</tr>
<tr>
<td>Debris</td>
<td>partly or fully saturated</td>
<td>- no established channel, - relatively shallow, steep source</td>
<td>Ex. Rapid</td>
<td>Debris avalanche</td>
</tr>
<tr>
<td>Fragmented Rock</td>
<td>various, mainly dry</td>
<td>- intact rock at source, - large volume</td>
<td>Ex. Rapid</td>
<td>Rock avalanche</td>
</tr>
</tbody>
</table>

1. Water content of material in the vicinity of the rupture surface at the time of failure.
2. Highly porous, weak rock (examples: weak chalk, weathered tuff, pumice).
3. The presence of full or partial in situ liquefaction of the source material of the flow slide may be observed or implied.
4. Relative to in situ source material.
5. Presence or absence of a defined channel over a large part of the path, and an established deposition landform (fan). Debris flow is a recurrent phenomenon within its path, while debris avalanche is not.
6. Peak discharge of the same order as that of a major flood or an accidental flood. Significant tractive forces of free flowing water. Presence of floating debris.
7. Volume greater than 10,000 m$^3$ approximately. Mass flow, contrasting with fragmental rock fall.

The detailed mechanism of motion of liquefied granular flow slides is often difficult to reconstruct from surface observations, as the liquefied zones are covered by drier or denser material. However, high velocity and long run-out on relatively gentle slopes are clear distinguishing signs (Figure 7A and B).

It must be stressed that the term flow slide implies liquefaction of the material forming the source volume of the landslide, albeit often only after a substantial displacement. Thus, if an investigation or laboratory testing identify the source material as being capable of liquefaction, then there is a potential for a flow slide to occur. Liquefaction may also develop in other types of landslides, such as debris flows, debris avalanches or rock avalanches defined below (Sassa, 1985), however, not spontaneously at the source, but during motion down the path, involving modified source material or other material entrained along the path. Obviously, there will always remain some overlap between flow slides and these other phenomena.

Certain types of rock, such as the soft chalk of Western Europe and some other high porosity deposits (e.g. weathered igneous rock or welded pumice beds) appear to have a tendency to produce unusually mobile flows, possibly through a process of "impact collapse," which involves liquefaction of saturated porous rock on impact, following a sliding failure from a steep rupture surface (Hutchinson, 2000). For this reason, Hutchinson (1992a) placed chalk flows among flow slides. Thus, the flow slide family comprises loose granular materials, sensitive
more highly saturated soil from the path. For subaqueous events, several mechanisms of dilution exist, through which flow slides may entrain water in the course of movement and eventually change into turbidity currents (e.g. Hampton, 1972).

The term flow slide is less ambiguous than Varnes’s (1978) term “rapid earth flow.” The latter is inconsistent with the same author’s definition of the “rapid” velocity class (<0.05 m/sec). Also, there is a potential for confusion with the term earth flow as defined below.

*Clay Flow Slide:* “Clay flow slide is a very rapid to extremely rapid flow of liquefied sensitive clay, at, or close to its original water content.”

Certain clays also exhibit structural collapse at failure, resulting in an extreme loss of strength and rapid motion. The classic extra-sensitive (“quick”) clay flow slides occur in clays of marine or brackish origin, rendered sensitive over time through leaching by fresh water (e.g., Crawford, 1968). Such clays (or clayey silts) are often slightly to moderately over-consolidated and may exhibit substantial undrained strength while in the intact condition. Most of this strength is lost due to a collapse of the soil structure during failure so that the remoulded material is essentially a viscous liquid (Locat, 1993). While the most notable localities with extra-sensitive marine clays are in eastern Canada and southern and central Norway and Sweden, these clays can also be found in many other regions such as northern British Columbia, Canada (Geertsema and Schwab, 1995).

*Clay flow slides* initiate as retrogressive multiple rotational failures or as spontaneous sheet-like liquefaction failures (Figure 8A; Bjerrum, 1955; Mitchell and Markell, 1974). The ensuing flow involves liquid clay, bearing flakes or rafts of non-liquefied desiccated crust. The flow may eventually become diluted upon entering a stream (Figure 8B).

