The Khyex River flowslide, a recent landslide near Prince Rupert, British Columbia

James W. Schwab, B.C. Ministry of Forests, P.O. Bag 6000, Smithers BC Canada VOJ 2NO
Andrée Blais-Stevens, Geological Survey of Canada, 601 Booth Street, Ottawa ON Canada K1A 0E8
Marten Geertsema, B.C. Ministry of Forests, 1011 4th Ave., Prince George, BC Canada V2L 3H9

ABSTRACT
On November 28, 2003, at about 00:30 PST, on the Khyex River, 35 km east of Prince Rupert in northwestern British Columbia, a low gradient extremely rapid, liquefaction earthflow, or a clay flowslide severed the natural gas pipeline. Displaced material flowed up and down river over a distance of 1.7 km, blocked the river, and caused flooding upstream for a distance of 10 km. The landslide is characterized by a steep main scarp 45 m high by 345 m wide that consists of glaciomarine sediments mantled by rubbly colluvium. The landslide covers an area of 32 ha and displaced about 4.7 M m^3 of material. Retrogression from the river bank, back to bedrock of the valley wall, is about 480 m. Five similar landslides have occurred in the region over the last four decades. This type of landslide poses a high risk to infrastructure within river valleys flanked by sensitive glaciomarine sediments in northwestern British Columbia.

RÉSUMÉ
À environ 35 km de Prince Rupert au nord-ouest de la Colombie-Britannique, un glissement de terrain a eu lieu sur la rivière Khyex, vers 00h30 (HNP), le vendredi, 28 novembre, 2003. Ce glissement de terrain a coupé le gazoduc et donc, le chauffage aux communautés de Prince Rupert et de Port Edward pendant dix jours. C'était une coulée de boue rétrogressive à faible pente dans des sédiments argileux qui se sont liquéfiés de façon extrêmement rapide. Les sédiments se sont écoulés non seulement en aval mais aussi en amont sur une distance de plus de 1,7 km. Ils ont aussi bloqué le drainage et ont causé une inondation sur une distance de 10 km en aval. Ce glissement de terrain est caractérisé par un escarpement abrupt, 45 m de hauteur et 345 m de largeur contenant des sédiments fins glaciomarins, couverts d'une couche de colluvion. La superficie du glissement de terrain est de 32 ha et le volume de sédiments déplacés est de 4,7 M m^3. Le mouvement de rétrogression des sédiments à partir de la rivière jusqu'au flanc rocheux de la vallée est d'environ 480 m. Il y a eu cinq glissements de terrain semblables dans la région depuis les 40 dernières années. Or, ce type de glissement de terrain crée un risque aux infrastructures situées dans les vallées remplies de sédiments glaciomarins sensibles du nord-ouest de la Colombie-Britannique.

1. INTRODUCTION

On November 28, 2003, at about, 00:30 PST, a low-gradient rapid-flowslide severed about 350 m of natural gas pipeline, 35 km east of Prince Rupert in northwestern British Columbia, Canada. The landslide is located 6.8 km upstream on Khyex River above its confluence with Skeena River (139° 46′.31.00 W; 54° 17′.17.00 N) (Figures 1 and 2). The community of Port Edward and city of Prince Rupert were left without natural gas service for 10 days. The estimated cost just for the city alone in emergency food and shelter over the 10 day period was about $300,000. A temporary gas line placed over the landslide to restore service cost in excess of $1,000,000. The cost for a permanent repair to the line may exceed five million dollars. Repairs were not completed by the summer of 2004.

The landslide occurred in glaciomarine sediments. It is the latest of five large flowslides that have occurred in northwestern British Columbia over the last four decades. Two flowslides occurred at Lakeles lake in the spring of 1962, the Kitsault flowslide occurred in September 1969, and the Mink Creek flowslide, in late December 1993 or early January 1994 (Clague, 1978; Geertsema and Schwab, 1997; Geertsema, 1998; Geertsema et al., 2003). Presented in this paper, is a description of the landslide, its geotechnical properties, possible trigger mechanisms, and the implications for natural hazard mapping.

