Regions and Themes / Régions et thèmes

Articles

Geological Survey of Canada

CURRENT RESEARCH
2006-A9

Landslide processes in the south-central Mackenzie River valley region, Northwest Territories

David Huntley and Alejandra Duk-Rodkin

2006

Natural Resources Canada   Ressources naturelles Canada

Canada

CURRENT RESEARCH

ISSN 1701-4387
Catalogue No. M44-2006/A9E-PDF
ISBN 0-662-43559-1

A copy of this publication is also available for reference by depository libraries across Canada through access to the Depository Services Program's Web site at http://dsp-psd.pwgsc.gc.ca

A free digital download of this publication is available from GeoPub: http://geopub.nrcan.gc.ca/index_e.php

Toll-free (Canada and U.S.A.): 1-888-252-4301

Critical reviewers
R. Couture
R. Klassen

Authors' addresses

David Huntley (dhuntley@nrcan.gc.ca)
Alejandra Duk-Rodkin (adukrodk@nrcan.gc.ca)
GSC Calgary
Geological Survey of Canada
3303–33rd Street NW
Calgary, Alberta T2L 2A7

Publication approved by GSC Calgary

Original manuscript submitted: 2006-03-28
Final version approved for publication: 2006-04-06

Correction date:

Landslide processes in the south-central Mackenzie River valley region, Northwest Territories

David Huntley and Alejandra Duk-Rodkin

Huntley, D. and Duk-Rodkin, A., 2006: Landslide processes in the south-central Mackenzie River valley region, Northwest Territories; Geological Survey of Canada, Current Research 2006-A9, 7 p.

Abstract: As part of the Northern Energy Development Mackenzie Valley Project, an inventory of terrain, landforms and geomorphic processes is currently being compiled for the Camsell Bend (NTS 95 J), Root River (NTS 95 K), Dahadinni River (NTS 95 N), and Wrigley (NTS 95-O) 1:250 000 scale map sheets. This database will provide insight into the types of landslides and their geological setting, dimensions, age, distribution, activity, and density in the study area. The landslide data recorded by this study will provide calibration for future predictive mapping and hazard analyses in the Mackenzie River valley transportation corridor.

Résumé : Dans le cadre du projet de la vallée du Mackenzie visant le développement de l'énergie dans le Nord, nous procédons actuellement à la compilation d'un inventaire du terrain, des formes de relief et des processus géomorphologiques dans les régions visées par les cartes suivantes à l'échelle du 1/250 000 : Camsell Bend (SNRC 95 J), Root River (SNRC 95 K), Dahadinni River (SNRC 95 N) et Wrigley (SNRC 95-O). Cette base de données fournira un aperçu des types de glissements de terrain dans la région à l'étude, de leur contexte géologique, de leurs dimensions, de leur âge, de leur répartition, de leur activité et de leur densité. Les données sur les glissements de terrain consignées dans le cadre de cette étude serviront de données d'étalonnage pour les futures activités de cartographie prévisionnelle et d'analyse des risques dans la voie de communication de la vallée du Mackenzie.

INTRODUCTION

Geological and geomorphological studies in the Mackenzie River valley region by the Geological Survey of Canada (GSC) provide valuable information on bedrock, surficial deposits, permafrost, and landslides for the Northern Energy Development Mackenzie Valley Project. These data are essential for effective land management decisions regarding pipeline, highway, and settlement construction, and the extraction of aggregate and groundwater resources in the region (Fig. 1). Current research (e.g. DiLabio, 2005; Couture et al., 2005; Huntley and Duk-Rodkin, 2005; Pyle et al., 2005; Sidwell et al., 2005; Smith et al., 2005; Wang et al., 2005) builds on legacy terrain data (e.g. Aylsworth et al., 2000a, b; Dyke, 2000; Heginbottom, 2000; Ayslworth and Traynor, 2001; Duk-Rodkin and Hood, 2004), and will be applicable to a wide range of end users. The focus in this paper is on landslides as geoindicators of slope instability in the Mackenzie River valley transportation corridor and adjacent areas.

