The Working Classification of Landslides: material matters

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ABSTRACT
The nomenclature established by the Working Party for World Landslide Inventory has become the basis for an emerging consensus on landslide classification. This Working Classification encompasses seven mutually exclusive descriptors of the state of activity of the landslide, seven of the distribution of movements and five to describe the style of activity. The velocity of the movements can be described from an open-ended, seven division scale, ranging from extremely slow to extremely rapid. The material displaced may be rock, debris or earth with a range of four qualitatively-estimated water contents. We suggest additions to the Classification, additional states of activity preceding displacements and inclusion of frozen water in the description of water content. An International Standard allows earth to be divided into sand, silt, and clay. Careful documentation of these additions would lead to more comprehensive landslide characterization and better management of landslide risk.

RÉSUMÉ
La terminologie établie par le Working Party for World Landslide Inventory est devenue le fondement d'un concensus émergeant sur la classification des glissements de terrain, la 'Classification en évolution'. Cette classification comprend sept identificateurs mutuellement exclusifs sur l'état d'activité, sept sur la distribution de l'activité et cinq décrivant le style d'activité. La vitesse de déplacement peut être illustrée à l'aide d'une échelle ouverte à sept divisions, d'extrêmement lent à extrêmement rapide. Le matériau déplacé peut être du roc, des débris, ou du sol, et accompagné de quatre identificateurs qualitatifs de la teneur en eau. Nous suggérons l'ajout d'états d'activité additionnels précédents le mouvement d'un glissement de terrain et l'inclusion du terme gelé aux descripteurs de la teneur en eau. Une norme internationale permet de diviser le sol entre sable, silt et argile. Une documentation détaillée de ces additions pourrait mener à une caractérisation plus complète des glissements de terrain et à une meilleure gestion de leur risque.

1 INTRODUCTION

Suppose you are sent to investigate a landslide. What can you usefully observe? How can these observations be succinctly and unambiguously described? These are questions which have found answers in classifications of landslides. The International Union of Geological Sciences (IUGS) Working Group on Landslides has developed an international consensus on landslide classification which has been summarized in the Multilingual Landslide Glossary (WP/WLI 1993b). This classification, the Working Classification, has been used in the latest edition of the Transportation Research Board's Special Report on landslides (Turner & Schuster 1996) to update Varnes' (1978) widely-used classification of landslides.

The criteria used in the description of the landslides (Cruden & Varnes 1996) follow Varnes (1978) in emphasizing type of movement and type of material. We have not included here supplementary references given in those reports. A landslide can be described by a word describing the material and a second word describing the type of movement. The divisions of materials are unchanged from Varnes (1978): rock, debris and earth. Movements have again been divided into five types: falls, flows, slides, spreads and topples. The sixth type proposed by Varnes (1978), complex landslides, has been dropped from the formal classification though the term "complex" has been retained as a description of the style of activity of a landslide. Complexity can also be indicated by combining the five types of landslide in the ways suggested below.

The name of a landslide can become more elaborate as more information about movement becomes available. Adjectives can be added in front of the noun string defining the type of landslide to build up the description of the movement. A preferred sequence of terms in naming the movement which indicates a progressive narrowing of the focus of the descriptors, first in time, then in space, from a view of the whole landslide to parts of the movement and to the materials involved, would follow a typical landslide reconnaissance. The recommended sequence (WP/WLI 1990), Activity, Rate of Movement, Water Content, Material, Type of Movement, is the sequence of Sections in this paper.

If descriptors of second or subsequent movements in complex or composite landslides are the same as those for the first movement, they may then be omitted from the name. The Frank Slide, for instance, was a complex, extremely rapid, dry rock-fall debris-flow. The sequence of types of movement, fall then flow, indicates the sequence of movements in the landslide; the addition of the "complex" descriptor to the name distinguishes the landslide from a composite rock-fall debris-flow. The full name of the Frank Slide implies that the debris flow was both extremely rapid and dry as those descriptors are used for the initial rock-fall. The full name of the landslide need only be given once; subsequent references should then be to the initial material and type of movement as in "the rock fall" for the landslide at Frank.