Figure 5. A slow dry sand flow on the lee slope of a sand dune in the Namib Desert (photograph courtesy of G. D. Plage).

Figure 6. A dry silt flow triggered by a block fall from a scarp in cemented glacio-lacustrine silt, central British Columbia. The flow front crossed the road from right to left in a few seconds (photo courtesy Mr. J. Valentinuzzi, British Columbia Ministry of Transportation and Highways).
Occasionally, a flow slide occurs in clay with limited sensitivity. An example is the Attachie Slide on the Peace River in northeastern British Columbia, Canada (Evans et al., 1996). This 7 million m$^3$ landslide involved very stiff, heavily over-consolidated glacio-lacustrine silt and clay strata of moderate sensitivity, overlain by Pleistocene glacial till, which had previously been severely disturbed by ductile slumping, yet the catastrophic failure of May 1973 moved a horizontal distance of over 1,000 m in a few minutes, strongly indicating the presence of a structural collapse within the soil (Figure 9). This is an example of a clay flow slide in which the presence of excess pore-presures can only be inferred from the character of the observed movement, though the precise mechanism of movement remains obscure.

Figure 7. A) A debris flow slide involving 60,000 m$^3$ of coal mine waste near Sparwood, British Columbia, Canada. The source area: notice scarps and tension cracks surrounding the crown of the landslide. B) A view from the slide crown down the flow slide path. The super elevation trace indicated by arrow corresponds to a velocity of about 15 m/sec (54 km/h). The bulk of the coarse waste material is dry, but the presence of partial liquefaction in saturated zones is implied by the great mobility of the flow slide. The total displacement of the toe was approximately 2 km.

Figure 8. A) A clay flow slide in extra sensitive marine clay at South Nation River, St. Lawrence Lowland near Ottawa, Canada. Source scar: note elongated slices of desiccated crust formed by retrogressive slumping. B) Clay flow slide in river channel, with the source scar in the background.

**Peat Flow:** "Peat flow is a slow to very rapid flow-like movement of saturated peat, involving high pore-presures."

A distinctive type of flow derives from the failure of peat deposits. It may be triggered by some external process causing rapid loading of a saturated peat layer (e.g., Hungr and Evans, 1984) or naturally by the breaching of an oversteepened rim of a raised bog ("bog burst," Colhoun et al., 1965). In either case, considerable pore-pressure is inferred, to allow motion of a highly frictional organic material on gentle slopes. However, this may not be excess pore pressure, as light peat fibers may actually float in the pore water. Velocities of movement depend on the slope angle and there is a continuum from slow to very rapid peat flows on slopes as low as 5°.

**Earth Flow:** "Earth flow is a rapid or slower, intermittent flow-like movement of plastic, clayey earth."
Figure 9. The Attachie slide on the Peace River, northeastern British Columbia, Canada. This is a clay flow slide involving 7 million m$^3$ of heavily over-consolidated glacio-lacustrine silt and clay, overlain by glacial till.

If significant collapse-related pore-pressure increase does not take place, clay landslides generally do not reach high velocities (Hutchinson, 1970; Keefer and Johnson, 1983). Nevertheless, disturbed, predominantly saturated clayey soil may accumulate on the slope in a tongue-like form (e.g. Bovis, 1985). Continued movement may be maintained over long distances and periods of time by intermittent plastic deformation combined with internal creep, aided by pore-pressure fluctuations. This type of flow is characteristic of over-consolidated clays, weathered soft rocks and the weathering or erosion products derived from such deposits (Figure 10).

The velocity profiles of earth flows generally show the existence of basal and lateral shear surfaces normally associated with sliding movement. In spite of their flow-like morphology, the dominant mechanism of earth flow movement is sliding at residual strength (Hutchinson, 1970 and Figure 1). Consequently, Hutchinson (1988) preferred the term “mudslide,” which is defined by Hutchinson and Bhandari (1971). It is of concern that the word mudslide is presently being widely used in North-American mass media reports to describe a range of shallow, extremely rapid mass movements, which would be referred to as debris flows or debris avalanches in both Varnes’ and Hutchinson’s systems.