Regional physiographic setting

During the 2005 field season, surficial deposits and landslides were described and mapped in the Camsell Bend (NTS 95 J), Root River (NTS 95 K), Dahadinni River (NTS 95 N), and Wrigley (NTS 95-O) 1:250 000 NTS map sheets. The study area comprises three major physiographic elements (Fig. 2):

A) Mackenzie Mountains and McConnell Range (Franklin Mountains): montane terrain with exposed folded and thrust-faulted carbonate and clastic sedimentary rocks, characterized by high relief and steep slopes (Fig. 3).

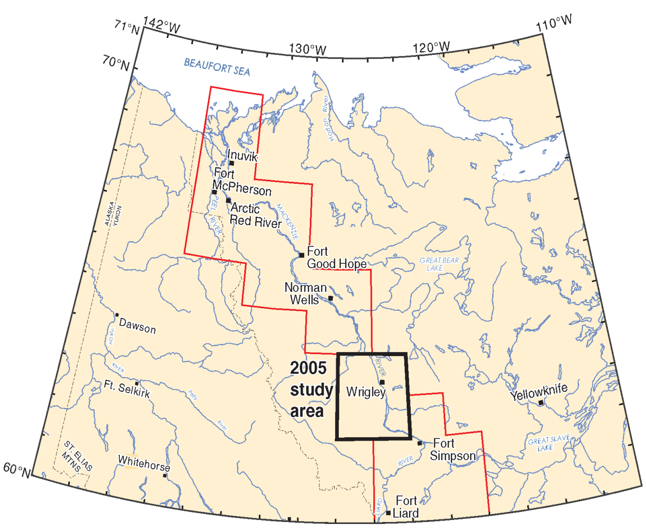

Figure 1. Limits of the Northern Energy Development Mackenzie Valley Project and location of the 2005 study area.

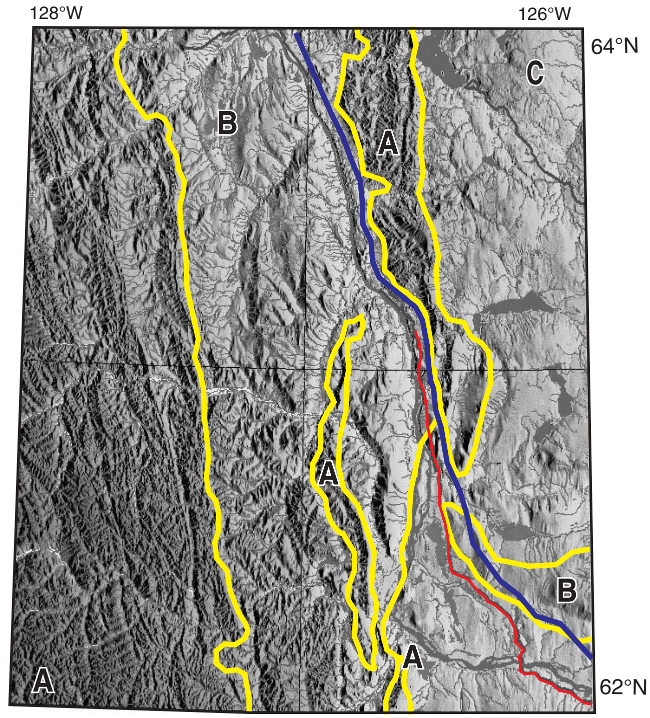

Figure 2. Generalized physiography of the south-central Mackenzie River valley region, Northwest Territories: **A**) montane terrain, **B**) foothills and intermontane plateaus, **C**) plains (*modified from* Duk-Rodkin and Lemmen, 2000). Symbols: red line, Mackenzie Highway; blue line, proposed pipeline route (AMEC Americas Limited, 2005).

B) Mackenzie Lowland: drift-covered foothills and intermontane plateaus, underlain by folded and faulted weak shale, limestone, and sandstone, and deeply incised by tributaries draining to the Mackenzie River (Fig. 3).