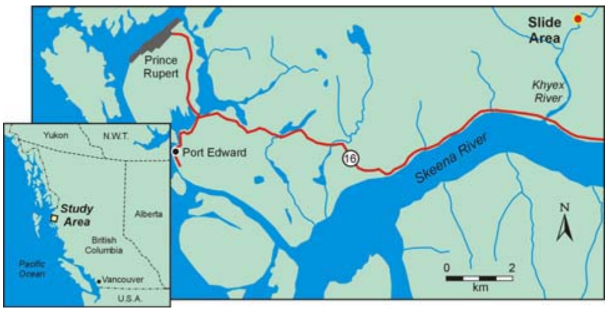

Figure 1. Location of the Khyex River Landslide

2 PHYSIOGRAPHIC SETTING

The Khyex River is located within the Kitimat Ranges of the Coast Mountains (Holland, 1976; Mathews, 1986). These mountains are round-topped, dome-like mountains overridden by glacial ice with relatively uniform elevations between 1800-2400 m. Higher peaks, up to 2800 m,

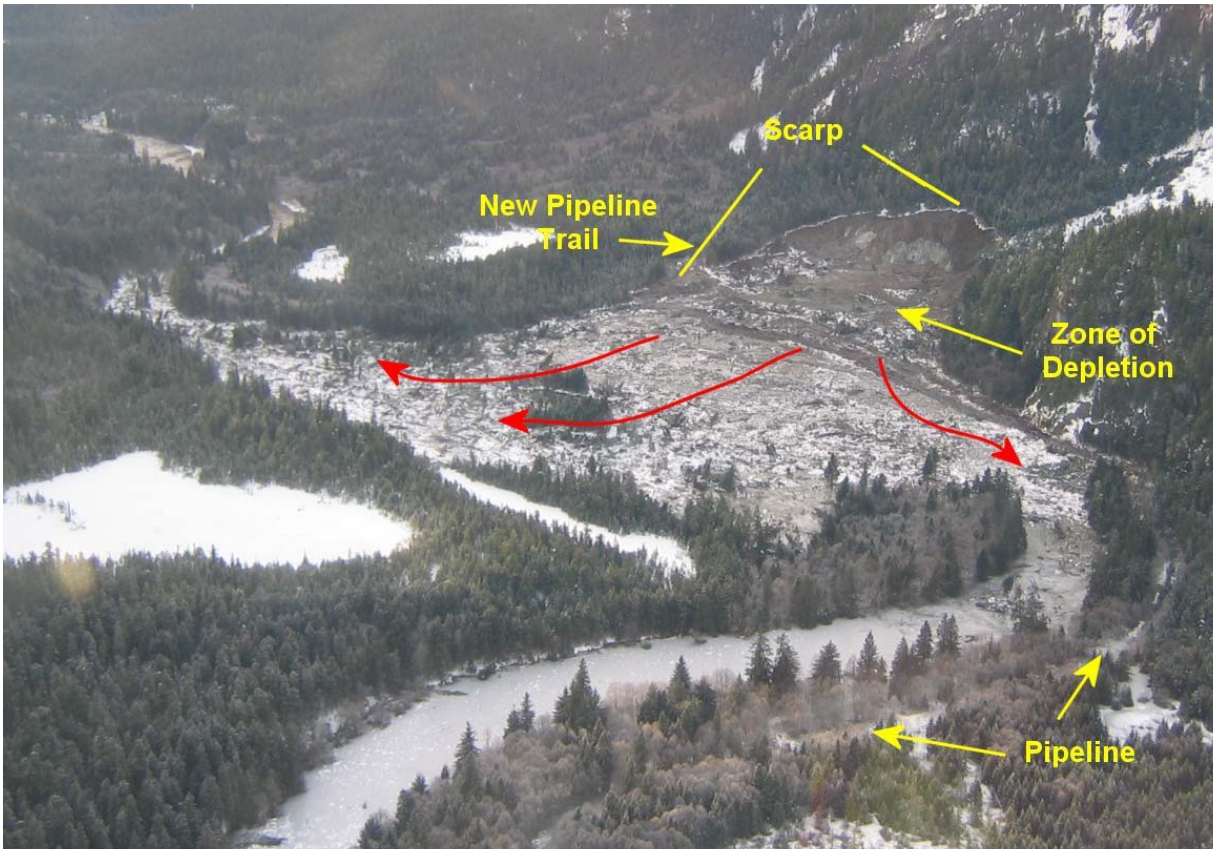

Figure 2. View down valley of the Khyex landslide. Photographed by Tim Keegan, December 9, 2003. Red arrows show direction of movement. The river is filled with displaced material over a distance of 1.7 km.

project as nunataks. Valleys, including the Khyex Valley, are glacially carved with steep side profiles and filled with glacial and post-glacial sediments. Rivers such as the Skeena follow long fjords. Khyex River flows south into Skeena River at tidewater. Tidal effects on the Khyex extend up river for about 12 km. However, tidal influence is minimal at the site of the landslide except during an extreme high tide combined with an extreme high river flow.