The Working Classification of Landslides is open. We believe the Working Party's terms, "preparatory" and "marginal" along with "repaired" are useful descriptors of states of activity. Adding "frozen" and 'thawed' to water content descriptors would allow the description of landslides in permafrost (in Capital letters in Table 1).

Table 1. Descriptive terms for forming names of landslides (modified after Cruden and Varnes 1996).

Activity State	**Distribution**	**Style**
PREPARATORY	Advancing	Complex
MARGINAL	Retrogress.	Composite
Active	Widening	Multiple
Reactivated	Enlarging	Successive
Suspended	Confined	Single
Inactive	Diminishing	
Dormant	Moving	
Abandoned		
Stabilized		
REPAIRED		
Relict		

Rate	**Water Content**	**Material**	**Type**
Extrem. rapid	Dry	Rock	Fall
Very rapid	Moist	Soil	Topple
Rapid	Wet	Earth	Slide
Moderate	Very wet	SAND	Spread
Slow	FROZEN	SILT	Flow
Very slow	THAWED	CLAY	
Extrem. slow		Debris	

2 ACTIVITY

Under activity, broad aspects of landslides are described, those aspects that should focus the initial reconnaissance of movements before more detailed examination of materials displaced (WP/WLI 1993 a, b). The terms Varnes (1978) considered relating to age and state of activity with some of the terms from sequence or repetition of movement have been regrouped under three headings; State of Activity which describes what is known about the timing of movements, Distribution of Activity, which describes broadly where the landslide is moving, and Style of Activity, which indicates how different movements contribute to the landslide.

2.1 State of activity

Active landslides are those that are currently moving. Landslides which have moved within the last annual cycle of seasons but which are not moving at present were described by Varnes (1978) as suspended. A landslide which is again active after being inactive may be called reactivated.

Inactive landslides are those which have last moved more than one annual cycle of seasons ago. This state can be subdivided. If the causes of movement apparently remain, then the landslides are dormant. Perhaps, however, the river which had been eroding the toe of the moving slope has itself changed course and the landslide is abandoned. If the toe of the slope had been protected against erosion by bank armoring or other artificial remedial measures have stopped the movement, the landslide can be described as stabilized. Landslides often remain visible in the landscape for thousands of years after they have initially moved. Landslides which have clearly developed under different geomorphological or climatic conditions perhaps thousands of years ago can be called relict.

Discussing the causes of landslides, WP/WLI (1994) distinguished preparatory causes from triggering causes. Preparatory causes affect stable slopes, tending to reduce their stability towards marginally stable states. In a marginally stable state, a triggering cause may initiate movement of a slope. These different states of activity, preparatory and marginal, can be placed in Hutchinson's (1973, Figure 5) cycle of successive stages of the behaviour of London Clay cliffs subject to strong toe erosion. Our Figure 1 shows preparatory activity at Stage 1 in the cycle. Marginal activity occurs at Stage 1.5, between Stage 1 and Stage 2. At Stage 2 the slope is active. When the slope is marginal the surface of rupture of the slide is forming and growing in length as softening processes destroy cohesion.

Keegan et al. (2007, Table 4) suggested that the marginal state of activity was similar to the suspended state. Slopes in both these states "will fail at some time in response to destabilizing processes…triggering causal factors [had been] identified that can make the [slopes] actively unstable."

The preparatory state of activity is similar to the dormant and repaired states of activity where destabilizing processes at present are insufficient to cause failure. So monitoring is required only to check that there is little change in the state of activity. The repaired state is a new name for the " stabilized recently " state defined by Keegan et al. (2007); artificial remedial measures have stopped movements within the last cycle of seasons. With the passage of years, the repair may become regarded as a slope stabilization and the state of activity of the slope changed to stabilized.