C) Great Slave Plain: till and glaciolacustrine plains blanketed by outwash and extensive organic deposits, and overlying relatively undeformed shale, sandstone, and limestone (Fig. 3).

TERRAIN AND LANDSLIDE MAPPING

To better understand landslide processes and their impacts, an important terrain-mapping objective was to identify and classify individual and groups of landslides. Surficial geology and applied terrain maps to be produced as part of this study will provide an objective quantitative inventory of landslide hazards, showing the range, distribution, and magnitude of events by the number and size of mass movements (cf. Aylsworth and Traynor, 2001; Duk-Rodkin and Hood, 2004). These maps can be applied at a later date to more elaborate landslide-hazard analyses, including the spatial probability of occurrence, magnitude, and intensity of landslides in the initiation zone, and the extent and nature of landslide run-out. Landslide risks can also be derived from the landslide-hazard maps by including elements at risk, vulnerability, and consequence in the Mackenzie River valley transportation corridor.

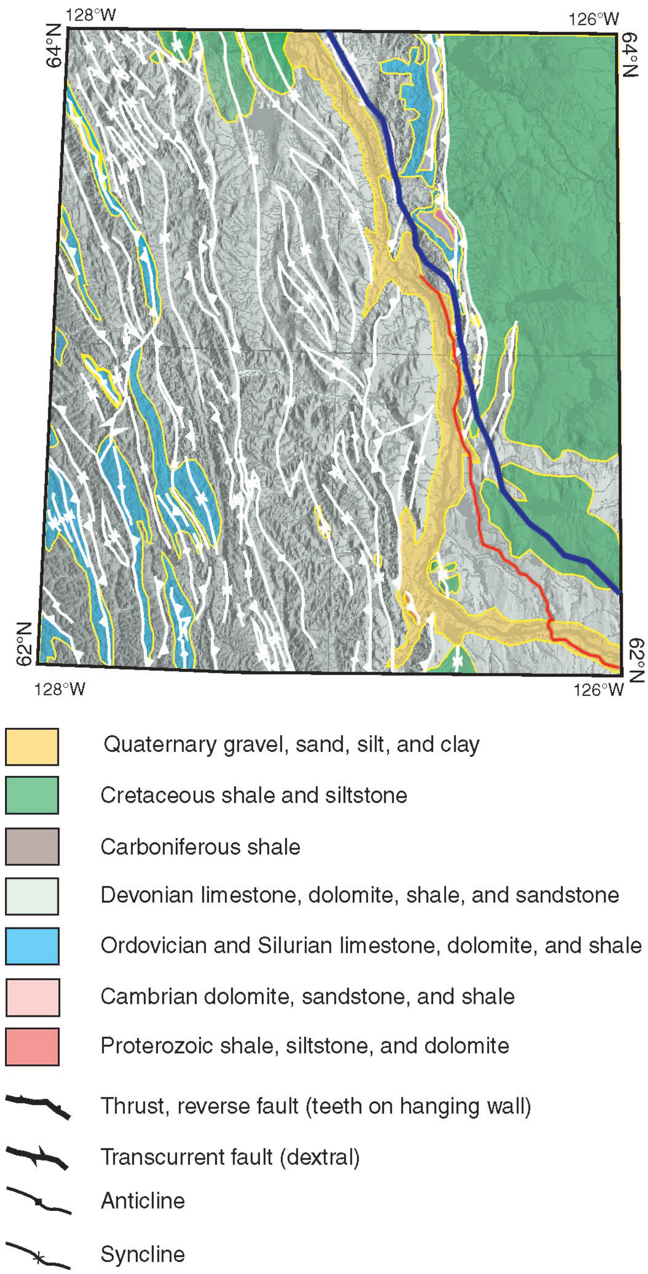

Figure 3. Simplified geology of the south-central Mackenzie River valley region, Northwest Territories (*modified after* Douglas and Norris, 1976a–d; Okulitch, work in progress, 2006), showing the Mackenzie Highway (red line) and proposed pipeline route (blue line; AMEC Americas Limited, 2005). *See* Tables 1 to 3 for explanation of terrain-classification symbols.