2.1 Climate and vegetation

The Khyex Valley is situated in the submontane variant of the Very Wet Maritime subzone of the Coastal Western Hemlock biogeoclimatic zone (Meidinger and Pojar 1991; Banner et al. 1993). This subzone, situated on the north coast of British Columbia, is characterized by extremely wet mild winters and cool summers. Annual precipitation is about 3600 mm/year with much greater amounts falling at higher elevation. Forty percent of the precipitation often falls as snow at higher elevations between October and March.

3. BEDROCK GEOLOGY

Bedrock exposed along the Khyex Valley walls appears massive, polished by glacial ice, and almost devoid of small scale jointing. The bedrock is a diorite to quartz diorite, part of the northwest-southeast trending Coast Plutonic Complex composed of mainly granitic plutons and high grade gneiss, which are Jurassic to Cretaceous in age (Duffel and Souther 1964; Hutchison, 1982).

4. SURFICIAL GEOLOGY

The surficial geology of the area was mapped and described by Clague (1984). The area was isostatically depressed during deglaciation (11-12ka BP), which caused coastal river valleys, including the Skeena and Khyex, to be inundated by marine waters. Glaciomarine sediments were deposited as glaciers melted and retreated up the Khyex Valley. The upper elevation of glaciomarine sediments found in the near vicinity of the landslide within the Khyex Valley was about 30 masl. Laminated glaciomarine silts and clays, 5-10 m thick, were found on the bedrock surface at the head scarp of the Khyex landslide (Figure 3). Overlying this unit is

Figure 3. Laminated silts and clays. Bedrock wall is speckled with remnant barnacle traces (arrows).

Figure 4. Sediments exposed at the headscarp.

coarse pebbly sand (< 1m thick), thought to represent fluvial sediments. Rubbly colluvium with a thickness ranging between 5-10 m overlies the discontinuous sand. The colluvium is part of a cone-shaped mantle deposited at the base of a snow avalanche track (Figure 4). Along the south flank of the landslide, a 1.5 -2 m thick organic soil was found buried below 2 m of colluvium. The organics are believed to overly the marine sediments.

Contained within the glaciomarine silt and clay laminae were whole, to partially broken shelled macrofossils. These molluscs have been identified (Abbott, 1974) and consist of three species of bivalves, three species of gastropods, i.e., one limpet and three snails, and pieces of barnacles. One of the bivalves, Portlandia arctica, is known as a colonizer found in close proximity to glaciers, and living in fine sediment accumulating in turbid brackish arctic waters (Dyke et al., 1996). The gastropods as well as some of the bivalves indicate a rocky to sandy near shore environment. Moreover, limpets and barnacles are often found adhering to rock in a cold marine environment.

5. MATERIAL DISCRIPTION

5.1 Material characteristics

Analysis was undertaken of three grab samples of the dark grey glaciomarine sediments that remained along the bedrock surface in the main scarp. Particle size analysis showed sand, silt and clay in the order of 5-13 %, 45-48%, 41-47%, respectively (Table 1). The material is classified as a clayey silt. Natural moisture content was relatively low (24 to 32%), compared with sensitive sediments. This may in part be due to freezing of the samples. Liquid limits were about 30% and plastic limits 19%. Plasticity indices ranged from 9.2 to 12.4 and liquidity indices, from 0.4 to 1.0. These values may not be indicative of conditions at the rupture surface, and are somewhat low compared with sensitive soils in eastern Canada (Mitchell and Markell, 1974). They are, however, similar to the range of values of the nearby large rapid flowslides at Mink Creek and Lakelse Lake that occurred near Terrace British Columbia (Geertsema and Schwab, 1995). The glaciomarine sediments at Khyex and in the Terrace area have a much lower amount of primary minerals (rock flour) than phyllosilicates (true clay minerals) in the clay fraction and are dominated by silt. Hence, low liquidity indices may reflect a lack of cementation due to a paucity of primary minerals (Quigley, 1980) and a high silt content.

The sediment at Khyex has a Low activity level at about 0.42 (Plasticity index divided by % clay). A value of <1 is a prerequisite for quick clay and sensitive soil (Torrance, 1987). The value for Khyex sediments is slightly higher than the values reported by Geertsema and Schwab (1997) for Mink Creek.

Table 1. Material characteristics

Sample	01B	02B	03B	04B
Sand %	34.4	5.3	13.4	11.4
Silt %	59.8	48.2	45.6	47.8
Clay %	5.8	46.5	41	41.8
Water content %	23.6	32.1	25.4	24.7
Liquid Limit %	27.7	32.2	26.4	31.8
Plastic Limit %	0	20.5	17.3	19.4
Plasticity Index	NA	11.7	9.2	12.4
Liquidity Index	NA	1.0	0.9	0.4
Classification	NP	CI	CL	CI

5.2 Mineralogy

Semi-quantitative clay mineralogy analyses were obtained by X-ray diffraction. All four samples are comparable in composition (Table 2). They are dominated by chlorite and illite with some plagioclase and quartz. Amphibole occurs in minor to trace amounts. Sample 02B showed evidence of a mixed-layer clay mineral that contains swelling clay (smectite). However, this occurs only in trace amounts and likely indicates that some weathering of illite has occurred.