2.2 Distribution of activity

Varnes (1978) defined a number of terms that can be used to describe the activity distribution in a landslide. Movement may be limited to the displacing material or the rupture surface may be enlarging, continually adding to the volume of displacing material. If the rupture surface is extending in the direction opposite to the movement of the displaced material, the landslide is said to be retrogressing. If the rupture surface is extending in the direction of movement the landslide is advancing. If the rupture surface is extending at one or both lateral margins, the landslide is widening. Confined movements have a scarp but no rupture surface visible in the foot of the displaced mass; displacements in the head of the displaced mass are taken up by compression and slight bulging in the foot of the mass. If the rupture surface of the landslide is enlarging in two or more directions, Varnes (1978, p. 23) suggested the term progressive for the landslide while noting this term had also been used for both advancing and retrogressing landslides. This term is also current for describing the process, progressive failure, by which the rupture surface in some slides extends. The possibility of confusion seems sufficient now to abandon "progressive" in favour of describing the landslide as enlarging.

To complete the possibilities, terms are needed for landslides in which the volume of displacing material can be seen to be reducing with time and for those landslides where no trend is obvious. Movements such as rotational slides and topples may stop naturally after substantial displacements because the movements themselves reduce the gravitational forces on the displaced masses. Alternatively, rock masses may be dilated by movements that rapidly increase the volumes of cracks in the masses and cause decreases in fluid pore pressures within these cracks. However, to conclude that the displacing mass is stabilizing because its volume is decreasing may be premature; the activity of rotational slides caused by erosion at the toe of slopes in cohesive soils is often cyclic. The term, diminishing, for a landslide whose displacing material is decreasing in volume seems free of undesired implications. Landslides whose displaced materials continue to move but whose rupture surfaces show no visible changes can be simply described as moving.

2.3 Style of activity

The way in which different movements contribute to the landslide, the style of the landslide activity, can be described by terms from Varnes (1978, p. 23). There, complex landslides are defined as exhibiting at least two types of movements. We propose to limit the term here to movements in which the types are in sequence; a topple in which some of the displaced mass subsequently slid is a complex rock-topple rock-slide. Not all the toppled mass slid but no significant part of the displaced mass slid without first toppling. Notice that some of the displaced mass may be still toppling while other parts are sliding.

We can use a former synonym of complex, composite, to describe landslides in which different types of movement occur in different areas of the displaced mass, sometimes simultaneously. These different areas of the displaced mass show different sequences of movements. WP/WLI (1993 a, b) adopted the convention of treating the higher of the two movements as the first movement and the lower of the two movements as the second movement in the absence of more definite information.

A multiple landslide shows repeated movements of the same type, often following the enlargement of the rupture surface. The newly displaced masses are in contact with previously displaced masses and often share a rupture surface with them. In a retrogressive, multiple, rotational slide, two or more blocks have each moved on curved rupture surfaces tangential to a common generally deep rupture surface.

A successive movement is identical in type to an earlier movement but in contrast to a multiple movement it does not share displaced material or a rupture surface with it.

Single landslides consist of a single movement of displaced material often as an unbroken block. They contrast with the other styles of movement which require disruption of the displaced mass or independent movements of portions of the mass.