Figure 10. A stereo view of a large earth flow at Pavilion, British Columbia (Air photographs BC 7788: 242–243). Note flow bifurcation into separate lobes, and prominent lateral deposits along the margins of each lobe. Upper right-hand side of flow is undergoing reactivation by retrogression. Annual movement rate is 0.5–1 m/yr. Distance from crown to toe is 3 km. Deposit attains a maximum width of 2 km.

Many earth flow tongues attain a certain steady-state condition, since material discharged downslope is periodically replenished through back-scarp retrogression in the form of slumps or falls. The toe of the elongated earth flow lobe may extend into a river, lake or sea where it is eroded by stream flow or wave action. This unloads the toe and enhances further downslope movement of the mass. The earth flow itself acts as a conveyor belt between the material source and sink. Depending on the availability of an unobstructed sloping path, earth flows may develop elongate or lobate forms (Hutchinson, 1988).

In some cases, continued movement is facilitated by the process of undrained loading, as observed by Hutchinson and Bhandari (1971). Rapid, episodic movement of an upper part of the earth flow leads to thrusting or overriding of material farther downslope, thereby increasing total stress. In fine-grained materials, a rapid increase in total stress causes a concomitant increase in pore pressure, resulting in acceleration of the earth flow. In this manner, a kinematic wave can sweep the entire length of the flow tongue, delivering a fresh mass to the eroding toe (Keefer and Johnson, 1983; Bovis and Jones, 1992). Especially large waves, usually triggered by a temporal increase in ground-water pressure (e.g., due to unusually high infiltration) are referred to as surges. Surge velocities of up to 0.13 m/sec have been reported (Hutchinson et al., 1974).
Several distinctive types of earth flows occur in periglacial regions as a result of pore-pressures trapped within the thawing active layer in fine-grained sediments. Specific movement types include skin flows and bimodal flows (McRoberts and Morgenstern, 1974).

Debris Flow: "Debris flow is a very rapid to extremely rapid flow of saturated non-plastic debris in a steep channel. (Plasticity Index < 5 percent in sand and finer fractions)"

A debris flow event may occur in a series of surges, ranging in number from one to several hundred and separated by flood-like intersurge flow (e.g. Pierson, 1980). Using the rate of movement categories proposed by Crudcn and Varnes (1996) as shown in Table 2, the indicated movement rates for debris flows imply velocities in excess of 0.05 m/sec (3 m/minute), although most move at a rate of more than 1 m/sec and up to 20 m/sec over much of their path (Figure 11).

The key characteristic of a debris flow is the presence of an established channel or regular confined path. The terms "confined" and "channelized," frequently used in published definitions of debris flow, have not yet been specifically defined. Hungcr and others (1984) suggested that a maximum width to average depth ratio of 5 was necessary to maintain motion of coarse debris flow boulder fronts on flat slopes. However, this is likely to be a function of many other variables. It appears more realistic to define the presence of a channel in geomorphological terms. The path is likely to be a first or second order drainage channel or an established gully that controls the direction of flow and in which debris flow is a recurrent process. This is evidenced by signs of scour along the gully path and by the presence of a well-defined depositional cone or fan built up by a number of separate events from the same path (Figure 11). Second-order channels may combine several branches and multiple sources of debris flows. Submerged gullies or canyons provide confinement for subaqueous debris flows.

The presence of a confined channel is important for the following reasons:

1. The channel carries surface water flow which is incorporated into the debris flow surges to increase their water content.
2. The lateral confinement helps to maintain fairly large flow depth and facilitates longitudinal sorting and surge development described below.
3. The existence of a regular path influences the approach towards practical hazard assessment for debris flows.

A distinguishing characteristic of debris flows is the presence of a certain degree of rough sorting, which tends to bring the largest clasts close to the flow surface producing inverse grading (Costa, 1984). The same process, combined with a strong vertical velocity gradient, also often leads to longitudinal sorting and the building of an accumulation of boulders and timber debris near the front of a surge (Pierson, 1980; Iverson, 1997, Figure 12).