Terrain and landslide classification

Surficial units, landforms, and geomorphic processes were pre-typed onto 1:40 000 to 1:60 000 scale black-and-white stereopair airphotos (from 1947, 1961, and 1971). Selected polygons were benchmarked during the 2005 field season. At more than 800 ground-control stations, surficial deposits were defined on the basis of landform associations, texture, sorting, fissility, colour, sedimentary structures, consolidation, presence of permafrost, and contact relationships. After revising the pre-typed airphotos, polygon linework and onsite symbols were digitized in ArcMap and terrain labels transcribed into a corresponding database. When combined with georeferenced field data, the resulting geographic information system will be used to generate a range of applied terrain products, including landslide-hazard maps.

Landslide events and terrain modified by mass wasting were classified according to type of earth material involved (e.g. bedrock or surficial deposits), rate of movement, presence of permafrost, nature of movement and associated processes (e.g. fall, topple, flow, slide, spreading), status of activity (i.e. active or stable), triggering mechanism(s), aspect, and dimensions. Other data captured during landslide pre-typing included information on bedrock and geological structures (strike directions of faults and fold axes). Landform, surficial-unit, and geomorphic-process codes (Tables 1–3) used in this study are derived from

Table 1. Earth-material classification for the south-central Mackenzie River valley region, Northwest Territories.

Map symbol	Earth material
A	Alluvial
C	Colluvial
E	Eolian
G	Glaciofluvial
L	Glaciolacustrine
O	Organic
R	Bedrock
T	Moraine (till)
U	Undifferentiated

Table 2. Surface-expression classification for the south-central Mackenzie River valley region, Northwest Territories. *See* Table 4 for hazard rating.

Map symbol	Surface expression	Description
Sediment depth		
b	Blanket (>2 m)	
v	Veneer (<2 m)	
Surface forms		
p	Plain (<5%)	Planar surface
t	Terrace	Single/stepped platform
(G) d	Delta	Fan to irregular platorm
(T) d	Drumlin	Elongated hillock >1 m
f	Fan (<26%)	Cone shape
h	Hummock (26–70%)	Local relief >1 m
r	Ridge (26–70%)	Elongated hillocks >1 m
x	Complex	Complex of surface forms

mapping conventions used by the Geological Survey of Canada (e.g. Evans and Savigny, 1994; Aylsworth and Traynor, 2001), the Mackenzie Gas Project Landform Sensitivity Atlas (AMEC Americas Limited, 2005), and terrain analysts in British Columbia and the Yukon (e.g. Varnes, 1978; Cruden and Varnes, 1996; Resource Inventory Committee, 1996; Howes and Kenk, 1997; Huscroft et al., 2004). This classification scheme is specific to the study area and accommodates complex events involving a range of materials and flow regimes over several orders of magnitude and time.

Table 3. Geomorphic-process classification for the south-central Mackenzie River valley region, Northwest Territories. *See* Figure 4 for classification of landslides and periglacial processes.

Process type	Map symbol	Geomorphic process
Fluvial	B	Braiding channel
	M	Meandering channel
Erosional	D	Deflation
	K	Karst processes
	V	Gully erosion
	W	Washing
Mass movement	F	Slow mass movements
	R	Rapid mass movements
Glacial	E	Channeling by meltwater
	H	Kettled
Periglacial	X	Permafrost processes

Table 4. Terrain-stability classification for the south-central Mackenzie River valley region, Northwest Territories.

Slope class	Terrain-stability class definition *Following disturbance of slope by natural events and human modification*
I	No significant slope-stability problem
II	Low likelihood of slope failure
III	Moderate likelihood of slope failure
IV	High likelihood of slope failure
V	Very high likelihood of slope failure

Table 5. Terrain and geomorphic-process associations for the south-central Mackenzie River valley region, Northwest Territories.