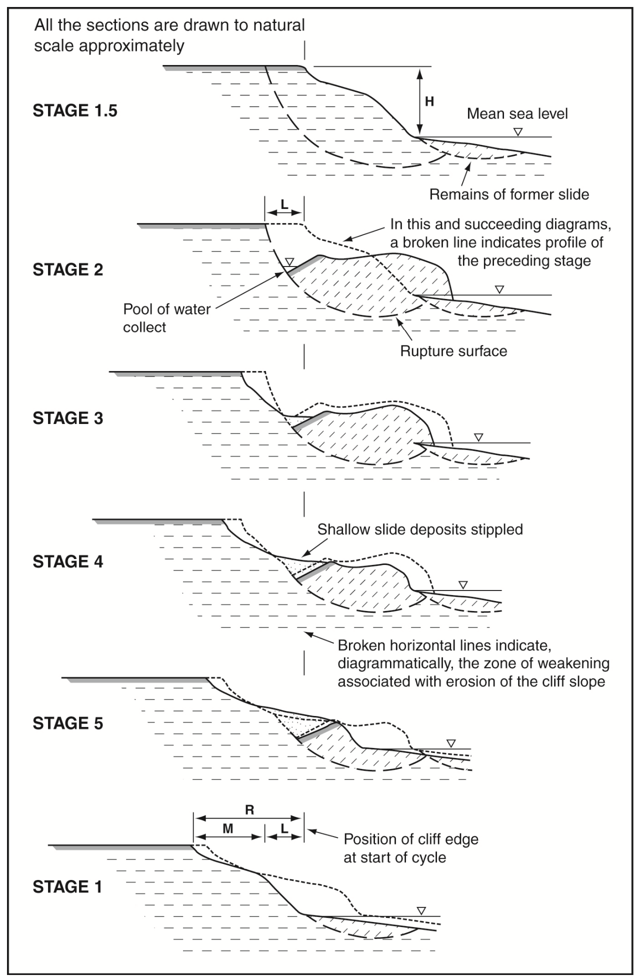


Figure 1. Successive stages in the cyclic behaviour of London Clay cliffs subjected to strong toe erosion (adapted from Hutchinson 1973

3 RATE OF MOVEMENT

The IUGS Working Group (1995) modified the rate of movement scale given in Varnes (1978, Figure 2:1 u). The seven divisions of the scale are now adjusted to increase in multiples of 100 by slightly increasing the uppermost limit of the scale and decreasing the lowest limit of the scale. These two limits span ten orders of magnitude (from 0.5x10-6 to 5x103 mm/sec).

An important division between very rapid and extremely rapid movement, approximates the speed of a person running (5 m/sec.). Another important boundary is between the slow and very slow classes (1.6 m/year), below which some structures on the landslide are undamaged. Terzaghi (1950, p. 84) identified slope movements "proceeding at an imperceptible rate" as "creep". The many uses of the term "creep" have been discussed by Varnes (1978, p. 17), the term is now too ambiguous for general use and should be replaced by the appropriate modifiers, either very slow or extremely slow, applied to the other landslide descriptors.

4 WATER CONTENT

Varnes (1978) suggested four terms derived from simple observations of the water content of the displaced material: 1) Dry, no moisture, 2) Moist, contains some water but no free water, the material may behave as a plastic solid but does not flow, 3) Wet, contains enough water to behave in part as a liquid, has water flowing from it, or supports significant bodies of standing water, and 4) Very wet, contains enough water to flow as a liquid under low gradient. A fifth term, 5) Frozen, was suggested by Cruden and Couture (2010) for use in permafrost terrains

As most slope instabilities in permafrost terrain result from or are directly related to the phase change of water, it may be worth introducing the term ‘thawed’, which better expresses the state of the ground and its water content while landsliding. In the ‘thawed’ state, or in the transition from frozen to ‘thawed’, such terrain provides significant amounts of water in a liquid phase that contribute to slope instability (Figure 2).

These terms should be used to describe the masses displaced by the landslide. The water content of the displaced masses may give useful guidance for assumptions about the water content of the displacing materials while the materials were displacing. However soil or rock masses may drain quickly after displacement and individual rock or soil masses may have water contents which differ considerably from the average water content of the displacing material. In some fine-grained soils, the boundaries between the terms may correspond approximately with Atterberg Limits, the Shrinkage, Plastic and Liquid Limits separating dry, moist, wet and very wet soils respectively.

5 MATERIAL

The Working Party followed Varnes (1978) in describing materials in landslides as either rock, a hard or firm mass that was intact and in its natural place before the initiation of movement, or soil, an aggregate of solid particles generally of minerals and rocks which has either been transported or formed by the weathering of rock in place. Gases or liquids filling the pores of the soil form part of the soil.