As a result of the surging behavior and the building of coarse surge fronts, peak discharges of debris flows are up to 40 times greater than those of extreme floods (Van Dine, 1985; Hungr, 2000). This gives debris flows considerable momentum and high destructive potential. Longitudinal sorting also generates distinctive depositional landforms. Boulder fronts build in the process of a surge’s travel through a confined channel (“gorge”). As the debris flow reaches the apex of the depositional fan, the channel widens and coarse debris is expelled to the sides to form steep ridges or levees. The front may be bypassed by the finer liquefied debris travelling behind it and come to rest as a thick boulder train or lobe. Such forms, together with large boulders and other evidence of high discharges and impacts, constitute “silent witnesses,” indicating past occurrences of debris flows (Aulitzky, 1980).

Figure 11. The path of a 1984 debris flow at Cathedral Mountain, Yoho National Park, British Columbia, Canada, triggered by an outburst of water from a small glacier.
Debris flows are fully saturated, with the possible exception of matrix-poor zones in the frontal boulder accumulations (Iverson, 1997). Water content is a highly variable quantity due to the heterogeneity of debris flow surges and the transition from dense and coarse-grained surge front to more fluid inter surge flow. Water content also varies temporally, as a result of gradual dilution of flows as they pass down stream channels (e.g., Scott et al., 1992).

Materials involved in debris flows range from clay to boulders several meters in diameter. In forested areas, as much as 80 percent of the volume may be organic material, such as timber (Swanson, 1974). Areas underlain by unweathered crystalline or metamorphic rocks tend to produce coarse debris flows, which may be practically devoid of silt and clay fractions but are dominated by boulders. Coarse-grained debris flows of the Pacific Northwest have been referred to locally as debris torrents, but use of this term is to be discouraged as it conflicts with the meaning of "torrent" in English and other languages (Slaymaker, 1988).

Figure 12. The bouldery front of a debris flow surge (drawing from Pierson, 1986).

Figure 14. The effect of a catastrophic debris flood caused by an accidental damming of Britannia Creek, north of Vancouver in 1921, followed by a sudden release of 60,000 m$^3$ of water, dammed behind a blocked railway culvert. The mountain stream has a drainage area of 28.5 km$^2$ and an overall relief of over 1,500 m (courtesy of Vancouver Public Library).

Some authors prefer to place volcanic debris flows, mud flows and debris avalanches into a special category, often referred by the Indonesian word “lahars.” “Cold” lahars are those not associated with eruptive processes, involving instead a slope failure on the volcanic cone. A special distinction for flow-like landslides of volcanic origin is justified, since they are often unusually large and more fine-grained than other similar events. The prefix “volcanic” can easily be used with the terminology being proposed here (e.g. volcanic debris flow, volcanic debris avalanche).

Mud Flow: “Mud flow is a very rapid to extremely rapid flow of saturated plastic debris in a channel, involving significantly greater water content relative to the source material (Plasticity Index > 5 percent)."

Under certain conditions, clayey colluvium can become diluted beyond its Liquid Limit. This may occur by sudden wetting of desiccated dispersive clays by rainstorms under arid conditions (Blackwelder, 1928; Bull, 1964). Some earlier classification systems distinguished between “semi-arid” and “alpine” mud flows (e.g., Sharpe, 1938), the latter probably identifiable with debris flows as defined in the preceding paragraph.

Another important group of plastic mud flows occurs by gradual dilution of low plasticity clays derived from volcanic origins. Scott and others (1992), in their work on volcanic debris flows, suggested a distinction between cohesive and non-cohesive types, which appears equivalent to the distinction between debris and mud flows proposed here.

The distinction between mud flows and debris flows is perhaps not of primary importance, as both have similar
“hyperconcentrated flows.” Costa (1984) suggested a solids concentration of 80 percent as the dividing line between hyperconcentrated flow and debris flow. However, sediment concentration is a highly variable quantity in any given event. The term debris flood has been applied by Aulitzky (1980) to cases of massive bedload transport characterized by limited maximum grain size and thickness of deposits and gently sloping deposition areas. However, parts of a debris flow often become diluted downstream to the point of assuming the character of a debris flood. Thus, the naming of an event as a whole should be based on its behavior in the central part of the deposition zone.