Table 2. Semi-quantitative clay mineralogy by X-ray diffraction analyses (GSC, Mineral Resources Division). Values represent percentages.

Sample No	01B	02B	03B	04B
Quartz	10	9	16	13
Plagioclase	16	15	15	13
Amphibole	4	tr	6	tr
Illite	32	32	25	32
Chlorite	38	44	38	43
Mixed-layer clay mineral		Tr		

5.3 Pore-water salinity

Five samples collected from ridges and spoil were analysed for pore-water salinity. Values of 3.54 and 2.52 g/l were obtained from ridge sections remaining along the southern portion of the landslide. However, a portion of a ridge remaining along the north flank showed salinity of 0.22 g/l. Salinity values recorded for samples collected from the remoulded spoil indicate 0.12 and 0.65 g/l.

The values recorded for Khyex samples compared to the salinity for normal marine conditions, brackish water, and freshwater of 35, less than 25, and 0.0 g/l, respectively, show that considerable leaching of salts has occurred from the marine sediments. This leaching is expected in the extremely wet environment of north coastal British Columbia.

The low salinity values for the remoulded mud are indicative of marine muds that show quick clay behaviour Torrance (1987). However, the higher values obtained for the intact ridge material suggests some marine sediments involved in the landslide were not quick clays (values greater than 2g /l).

5.4 Vane shear strength

An attempt was made to collect vane shear profiles with a Nilcon vane borer outside the landslide above the southern lateral scarp. However, it was not possible to penetrate through the rubbly colluvial blanket to obtain shear profile information for the underlying glaciomarine sediments.

A vane shear profile was obtained within the zone of depletion, however the results as presented in table 3 are not characteristic of sensitive glaciomarine sediments. The undrained shear strength (Su) at 1 m depth was the only soft sediment encountered. All of the remoulded strengths (Sr) were high, giving low sensitivities. It was not until the 12 m reading that the Su plot had a characteristic rising limb followed by an abrupt fall. In the first 11 metres, the Su plots, closely resembled remoulded soils. A possible explanation, for the high strengths, is de-watering of the sediment in that the strength profile was obtained near a mud volcano.

The depleted mass is generally stronger and denser than undisturbed material, as such, a thick depleted mass appears to have remained within the zone of depletion. The basal rupture surface is thus somewhere between 11 and 12 m depth, below the landslide surface. The depth of this assumed rupture surface corresponds closely with river level.

Table 3. Vane shear data,

Depth (m)	Su (kPa)	Sr (kPa)	St (Su/Sr)
1	13.42	8.39	1.60
2	38.02	22.37	1.70
3	>53.68	0.00	0.00
3.5	67.10	53.68	1.25
4	102.89	58.15	1.77
5	89.47	51.44	1.74
6	73.81	49.21	1.50
7	100.65	46.97	2.14
8	69.34	49.21	1.41
9	78.28	40.26	1.94
10	55.92	33.55	1.67
11	87.23	46.97	1.86
12	98.41	40.26	2.44
13	91.70	42.50	2.16

5.5 Thickness of the depleted mass

The thickness and amount of depleted mass remaining in the landslide is considerable in comparison to the Mink Creek landslide and somewhat puzzling. At Mink Creek, in the flow portion of the landslide, spreading and flowing occurred leaving extensive areas of the exposed rupture surface and a very small amount of depleted mass (Geertsema et al., 2003).

The large amount of deleted mass remaining within the Khyex zone of depletion was likely determined by topographic control as discussed by Carson and Lajoie (1981) and Carson and Geertsema (2002). Although the Khyex landslide was very mobile, as reflected by the distance of movement up and down river, once the displaced mass formed a level plain in front of the landslide, it became impossible for more material to leave the zone of depletion. Had the rupture surface been perched high above river level, as at Mink Creek, or if the displaced material flowed further, more of the depleted mass would likely have been removed from the zone of depletion.

6. SITE HISTORY

The landslide area was logged in December 1959. No site disturbance other than tree removal is visible on 1962 air photographs. Bank disturbance appears evident along a portion of the bank at a location where the logs were lowered down to the river. In 1968, a natural gas pipeline was installed mid-way through the present zone of depletion. Silviculture surveys over the block in 1997 indicated that the site was completely restocked with Sitka spruce (Picea sitchensis), western hemlock (Tsuga heterophylla) at 3,200 to 3,900 stems per hectare. Average tree height was 3.5 m at the time of the survey. Tree height had reached about 5 m at the time of failure, six years later.