Terrain unit	Geomorphic process(es)	Ice content	Drainage	Terrain stability rating
pO, fO	X	20–80 %	Poor	I to V
Ev, Eb, Er	D	Low	Good	I to II
Ax, Ap, Af, Ar	B, M	Low	Good	III to V
Cx, Cz, Cy, Cf, Cb, Cv	F, R, X	Variable	Good	III to V
Lx, Lp, Lt, Lb, Lv	F, R, V, X	10–25 %	Poor	I to V
Gx, Gp, Gt, Gd, Gf	D, F, R, V, X	Low	Good	II to IV
Tx, Td, Tr, Tb, Tv	E, F, R, X	10–25%	Moderate	I to III

Subjective geomorphic analysis

Qualitative terrain-stability classes (Table 4) were assigned to each map polygon based on airphoto interpretation, field observations, previous studies, and experience of the terrain analyst. Terrain stability was defined in terms of predictable changes in terrain and the probability of occurrence of landslides following disturbance (either natural or anthropogenic). Classes were assigned subjectively by the judgmental weighting of the following key terrain attributes observed in a polygon:

- surficial materials
- geomorphic processes, active and inactive
- slope gradient and local relief
- factors such as soil drainage, soil depth, vegetation cover, and fire history
- presence of existing landslides

Terrain-stability classes will be coloured on landslide-hazard maps to distinguish zones of extreme and high landslide hazard (red), zones of moderate hazard (yellow), and zones of little or no perceived hazard (green).

LANDSLIDE ANALYSIS AND GEOMORPHIC MODEL

The interaction between high relief, steep slopes, heavy precipitation, complex tectonic and glacial history, and the nature of surficial deposits and bedrock has produced a variety of landslides along the Mackenzie River valley transportation corridor (Aylsworth and Traynor, 2001; Duk-Rodkin and Hood, 2004; Huntley and Duk-Rodkin, 2005; Couture et al., 2005). Table 5 summarizes the dominant terrain units and geomorphic processes observed in the study area during 2005. Estimates of ice content and nature of drainage are based on field observations and data from adjacent areas (Aylsworth et al., 2000a, b; Dyke, 2000; Heginbottom, 2000). Slope classes were derived from contour intervals and ground measurement at field stations.

The geomorphic model (Fig. 4) developed as part of this study is intended to provide baseline geomorphic information for a range of potential end-users, including research scientists, construction engineers, land-use managers, terrestrial ecologists, and information specialists. The distribution, activity, and density of landslides recorded as part of current research will help calibrate future predictive mapping and hazard analyses in the Mackenzie River valley transportation corridor. Throughout the study area, bedrock and debris slopes exceeding 28% and 30 m in height are potentially unstable. In the Mackenzie Mountains and foothills of the Mackenzie Lowland, rock falls and topples are triggered by gravitational spreading, seismic activity, and weathering processes. Some mountain summits display cryoplanation

TERRAIN CLASSIFICATION and LANDSLIDE CLASSES

Rapid mass movement (R)
Rb Rockfall
Rd Debris flow
Rf Debris fall
Rm Bedrock slide (slump)
Rt Bedrock topple
Ru Debris slide (slump)
Rx Landslide complex

Slow mass movement (F)
Fg Gravitational spreading
Fm Bedrock slide (slump)
Fu Debris slide (slump)
Fx Landslide complex

Permafrost (X)
Xc Cryoplanation
Xe Thermal erosion by water
Xf Retrogressive thaw flow slides
Xk Thermokarst processes
Xz Gelifluction