Soil is divided into debris and earth. Debris contains a significant proportion of coarse material; 20 to 80 percent of the particles are larger than 2 mm, the remainder are less than 2 mm. Earth describes material in which 80 percent or more of the particles are smaller than 2 mm; it includes a range of materials from non-plastic sand to highly plastic clay.

In the absence of international standards, the Working Party was unable to progress beyond this simple division. With the adoption of an International Standard (ISO 14688-1) for the identification and description of soil, some further observations may be useful during the reconnaissance of the landslide. Flow charts have been developed for the identification and description of soils (Figure 3; Norbury 2010, Figures 4.1 and 4.3).

a)


b)

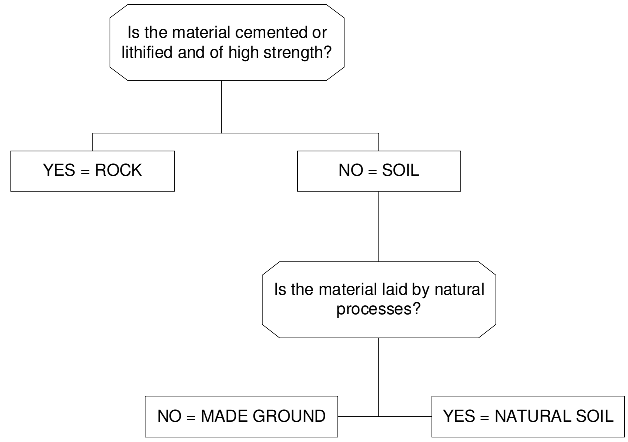
Figure 2. a) Retrogressive thaw flows are retrogressive, complex, slow, 'thawed', moist, earth slide-wet earth flows in the Working Classification (GSC-ESS Photo No. 2007-51; Photographer: R. Couture). b) A bimodal flow or retrogressive thaw flow is a retrogressive, complex, moderate, 'thawed' earth slide-very wet, earth flow in the Working Classification (GSC-ESS No. Photo 2007-59; Photographer: R. Couture).

They first distinguish materials, made ground, organic soil, and volcanic soil by the way in which they are formed (Figure 3a). These materials have been the subjects of specialized studies by construction, transportation, and forestry engineers and by volcanologists among others (Keegan 2007; MacFarlane 1969; Francis 1993) Specialized terminologies exist for describing particular types of landslides that occur in these materials. The merging of these terminologies with the Working Classification awaits further study.

It is interesting however to ask whether the grain size description of materials advocated in the remaining part of the flow diagram might also be usefully applied to these materials (Figure 3b). Keegan et al. (2007) suggested this possibility.

The International Standard (ISO 14688-1) divided soils into cohesive (fine) and cohesionless (coarse) soils. Fine soil can be conveniently divided into silts and clays by the qualitative observations of plasticity, dilatancy and other properties.

a)



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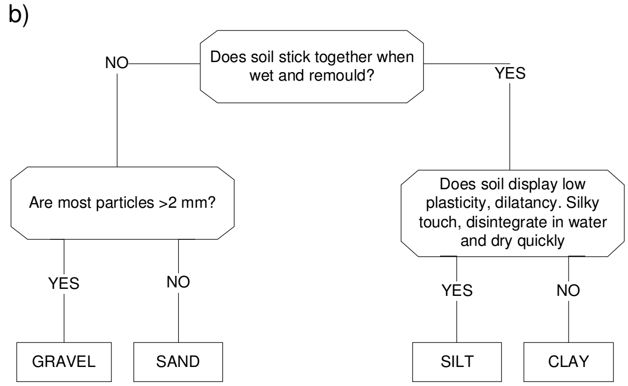

Figure 3. Flow charts for the identification of soils (adapted from Norbury 2010, Figs. 4.1 and 4.3).

So, when a uniform soil is displaced in an earth landslide, it should be possible to readily classify the material as debris, sand, silt, or clay by inspection of either the margins or main scarp of the landslide or of undeformed material amid the landslide deposits (Figure 4). As examples of this practice, Varnes (1978, Figures 2:24, 2:25) and Hungr et al. (2001, Figures 5, 6) have illustrated both sand and silt flows.