7. LANDSLIDE DESCRIPTION

The Khyex landslide involved glaciomarine sediments as well as rubble from the colluvial cone (Figures 2 and 5). About 4.7 M m^3 of sediments were displaced in the landslide, which cover an area of 32 ha, with 13 ha in the zone of depletion. The landslide flowed across the Khyex floodplain and filled the river over a length of 1.7 km. Displaced material flowed up and down the river and caused flooding upstream for a distance of 10 km. The slide is characterized by a steep main scarp, 45 m high by 345 m wide, and controlled by the smooth bedrock surface of the valley wall. The flanks or lateral scarps are found within glaciomarine sediments. Slope of the original ground surface over much of the zone of depletion was about 4.5° with the colluvial cone considerably steeper at about 30°. The present slope through the zone of depletion is about 2.5° tending toward a flat plain within the zone of deposition. Estimated retrogression from the assumed point of initiation on the riverbank is about 480 m. Pre-failure bank height was about 10 m. The landslide is classified as an extremely rapid, retrogressive liquefaction earthflow according to the classification of Cruden and Varnes (1996), or a clay flowslide according to the classification of Hungr et al. (2001).

7.1 Morphology—zone of depletion

Below the head scarp are large blocks of rubble that

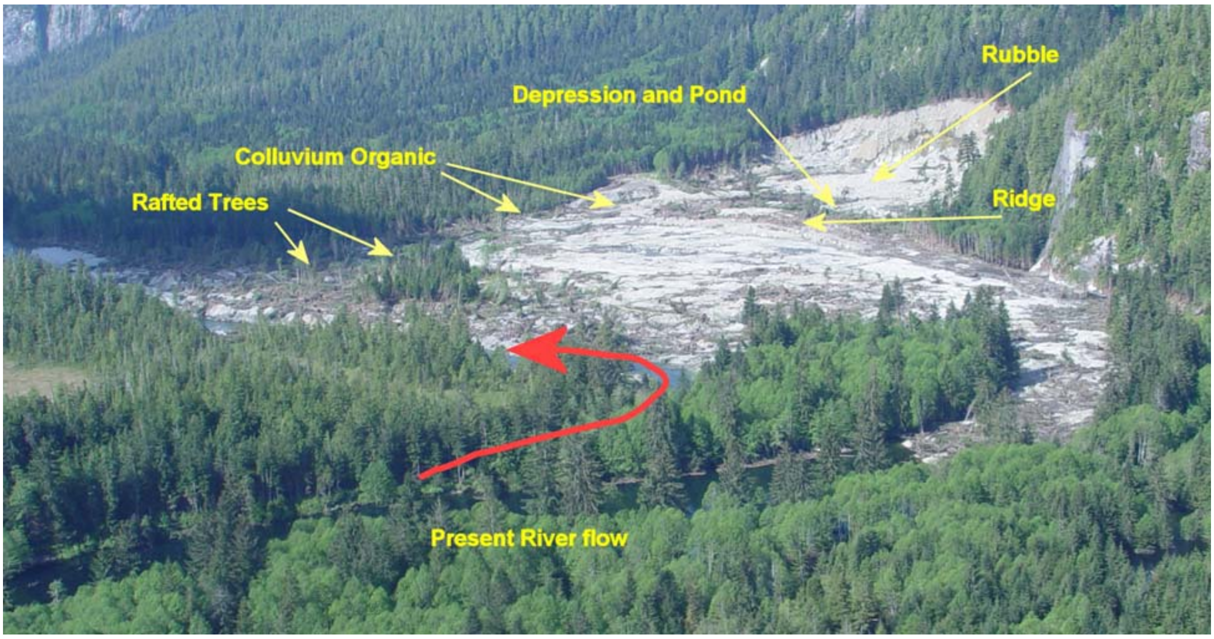

Figure 5. Khyex landslide, May 18, 2004. Note: location of present river flow (red arrow), long ridge and pond location.