Other Processes
E Meltwater channel
V Gully erosion

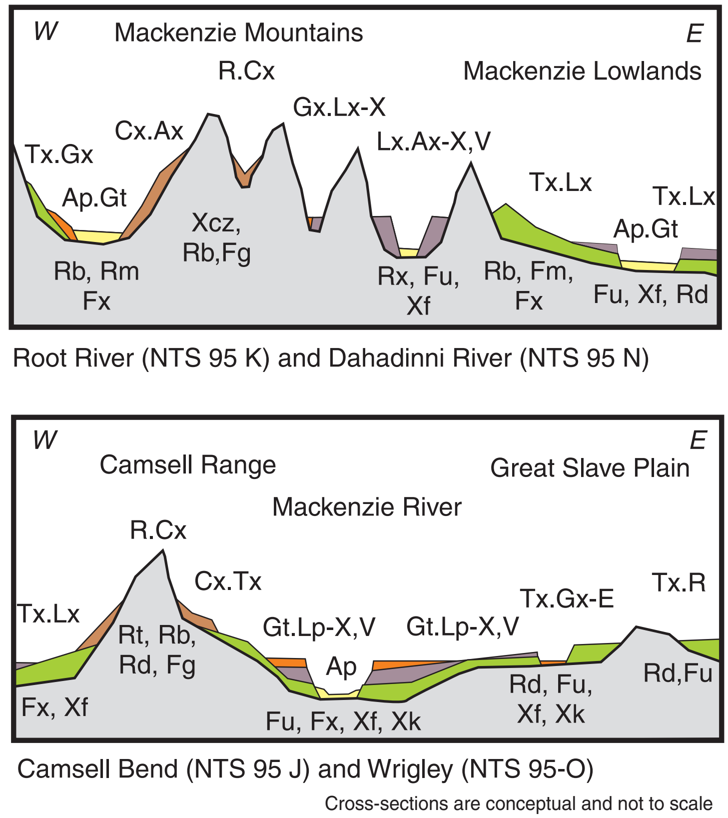

Figure 4. Geomorphic model for the south-central Mackenzie River valley region, Northwest Territories. *See* Tables 1 to 3 for explanation of terrain classification.

surfaces on which weathered bedrock and surficial deposits have been locally remobilized by gelifluction (Fig. 4). In the Mackenzie Lowlands and over the western Great Slave Plain, unfrozen and saturated shale beds can move as saturated debris flows or rock slides. The Devonian Fort Simpson Formation is the rock unit most susceptible to failure. Most landslides, however, occur in glaciolacustrine sediments and fine-grained, ice-rich till. Because of the low shear strength of water-saturated sediments, thawing of ice-rich, fine-grained sediments on gentle slopes (5–27%) usually gives rise to active-layer detachments and retrogressive-thaw flows. Rapid debris flows in fine-grained deposits occur in areas with high relief or where saturated sand deposits occur (Fig. 4).

Along the Mackenzie River and its tributaries, frozen gravel and sand can move as blocks in rotational and translational debris slides, with failure occurring along planes developed in underlying weak, unfrozen, glaciolacustrine clay and silt. Where the height of channel banks and thickness of coarse-grained sediment are greater than the depth of permafrost, groundwater flow below the permafrost and above underlying impermeable deposits gives rise to artesian flow conditions (Aylsworth et al., 2000b; Dyke, 2000). Retrogressive-thaw flows and debris flows may develop if river erosion removes frozen, ice-cemented colluvium at the base of slopes. Thermokarst subsidence and thermal erosion of frozen organic deposits, outwash, and lake sediments by streams will also trigger translational slides along valley floors (Fig. 4).

Dominant factors in triggering landslides and determining the speed of mass movement are the water content of bedrock and surficial material, and the occurrence of melting permafrost. Low water content reduces mass movement by increasing the cohesion of debris and shear strength. Saturating water levels decrease shear strength by increasing pore pressure, which triggers mass movement (Aylsworth et al., 2000b; Dyke, 2000; Couture et al., 2005; Wang et al., 2005). Other controls include distribution and intensity of annual taiga fires, earthquake activity, slope gradient, local relief, aspect of slope, debris thickness over bedrock, orientation of planes of weakness in bedrock, and bioclimatic factors (e.g. ice, precipitation, and vegetation cover).

For the current climate regime, there is a clear relationship between bank erosion and slope channel failure in the Mackenzie River valley (Aylsworth et al., 2000a, b; Dyke, 2000). Channel migration leads to overly steep and undermined riverbanks and terraces, and has triggered numerous complex landslides along the Mackenzie River and its tributaries (Huntley and Duk-Rodkin, 2005; Couture et al., 2005).

Removal of streamside vegetation and soil also leads to active-layer detachments, and retrogressive-thaw flows and slides in ice-rich terrain. Increased channel instability can be expected if there are changes in the amount and timing of precipitation, snow melt, and sediment supply to streams. Rates of bank erosion may increase as rivers adjust their gradients to accommodate changing discharge and sediment loads.