A debris flood may transport quantities of sediment comparable to a debris flow. The sediment may, furthermore, be transported in the form of massive surges, leaving sheets of poorly sorted debris ranging from sand to cobbles or small boulders. However, the sediment surges in a debris flood are propelled by the tractive forces of water overlying the debris. As a result, the peak discharge of

character. However, the clay fraction does modify the rheology of the material and this can be important in dynamic modelling (Takahashi, 1991; Jordan, 1994). The presence of clay also retards both dilution by water and drainage, causing longer runouts (Scott et al., 1992). Mud flows are distinguished from clay flow slides, as the former incorporate surface water during motion, like debris flows, while the latter liquefy in situ, without a significant increase in water content, at least in the initial stages of flow. Although direct evidence of water content changes may be difficult to obtain in the field, mud flows share many morphological and behavioral aspects with debris flows and this defines their separate identity.

Debris Flood: “Debris flow is a very rapid, surging flow of water, heavily charged with debris, in a steep channel.”

Beverage and Culbertson (1964) and Costa and Jarrett (1981) drew attention to the ability of major floods in steep channels to transport large quantities of sediment at relatively high solids concentrations in the form of
a debris flood is comparable to that of a water flood, perhaps multiplied by a "bulking factor" of between 1 and 2 (Costa, 1984). Debris flood velocities are similar to those of water during a flood.

Evidence of such limited discharges in channels and deposition areas clearly contrasts with that of debris flows which have peak discharges tens of times greater than major water floods (VanDine, 1985). Therefore, peak discharge is suggested as the most reliable criterion to distinguish between debris flows and debris floods. A further distinction is the morphology of deposits. Debris flows typically produce relatively thin, wide sheets of material, whereas debris flows produce thicker, more hummocky and lobate deposits. Maximum size of particles transported in a debris flood is of the same order as the peak depth in a major flood, up to several tens of centimeters in the case of typical small mountain streams. Another distinguishing characteristic is the absence of levees along the channel margins, due to the lack of longitudinal sorting and boulder fronts.

The destructiveness of debris flows is similar to that of water floods. Objects impacted by debris flows are buried or surrounded by debris, but are often undamaged (Figure 13).

An important exception to the above involves unusually high water discharges, which exceed the discharge of major precipitation-related floods. Such discharges may result from a sudden breach of natural or man-made dams, glacier outbursts, catastrophic melting of snow cover on volcanoes and similar events. In such cases, highly destructive discharges much in excess of major "hydrological" floods can occur, even in the rare case where no discharge magnification due to a buildup of a debris flow surge occurs (Figure 14 and Skermer and Russell, 1988).

Debris floods can continue moving in channels with considerably flatter slopes than those required for debris flows and are, therefore, observed on larger streams. In the Pacific Northwest, for example, coarse debris flows typically occur in basins smaller than 5 km², whereas debris floods have been observed in small river basins up to 50 km² and mean slope angles of less than 10°.

Strictly speaking, a debris flood is not a landslide, but a mass transport phenomenon. The distinction between debris flood and debris flow is of a very considerable practical interest in North America, where standard property insurance policies often cover flood damage, but not landslide damage. The concept of discharge magnification, elaborated above, can be used to make the required distinction.

Hutchinson (1988) does not include a separate term in his classification, but recognizes the continuity between debris flows and sediment-laden stream flow, based on water content.

Debris Avalanche: "Debris avalanche is a very rapid to extremely rapid shallow flow of partially or fully saturated debris on a steep slope, without confinement in an established channel."