occupy about 25% of the zone of depletion. This rubble originates from the colluvial cone/snow avalanche track that collapsed into the zone of depletion in the days following the landslide. Remaining in the zone of depletion are a few transverse ridges situated close to the front of the zone of depletion or the original river bank. The largest ridge extends about 300 m almost across the zone of depletion (Figure 5). Behind the ridge is the lowest portion of the zone of depletion, now filled with water. One large prism of glaciomarine mud remains in the northern portion of the spoil. Much of the material that appears as possible prisms and ridges is capped with sand and gravel. The strong remoulding of material, found within the zone of depletion and across the valley flat, suggests that movement was by flowing rather than spreading. There is little evidence to indicate lateral spreading in that there is a distinct lack of rib features in the zone of depletion. Also, no rotational blocks that tend to occur just prior to the cessation of movement were found along the back scarp and southern lateral scarp. Flow followed the bedrock of the valley wall along the north flank; hence, all materials were transported along the bedrock face. Only remoulded materials remain along the face. Patches of trees remaining upright on an organic mat appear to have rafted across the floodplain and down river. Numerous active mud volcanoes (silty in texture) were found throughout the zone of depletion in December 2003 (Figure 6). These mud volcanoes were likely created, as remoulded mud de-watered, forcing liquid mud and water upwards. They were found in and around zones of liquefied sediments. Further study is required to determine the exact origin of these features.

Figure 6. Mud volcano, some measure up to 2m in diameter.

8. PRECONDITIONS AND SLIDE MECHANICS

In a salt water environment as in a fjord that once occupied the Khyex River valley, silt and clay particles form floccules (small aggregates) and settle together in a random pattern (Torrance, 1983). This random alignment of particles gives the material a higher than normal amount of pore space and water content. Interparticle bonds are strong as long as pore water contains a high salt content. Leaching by fresh water gradually lowers the salinity. Once the salinity of pore water drops below a threshold (<0.2 g/l), marine clays are prone to structural collapse on disturbance. Clays that exhibit this type of behaviour are often called sensitive clays. In the extreme case, materials with high sensitivity and low remoulded undrained shear strength are termed Quick Clays (Torrance, 1983). Remoulded undrained materials behave like a liquid.

No earthquakes were recorded or could have been felt in the Prince Rupert area before or at the time of the landslide. (Geological Survey of Canada, National earthquake database, Sidney B.C., www.pgc.nrcan.gc.ca/seismo/recent/felt-events.htm).

Anecdotal weather information observed in the Lachmach watershed adjacent to and west of the Khyex watershed provides an indication of the weather conditions prior to the event (Pers comm., B. Cuthbert, B.C. Forests Service):

- November 23 to 26th, 214 mm rain fall;
- November 26th, 30-60 cm of snow on the ground;
- November 27th, 40 mm of rain fall;
- November 27th, Six debris flows/avalanches

The precipitation is not exceptional for the month of November along BC's north coast. However, rainfall and rapid snow melt that occurred on the 27th of November may have resulted in the Khyex River running at high levels immediately, prior to the event. Unfortunately, there are no recording river gauges in the area that could provide an indication of actual river levels.

The landslide occurred in uplifted glaciomarine sediments along an outside river bend. Pre-landslide bank height was about 10 m. A portion of the bank appeared sparsely treed as observed on 1988 aerial photography, and almost bare on 1962 aerial photography. Also, before the landslide occurred, the outside river bend did not form a uniform curve with the bank abruptly extending back into the channel immediately down stream of the sparsely treed bank section (Figure 7). The bank, upstream from this point, was prone to active bank erosion. Moreover, erosion and small slumps with trees fallen into the river were observed along the riverbank (R. Kline Pers. Comm., 2003; observations made while working in the Khyex Valley between 1959-1963 and visits to the valley in 1982 and 1984). Unknown, however, is the extent of bank erosion over the 10 years prior to the event.

The role logging played in bank disturbance and in any increase in bank erosion is likely minimal. The cable system used for transferring logs to the river, lifted the logs clear of the river bank—vegetation removal occurred along the bank, but very little ground disturbance occurred. Also, the logging was completed some 45 years earlier. The pre-landslide ground surface was completely reforested with trees up to 15 m tall and, for the most part, the bank was re-vegetated.

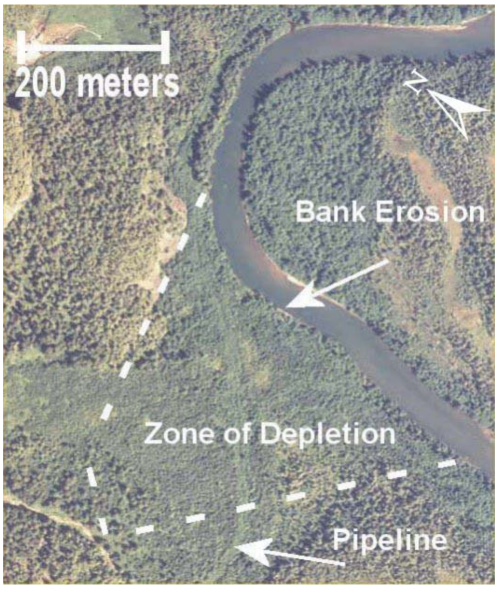

Figure 7. Landslide area indicated on 1988 air photograph.