To reduce the possibility of landslides in the transportation corridor, construction should aim to minimally disturb steep slopes at stream and river crossings, and where gently sloping terrain dominated by fine-grained glacial sediment with discontinuous permafrost is indicated on surficial-geology and applied-terrain maps. Wherever possible, construction should employ passive techniques that avoid potentially unstable terrain identified by terrain mapping; installation of piles into permafrost; aggregate pads to insulate subjacent permafrost; and preservation of the protective cover. Nonpassive construction involving the removal of surficial cover to bedrock may be possible in areas where the drift cover is less than 5 m thick.

ACKNOWLEDGMENTS

The authors would like to thank the following for their contribution to this project: GSC Calgary office staff and field crew, the Pehdzeh Ki Dene (Wrigley), and Great Slave Helicopters. The manuscript benefited from critical reviews by Réjean Couture (GSC Ottawa) and Rudy Klassen (GSC Calgary).

REFERENCES

AMEC Americas Limited
2005: Landform sensitivity atlas, Mackenzie Gathering System and Mackenzie Valley pipeline preliminary engineering alignment sheets; submission IPRCC.PR.2005.01 to National Energy Board by Imperial Oil Resources Ventures Limited, scale 1:30 000.

Aylsworth, J.M. and Traynor, J.A.
2001: Landslide inventory, Mackenzie Corridor (southern part); Geological Survey of Canada, Open File 3915, CD-ROM.

Aylsworth, J.M., Burgess, M.M., Desrochers, D.T., Duk-Rodkin, A., Robertson, T., and Traynor J.A.
2000a: Surficial geology, subsurface materials and thaw sensitivity of sediments; *in* The Physical Environment of the Mackenzie Valley, Northwest Territories: A Base Line for the Assessment of Environmental Change, (ed.) L.D. Dyke and G.R. Brooks; Geological Survey of Canada, Bulletin 547, p. 41–48.

Aylsworth, J.M., Duk-Rodkin, A., Robertson, T., and Traynor J.A.
2000b: Landslides of the Mackenzie valley and adjacent mountainous and coastal regions; *in* The Physical Environment of the Mackenzie Valley, Northwest Territories: A Base Line for the Assessment of Environmental Change, (ed.) L.D. Dyke and G.R. Brooks; Geological Survey of Canada, Bulletin 547, p. 167–176.

Couture, R., Riopel, S., Farley, C., and Singhroy, V.
2005: Regional terrain hazards and landslide mapping, Mackenzie Valley: project description and preliminary results from the 2005 field campaign and mapping; *in* 33rd Annual Yellowknife Geoscience Forum Abstracts Volume, (comp.) E. Palmer; Northwest Territories Geoscience Office.

Cruden, D.M. and Varnes, G.J.
1996: Landslide types and processes; *in* Landslides: Investigations and Mitigation, (ed.) A.K. Turner and R.L. Schuster;. National Academy Press, Washington, D.C., Transportation Research Board Special Report 247, p. 36–75

DiLabio, R.N.W.
2005: NRCAN's research program related to the Mackenzie Valley Pipeline; *in* 33rd Annual Yellowknife Geoscience Forum Abstracts Volume, (comp.) E. Palmer; Northwest Territories Geoscience Office.

Douglas, R.J.W. and Norris, D.K. (comp.)
1976a: Geology of Wrigley, District of Mackenzie; Geological Survey of Canada, Map 1373A, scale 1:250 000.
1976b: Geology of Dahadinni River, District of Mackenzie; Geological Survey of Canada, Map 1374A, scale 1:250 000.
1976c: Geology of Camsell Bend, District of Mackenzie; Geological Survey of Canada, Map 1375A, scale 1:250 000.
1976d: Geology of Root River, District of Mackenzie; Geological Survey of Canada, Map 1376A, scale 1:250 000 scale.