A debris avalanche begins as a more or less shallow surficial sliding failure on a slope and continues to develop into a rapidly moving wave-like flow, but does not move in an established channel. In its initial stages, before internal distortion and the development of flow-like character, it may be referred to as a debris slide. Sharpe (1938) defined debris avalanche as a shallow landslide which is morphologically similar to a snow avalanche (Figure 15). Debris avalanches take place in various parts of a slope and do not normally occur repeatedly at the same location, since depletion of material usually occurs. The depositional landform constructed by debris avalanches (if any) is a laterally unconstrained colluvial apron, difficult to interpret in terms of individual paths.

The practical consequences of the distinction between debris flows and debris avalanches are obvious. A debris flow hazard study begins with the definition of the path and at least the lateral limits of the deposition area (fan). The path and debris fan can be expected to contain evidence of past occurrences, which can be used to derive information on magnitude and frequency (Jakob, 1996). Debris avalanche studies, on the other hand, must examine tracts of steep slopes, many segments of which may not have experienced debris avalanches during the observable past.

For example, the deposit of a debris avalanche near Kelowna in the British Columbia, which destroyed a house and caused two deaths, is underlain by glacio-fluvial terrace gravels some 10,000 years old. This was therefore the first post-glacial occurrence of such a landslide at that location (Cass et al., 1992).

Debris avalanches may enter steep drainage channels or gullies and become debris flows (Figure 16). Therefore, the term debris avalanche should be reserved for events which remain poorly channelled over most of their length, without a defined recurrent path and a laterally bounded deposition landform. Varnes (1978) implies that debris avalanches have higher velocities than debris flows. Figure 4 suggests this may be true, but more systematic collection of data is needed. Multiple surges are not as common as in debris flows, but may occur as a result of retrogressive failures from the crown or sides of the source scar.

Other distinguishing characteristics of debris avalanches, also related to the lack of channeling, are a lesser degree of saturation and the absence of longitudinal sorting and a coarse front. Water content is a difficult parameter to determine in the case of debris avalanches, as it is spatially variable. Often, a relatively dry mass of debris, or a coherent vegetation mat, may move on a thin, saturated basal layer liquefied by over-riding and rapid loading which remains largely concealed.
Hutchinson's (1988) term for *debris avalanche* is "hillslope (unchannelized) debris flow." A corresponding German term is "Hangmure" (hillslope-debris flow), while Japanese is "hōkai."

*Rock avalanche*: "Rock avalanche is an extremely rapid, massive, flow-like motion of fragmented rock from a large rock slide or rock fall."

It is proposed that the term *debris avalanche* should be reserved for landslides originating in debris (see Table 3). Landslides deriving most of their volume from bedrock failure are often referred to as *rock avalanches* (Figure 17). The motion of *rock avalanches* is massive, in that the bulk of the rock fragments moves as a semi-coherent flowing mass ("Sturzstrom" of Heim, 1932). The term "rock fall," by contrast, should be reserved for talus-forming independent rolling, fall and bouncing of discrete rigid fragments, individually or in swarms ("fragmental rock fall," Evans and Hungr, 1993). The type of behavior depends on the volume of the event and on the mechanism of failure. Rock fall typically involves relatively small volumes (<10,000 m³, Whalley, 1984), or piecemeal failures involving sequential detachment of smaller blocks (e.g. the Motto d'Arbin case, Heim, 1932).

The source material of a *rock avalanche* may be any kind of rock, sedimentary, metamorphic or igneous, including pyroclastic deposits. Weak rock masses appear to be more likely to produce slow moving rock slides than strong, brittle rocks (Hungr and Evans, unpublished data).

Large *rock avalanches* tend to exhibit much greater mobility than could be predicted using frictional models appropriate for dry broken rock. The apparent mobility also increases with volume (Heim, 1932). A number of explanations for this phenomenon have been offered by various authors, although none can yet be accepted as universally valid (e.g. Hungr, 1990). Many *rock avalanches* are known to entrain and liquefy saturated soil from their path and may thus be mobilized by the presence of basal layers of liquefied debris, largely covered beneath dry fragmented rock. It is proposed here to apply the term *rock avalanche* to any landslide originating in rock and involving breakdown of the rock mass and massive, extremely rapid flow-like motion. While it is recognized that the largest *rock avalanches* tend to be more mobile, a unique relationship between volume and mobility cannot be established. Other factors, such as the character and water content of materials in the debris and along the path of the rock avalanche, also play an important role.