The most likely trigger appears to have been river bank erosion, considered the most common trigger of retrogressive flowslides (Lebuis et al., 1983; Viberg, 1983).

In the landslide hazard classification of Viberg (1983), this site would be given a high-hazard designation because of its topographic position and the presence of an eroding riverbank. Thus, a plausible scenario is that bank erosion, combined with seepage into overlying sand layers and coarser laminae within the marine sediments, may have resulted in a seepage-face failure. Presumably, sensitive marine sediments were exposed by the initial slope failure. The landslide enlarged retrogressively in the marine sediments to the maximum extent possible, movement being constrained by bedrock along the valley wall.

A depression that remains in the zone of depletion below the back scarp (Figure 5) does not fit well with models of retrogressive spreading by repeated back wall failure (Odenstad 1951; Carson 1977). Repeated retrogressive failure occurs until the backscarp is supported and the translational sliding stops. This should result in an up sloping surface in the zone of depletion. Instead, a large depression remained between the main back scarp and the main body of the zone of depletion. A factor however, that may have contributed to the lack of a sloping surface could possibly be the control exerted on retrogression by the bedrock of the valley wall. Further evidence against retrogressive failure is the lack of rotational blocks along the lateral scarps on the south side given that the main scarp and north flank of the landslide are controlled by bedrock. Rotational blocks are believed to be transitional forms between translational sliding and cessation of movement in retrogressive landslides.

Considering the above observations, what may have occurred at Khyex was an instantaneous liquefaction of a weak layer on which the remaining material was transported. The material largely remoulded during transport. Failure may have occurred as a monolithic flakeslide (Gregersen, 1981). The process is not incompatible with a flow. Elevated pore pressures along possible sand lenses, as found in the glaciomarine sediments, is a possible driving mechanism. Mobilization of the overlying material including the rubbly colluvium may have caused undrained loading of the intact glaciomarine sediments (above a liquefied zone) causing remoulding and catastrophic flow. This may explain to some degree the abundance of mud volcanoes, often termed loading structures.

9. SUMMARY

The 2003 Khyex River landslide is the most recent of five large destructive flowslides that have occurred over the last four decades in northwestern British Columbia (Two events Lakelse Lake, 1962; Kitsault, 1969; Mink Creek, 1993; and Khyex, 2003).

Sediments at the Khyex landslide are glaciomarine in origin. An abundance of well-preserved shell macrofossils were found in the laminated sediments and strewn over the landslide. The macrofossils are indicative of species found in turbid brackish cold marine environment in close proximity to glaciers.

The sediments are clayey silt, similar in composition to sites of other flowslides found in north western British Columbia. Liquidity index for the materials appears low when compared to sensitive soils found in eastern Canada. The low indices may reflect a lack of cementation due to a paucity of primary minerals and a high silt content. Furthermore, low salinity values obtained for the remoulded mud are indicative of marine muds showing quick clay behaviour.

A plausible scenario for failure is bank erosion combined with seepage into overlying sand layers and coarser laminae in the sediments resulted in a seepage face failure, exposure of sensitive material, and rapid retrogressive enlargement. However, based on features observed at the landslide, instantaneous liquefaction of a weak layer may have occurred with movement as a monolithic flakeslide.

Glaciomarine sediments are common in British Columbia's north coast valleys. Roads, railways, pipelines and utilities are located and constructed in these valleys on glaciomarine sediments. Thus infrastructure is at continual risk from catastrophic flowslides. Regional hazard mapping, geotechnical investigation, and risk assessments are necessary to avoid catastrophic impacts to utilities and infrastructure in the region.

10. ACKNOWLEDGMENTS

We thank M. Wygergangs J. Brennan for sample preparation, D. Mosher, O. Brown, and K. McKillop for sediment analyses, J. Percival for clay mineral analyses, and R. Franklin for drafting. A. Dyke helped in the mollusc identification. D. Boersema helped provided vane shear data. B. Pelletier and O. Hungr provided helpful suggestions, which improved the manuscript

11. REFERENCES

Abbott, R.T. 1974. American Seashells: The marine mollusca of the Atlantic and Pacific Coasts of North America. Van Nostrand Reinhold Company, New York, 663 p.

Banner, A., MacKenzie, W., Haeussler, S., Thomson, S., Pojar, J., Trowbridge, R. 1993. A field guide to site identification and interpretation for the Prince Rupert Forest Region. Land Management Handbook. No. 26, Part 1, British Columbia Ministry of Forests, 405 p.

Carson, M.A. 1977. On the retrogression of landslides in sensitive muddy sediments. Canadian Geotechnical Journal 14:582-602.