6 TYPES OF MOVEMENT

In this section, the five kinematically-distinct types of landslides are described in the sequence, fall, topple, slide, spread and flow.

A fall starts with the detachment of soil or rock from a steep slope along a surface on which little or no shear displacement takes place. The material then descends largely through the air by falling, saltation or rolling. Movement is very rapid to extremely rapid. Except when the displaced mass has been undercut, falling will be preceded by small sliding or toppling movements which separate the displacing material from the undisturbed mass. Under-cutting typically occurs in cohesive soils or rocks at the toe of cliffs undergoing wave attack or in the eroding banks of rivers.

A topple is the forward rotation out of the slope of a mass of soil or rock about a point or axis below the centre of gravity of the displaced mass. Toppling is sometimes driven by gravity exerted through material upslope of the displaced mass, and sometimes through water or ice in cracks in the mass. Topples may lead to falls or slides of the displaced mass depending on the geometry of the moving mass, of the surface of separation and the orientation and extent of the kinematically-active discontinuities. Topples range from extremely slow to extremely rapid, sometimes accelerating throughout the movement.

A slide is a downslope movement of a rock mass occurring dominantly on surfaces of rupture or relatively thin zones of intense shear strain. Movement is usually progressive; it does not initially occur simultaneously over the whole of what eventually becomes the surface of rupture, it propagates from an area of local failure. Often the first signs of ground movement are cracks in the original ground surface along which the main scarp of the slide will form. The displaced mass may slide beyond the toe of the surface of rupture covering the original ground surface of the slope which then becomes a surface of separation.

We define a spread as an extension of a cohesive soil or rock mass combined with a general subsidence of the fractured mass of cohesive material into softer underlying material. The rupture surface is not a surface of intense shear. Spreads may result from liquefaction or flow (and extrusion) of the softer material. Varnes (1978) distinguished spreads, typical of rock, which extended without forming an identifiable rupture surface from movements in cohesive soils overlying liquefied materials or materials which are flowing plastically. The cohesive materials may also subside, translate, rotate, disintegrate or liquefy and flow. Clearly these movements are complex but they are sufficiently common in certain materials and geological situations that a separate type of movement is worth recognizing.

A flow is a spatially continuous movement in which surfaces of shear are short-lived, closely spaced and not usually preserved. The distribution of velocities in the displacing mass resembles that in a viscous liquid. The lower boundary of the displaced mass may be a surface along which appreciable differential movement has taken place or a thick zone of distributed shear. There is then a gradation from slides to flows depending on the water content, mobility and evolution of the movement. Debris slides may become extremely rapid debris flows, debris avalanches, as the displaced material loses cohesion, gains water or encounters steeper slopes.

a)

b)

Figure 4. a) May 10th, 2010 St-Jude (QC) clay spread in Champlain Sea cohesive, fine sediments (Photo RNCan #2010-152; Photographer: R. Couture). b) 1996 Lemieux (ON) silt and clay flow in fine Champlain Sea deposits (Photo RNCan # 2002-690; Photographer: G.R. Brooks).

7 SUMMARY

An initial reconnaissance of a landslide might be expected to describe the activity and the materials displaced in this particular type of landslide. This format lends itself to the creation of simple databases suited to much of the database management software now available. The information collected can be compared with summaries of other landslides (WP/WLI 1991) and used to guide further investigations and mitigative measures. Further investigation increases the precision of estimates of the dimensions and confidence in the descriptions of activity and material and in the hypotheses about causes of the movement. The new information may finally be added to the database to influence the analysis of further landslides. These databases can be expected to form the foundations of systems for landslide mitigation and landslide risk assessment (Cruden & Fell 1997). The Working Classification of Landslides would benefit from the additional States of Activity, preparatory, marginal and repaired. Frozen as a descriptor of water content would allow the characterization of landslides in permafrost. According to an International Standard, earth may be divided into sand, silt or clay by simple field observations. More study may allow landslides in made ground and in organic and volcanic soils to be incorporated in the Working Classification.