A further subdivision of the *rock avalanche* category would be desirable, to account for the various mechanisms which increase the mobility of these landslides. However, existing hypotheses used to explain the motion of *rock avalanches* are insufficiently well understood to serve as a reliable basis for classification.

The simple term *rock avalanche* is preferable to the complex *rock fall-debris avalanche*, as proposed by Varnes (1978). The initial movement mechanism is often poorly understood. For example, the Frank Slide, discussed by Varnes (1978) and Cruden and Varnes (1996), started as a rock slide, not a rock fall (Cruden and Krahn, 1978). The complex terms "*rock fall-debris avalanche*" or "*rock slide-debris avalanche*" should be reserved for events in which an initial rock failure mobilizes a significant volume of debris, such as colluvium, entrained from the path of the event. The entrained volume of debris often exceeds the quantity of fragmented rock produced by the initiating rockslide (e.g. Figure 18 and Niederer, 1941).

Hutchinson (1988) applied the German term "*Sturzstrom*" (rock fall-stream). This term, coined by Heim (1932), implies flowing motion and is thus synonymous with the definition of *rock avalanche* given above.

**CONCLUSION**

Consistent with the above definitions, it is possible to formulate a systematic approach to the classification of flows. Table 4 is a suggested check list, indicating how each of the landslide types can be identified based on the material type (Table 3), water content, presence of excess pore-pressure or liquefaction at the source of the landslide, presence of a defined recurrent path (channel) and deposition area (fan), velocity, and peak discharge of the event. The type designations do not conflict significantly with their usage in most of the North American literature on landslides. The numerous distinctive characteristics of each group, as described in the preceding paragraphs, can be associated with each type. The scheme
of the geoscience profession, given the diversity of phenomena we are called upon to interpret.

ACKNOWLEDGMENTS

The authors are thankful for valuable comments and suggestions, obtained from P. Bobrowski, D. M. Cruden, M. Jakob, J. King, N. Skermer, D. F. VanDine and two anonymous reviewers.

REFERENCES


Table 5. Translation matrix for landslides of the flow type.

<table>
<thead>
<tr>
<th>Varnes (1978)</th>
<th>Hutchinson (1988)</th>
<th>Recommended (see Table 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet sand, silt flow</td>
<td>Flow slide</td>
<td>Sand, silt flow slide</td>
</tr>
<tr>
<td>Rapid earth flow</td>
<td>Flow slide (clay)</td>
<td>Clay flow slide</td>
</tr>
<tr>
<td>Loess flow</td>
<td>Flow slide (loess)</td>
<td>Loess flow slide</td>
</tr>
<tr>
<td>Dry sand flow</td>
<td>Mudslide</td>
<td>Dry sand flow</td>
</tr>
<tr>
<td>Earth flow</td>
<td>Mudflow</td>
<td>Earth flow</td>
</tr>
<tr>
<td>Rock avalanche</td>
<td>Hillslope debris flow</td>
<td>Mud flow</td>
</tr>
<tr>
<td>Debris avalanche</td>
<td>Debris flow</td>
<td>Debris avalanche</td>
</tr>
<tr>
<td></td>
<td>Hyperconcentrated flow</td>
<td>Debris flow</td>
</tr>
<tr>
<td></td>
<td>Sturzstrom</td>
<td>Rock avalanche</td>
</tr>
</tbody>
</table>
Classification of Landslides


Casagrande, A., 1936, Characteristics of Cohesionless Soils Affecting the Stability of Slopes and Earth Sills, Contributions to Soil Mechanics, 1925-1940: Boston Society of Civil Engineers.


Horton, O., 1990, Mobility of Rock Avalanches: Reports of the National Research Institute for Earth Science and Disaster Prevention, Tsukuba, Japan, Vol. 46, pp. 11-20.


Hungr and others

King, J., 2000, personal communication, Geotechnical Engineering Office, Hong Kong.