Carson, M.A., and Lajoie. G. 1981. Some constraints on the severity of landslide penetration in sensitive deposits. Géographie Physique et Quaternaire 35:301-316.

Carson, M.A., and Geertsema, M. 2002. Mapping in the interpretation and risk assessment of flowslides in sensitive Quaternary muddy sediments. Geoenviromental Mapping Methods, Theory and Practice. Bobrowsky, P.T. (Editor) A.A. Balkema Publishers, The Netherlands. 667-698.

Clague, J.J. 1978. Terrain hazards in the Skeena and Kitimat River Basins, British Columbia. Current Research, Part A, Geological Survey of Canada, Paper 78-1A, pp.183-188.

Clague, J.J. 1984. Quaternary geology and geomorphology, Smithers-Terrace-Prince Rupert area, British Columbia. Geological Survey of Canada Memoir 413, 71 p.

Cruden, D.M., and Varnes, D.J. 1996. Landslide types and processes. In: Turner, A.K. and Shuster, R.L. (Editors) Landslides investigation and mitigation, Special Report 247, Transportation Research Board, National Research Council, Washington DC, pp. 36-75.

Duffel, S., and Souther, J.G. 1964. Geology of the Terrace map-area, British Columbia (103 I E 1/2). Geological Survey of Canada Memoir 329, 117 p.

Dyke, A.S., Dale, J.E., and McNeely, R.N. 1996. Marine molluscs as indicators of environmental changes in glaciated North America and Greenland during the last 18, 000 years. Géographie Physique et Quaternaire, 50:125-184.

Geertsema, M. 1998. Flowslides in water lain muds of northwestern British Columbia, Canada. Proc. of the 8th Congress of the International Association of Engineering Geology and the Environment, Vancouver, Volume III, pp. 1913-1921.

Geertsema, M., Cruden, D.M., and Schwab, J.W. 2003. Style and sequence of movement in a landslide in sensitive glaciomarine sediments at Mink Creek, near Terrace, British Columbia. Proc. of the 3rd Canadian Conference on Geotechnique and Natural Hazards, Edmonton, pp.178-185.

Geertsema, M., and Schwab, J.W. 1995. The Mink Creek earthflow, Terrace, British Columbia. Proc. of the 48th Canadian Geotechnical Conference, Vancouver, pp. 625-633.

Geertsema, M., and Schwab, J.W. 1997. Retrogressive flowslides in the Terrace-Kitimat, British Columbia area: from early post-deglaciation to present and implications for future slides. Proc. of the 11th Vancouver Geotechnical Society Symposium, pp. 115-133.

Gregersen, O. 1981. The quick clay slide in Rissa, Norway. Proc. 10th ICSMFE, Stockholm, Vol 3, pp.421-426.

Holland, S.S. 1976. Landforms of British Columbia. British Columbia Department of Mines and Petroleum Resources, Bulletin 48, 138 p.

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

Hutchison, W.W. 1982. Geology of the Prince Rupert-Skeena Map area, British Columbia. Geological Survey of Canada Memoir 394, 116 p.

Lebuis, J.J., Robert, M., and Rissmann, P. 1983. Regional mapping of landslide hazard in Quebec. In: Bergren, B., and Lindgren, J. (Editors) Symposium on slopes on soft clays, Swedish Geotechnical Institute Report No. 17, Linköping, pp. 205-262.

Mathews, W.H. (Compiler) 1986. Physiography of the Canadian Cordillera. Geological Survey of Canada. Map 1701A.

Meidinger, D., and Pojar, J. 1991. Ecosystems of British Columbia. Special Report Series 6. B.C. Ministry of Forests. Victoria British Columbia.

Mitchell, R.J., and Markell, A.R. 1974. Flowing in sensitive soils. Canadian Geotechnical Journal 11:11-31.

Odenstad, S. 1951. The landslide at Sköttorp on the Lidan River. Proc. of the Royal Swedish Geotechnical Institute 4, pp. 1-38.

Quigley, R.M. 1980. Geology, mineralogy, and geochemistry of Canadian soft soils: a geotechnical perspective. Canadian Geotechnical Journal 17:261-285.

Torrance, J.K. 1983. Towards a general model of quick clay development. Sedimentology 30: 547-555

Torrance, J.K. 1987. Quick clays Chapter 14. *In* Slope stability. Anderson M.G., and Richards, K.S. (Editors) John Wiley and Sons Ltd., pp. 447-473.

Viberg, L. 1983. Experiences of mapping and classification of stability conditions. Bergren, B., and Lindgren, J. (Editors) Symposium on slopes on soft clays, Swedish Geotechnical Institute Report No. 17, Linköping, pp. 455-461.