Duk-Rodkin, A. and Hood, J.L.
2004: Landslide inventory for the Fort Norman map area (96 C), Northwest Territories; Geological Survey of Canada, Open File 4663, CD-ROM

Duk-Rodkin, A. and Lemmen, D.S.
2000: Glacial history of the Mackenzie region; *in* The Physical Environment of the Mackenzie Valley, Northwest Territories: A Base Line for the Assessment of Environmental Change, (ed.) L.D. Dyke and G.R. Brooks; Geological Survey of Canada, Bulletin 547, p. 11–20.

Dyke, L.D.
2000: Stability of permafrost slopes in the Mackenzie valley; *in* The Physical Environment of the Mackenzie Valley, Northwest Territories: A Base Line for the Assessment of Environmental Change, (ed.) L.D. Dyke and G.R. Brooks; Geological Survey of Canada, Bulletin 547, p. 177–186.

Evans, S.G. and Savigny, K.W.
1994: Landslides in the Vancouver–Fraser Valley–Whistler region; *in* Geology and Geological Hazards of the Vancouver Region, Southwestern British Columbia, (ed.) J.W.H. Monger; Geological Survey of Canada, Bulletin 481, p. 251–286.

Heginbottom, J.A.
2000: Permafrost distribution and ground ice in surficial materials; *in* The Physical Environment of the Mackenzie Valley, Northwest Territories: A Base Line for the Assessment of Environmental Change, (ed.) L.D. Dyke and G.R. Brooks; Geological Survey of Canada, Bulletin 547, p. 21–40.

Howes, D.E. and Kenk, E.
1997: Terrain classification system for British Columbia (revised edition): a system for the classification of surficial materials, landforms and geological processes of British Columbia; British Columbia Ministry of Environment, Manual 10, 90 p.

Huntley, D. and Duk-Rodkin, A.
2005: Landslides of the southern Mackenzie valley region, Northwest Territories; *in* 33rd Annual Yellowknife Geoscience Forum Abstracts Volume, (comp.) E. Palmer; Northwest Territories Geoscience Office.

Huscroft C.A., Lipovsky, P.S., and Bond, J.S.
2004: A regional characterization of landslides in the Alaska Highway corridor, Yukon Territory: digital compilation; Yukon Geological Survey Open File 2004-18(D), CD-ROM.

Pyle, L.J., Jones, A.L., Gal., L.P., and Abbott, J.G.
2005: 2005 Reconnaissance Program: regional geoscience studies and petroleum potential, Peel Plateau and Plain; *in* 33rd Annual Yellowknife Geoscience Forum Abstracts Volume, (comp.) E. Palmer; Northwest Territories Geoscience Office.

Resource Inventory Committee
1996: Terrain stability mapping in British Columbia: a review and suggested methods for landslide hazard and risk mapping; British Columbia Queen's Printer (www.publications.gov.bc.ca), Resource Inventory Standards Committee, ISBN 0-7726-3892-6, QP stock no. 7680000597, 88 p.

Sidwell, C., Huntley, D., and Duk-Rodkin, A.
2005: Surficial geology of the Wrigley area, Mackenzie Valley, NWT; *in* 33rd Annual Yellowknife Geoscience Forum Abstracts Volume, (comp.) E. Palmer; Northwest Territories Geoscience Office.

Smith, I.R., Lesk-Winfield, K., Liu, Y., and MacDonald, L.
2005: Creation of a seismic shot hole log geodatabase for the NWT: application and benefits for future resource development; *in* 33rd Annual Yellowknife Geoscience Forum Abstracts Volume, (comp.) E. Palmer; Northwest Territories Geoscience Office.

Varnes, D.J.
1978: Slope movement types and processes; *in* Landslides, Analysis and Control; National Research Council, Washington, D.C., Special Report 176, p. 11–33.

Wang, G., Nichol, S., and Su, X.
2005: Geotechnical studies of permafrost-related landslides in the Mackenzie Valley, NWT; *in* 33rd Annual Yellowknife Geoscience Forum Abstracts Volume, (comp.) E. Palmer; Northwest Territories Geoscience Office.

Geological Survey of Canada Project Y51-5001