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REFERENCES

Cruden, D.M. & Fell, R. (eds) 1997. *Landslide Risk Assessment*. Balkema, Rotterdam, 370 pages.

Cruden, D.M., Couture, R., 2010 More comprehensive characterization of landslides : Review & additions Proceedings, 11th IAEG Congress, Auckland, New Zealand, pp 1033-1042

Cruden, D.M. & Varnes, D.J. 1996. Landslide Types and Processes. In Turner, A.K., Schuster, R.L. (eds), *Landslides: Investigation and Mitigation*, Transportation Research Board, Special Report, 247: 36-75.

Francis, P. 1993. *Volcanoes: A Planetary Perspective*, Clarendon Press, Oxford, 443 pages.

Hungr, O., Evans, S.G., Bovis, M.J., Hutchinson, J.N., 2001, A review of the classification of landslides of the flow type, Environmental & Engineering Geoscience, 7, 221-238

Hutchinson, J.N. 1973. The response of London Clay Cliffs to differing rates of toe erosion. *Geologia Applicata e idrogeologica*, 8: 221-239.

International Organization for Standardization, 2002, Geotechnical investigation, 2002, Geotechnical investigation and testing – Identification and classification of soil – Part 1: Identification and description, ISO 14688-1 12 p.

International Union of Geological Sciences Working Group on Landslides 1995. A suggested method for describing the rate of movement of a landslide. *Bulletin International Association of Engineering Geology*, 52: 75-78.

Keegan, T. 2007. *Methodology for Risk Analysis of Railway Ground Hazards*. Ph.D. thesis, University of Alberta, Edmonton, 446 pages.

Keegan,T., Cruden,D.M., Martin,C.D., Morgenstern,N., Ruel,M. & Pritchard,M. 2007. A railway ground hazard risk management methodology overview. *Proceedings of the 60th Canadian geotechnical conference, Ottawa, 21-24 October, 2007*: 8 pages .

MacFarlane, I.C. 1969. *Muskeg Engineering Handbook*. University of Toronto press, Toronto, 297 pages.

Norbury D. 2010. Soil and Rock Description in Engineering Practice. CRC Press 283 pages.

Terzaghi, K. 1950. Mechanism of landslides. In S. Paige (ed.*), Application of Geology to Engineering Practice*, Geological Society of America, New York: 83-123.

Turner, A.K. & Schuster, R.L. (eds) 1996. *Landslides: Investigation and Mitigation*. Transportation Research Board, Special Report 247.

Varnes, D.J. 1978. Slope movement types and processes. In R.L. Schuster and R.J. Krizek (eds), *Landslides: Analysis and Control*. Transportation Research Board, National Academy of Sciences, Washington, D.C.

WP/WLI (International Geotechnical Societies' UNESCO Working Party on World Landslide Inventory) 1990. A suggested method for reporting a landslide. *Bulletin International Association of Engineering Geology*, 41: 5-12.

WP/WLI (International Geotechnical Societies' UNESCO Working Party on World Landslide Inventory) 1991. A suggested method for a landslide summary. *Bulletin International Association of Engineering Geology*, 43: 101-110.

WP/WLI (International Geotechnical Societies' UNESCO Working Party on World Landslide Inventory) 1993a. A suggested method for describing the activity of a landslide, Bulletin International Association of Engineering Geology, 47: 53-57.

WP/WLI (International Geotechnical Societies' UNESCO Working Party on World Landslide Inventory) 1993b. *Multilingual Landslide Glossary*. Bitech Publishers, Richmond, British Columbia, 59 pages.

WP/WLI (International Geotechnical Societies' UNESCO Working Party on World Landslide Inventory) 1994. A suggested method for describing the causes of a landslide. *Bulletin International Association of Engineering Geology*, 50: 71-74.