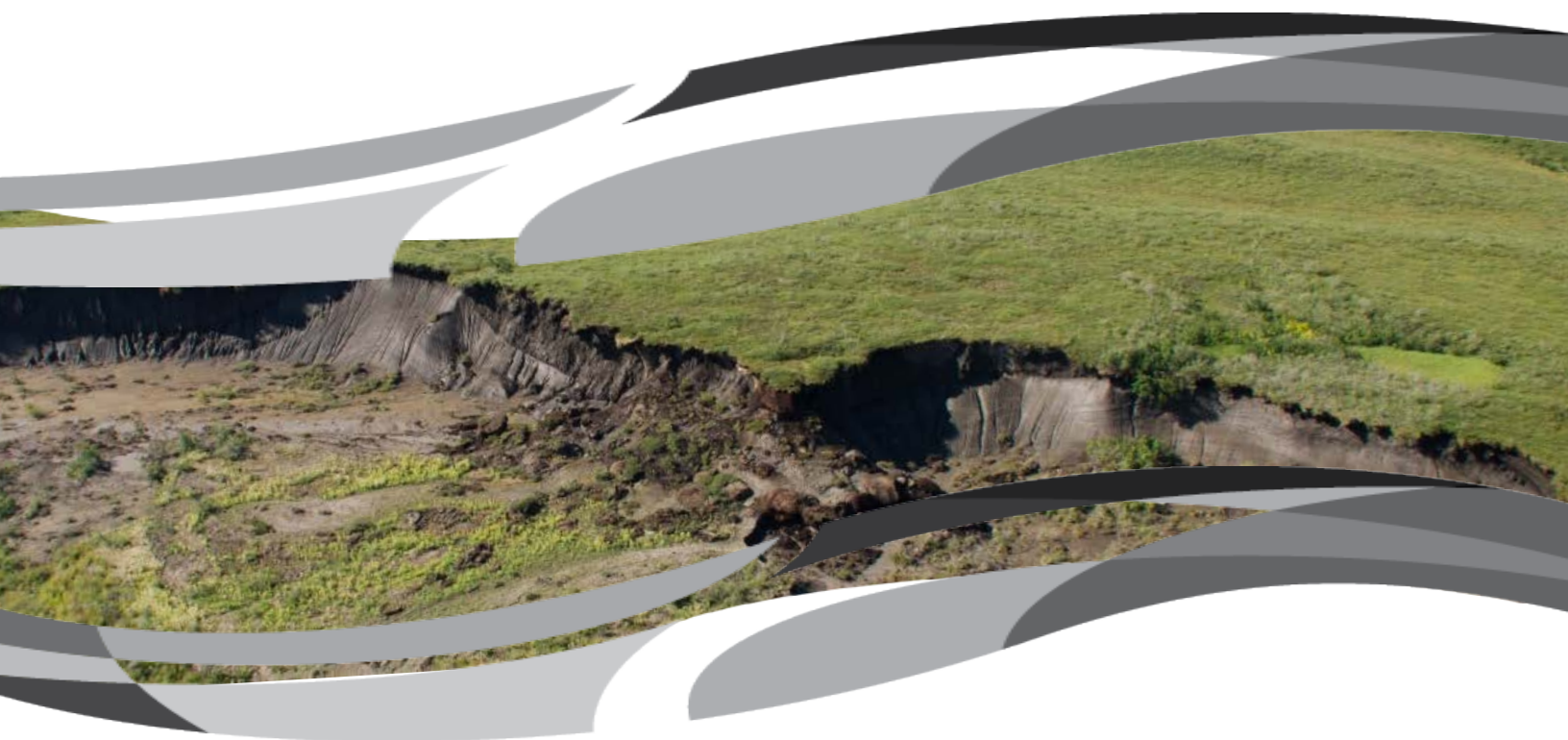




NWT Open Report 2016-008
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NORTHWEST TERRITORIES
GEOLOGICAL SURVEY

Government of
Northwest Territories

NWT Open Report 2016-008

Broad-Scale Mapping of Terrain Impacted by Retrogressive Thaw Slumping in Northwestern Canada

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Cover photo: Retrogressive thaw slump near Tuktoyaktuk Coastlands, NWT, showing characteristic headwall feature. Photo courtesy of Trevor Lantz.

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INTRODUCTION

This paper describes the method to obtain spatial data on the distribution of terrain affected by retrogressive thaw slumping and characterization of the relative density of these disturbances across the western and central regions of Subarctic and Arctic Canada. To map regions impacted by retrogressive thaw slumping, a georeferenced SPOT 5 and SPOT 4 orthomosaic was used and individual cells were classified in a 15 x 15 km grid system covering a terrain area of more than 1 270 000 km² in northwestern Canada. Detailed mapping instructions are described in Appendix A.

Retrogressive thaw slumps are a form of thermokarst that develop in sloping terrain underlain by ice-rich permafrost (Burn and Lewkowicz, 1990; Kokelj and Jorgenson, 2013). Active thaw slumps are characterized by an ice-rich headwall that defines the upslope boundary of the slump. Ablation of exposed ground-ice can cause retrogressive slumping and growth of the disturbance. The scar area of an active slump typically consists of saturated mineral soils and detritus, contrasting significantly with surrounding undisturbed forest or tundra. Colonizing vegetation can quickly establish on the warm, nutrient-rich slump soils (Burn and Friele, 1989; Lantz et al., 2009). The headwall or upslope margins of a slump are typically crescent-shaped (Figure 1). The saturated materials in the scar zone can move downslope by a variety of processes, which can result in the development of a debris tongue. Mass flows may cause the debris tongue to extend downslope and infill small valleys (Figure 1), or the materials may be transported into a lake or coastal zone. Slump stabilization occurs when the headwall becomes covered and insulated by debris (Kokelj and Jorgenson, 2013).



Figure 1. A retrogressive thaw slump in the Peel Plateau area (67.280°N, 135.162°W) in 2010. Arrows denote the features described in the text.

COMPILATION METHODS

To map active retrogressive thaw slumps in a study area that included portions of the Yukon, Northwest Territories, and Nunavut, mappable cells were created using a 15 by 15 km grid

system, covering a land area of 1,274,625 km² (Figure 2). Trained technicians assessed several disturbance and landscape attributes for each grid cell by viewing the georeferenced SPOT 5 and SPOT 4 orthomosaics from 2005-2010 (<http://www.geomatics.gov.nt.ca/sdw.aspx>; (NWT Centre for Geomatics, 2013; Latitude Geographics Group Ltd., 2014). The classification scheme described below provided a systematic basis for assessing the grid cells and populating all required data fields.

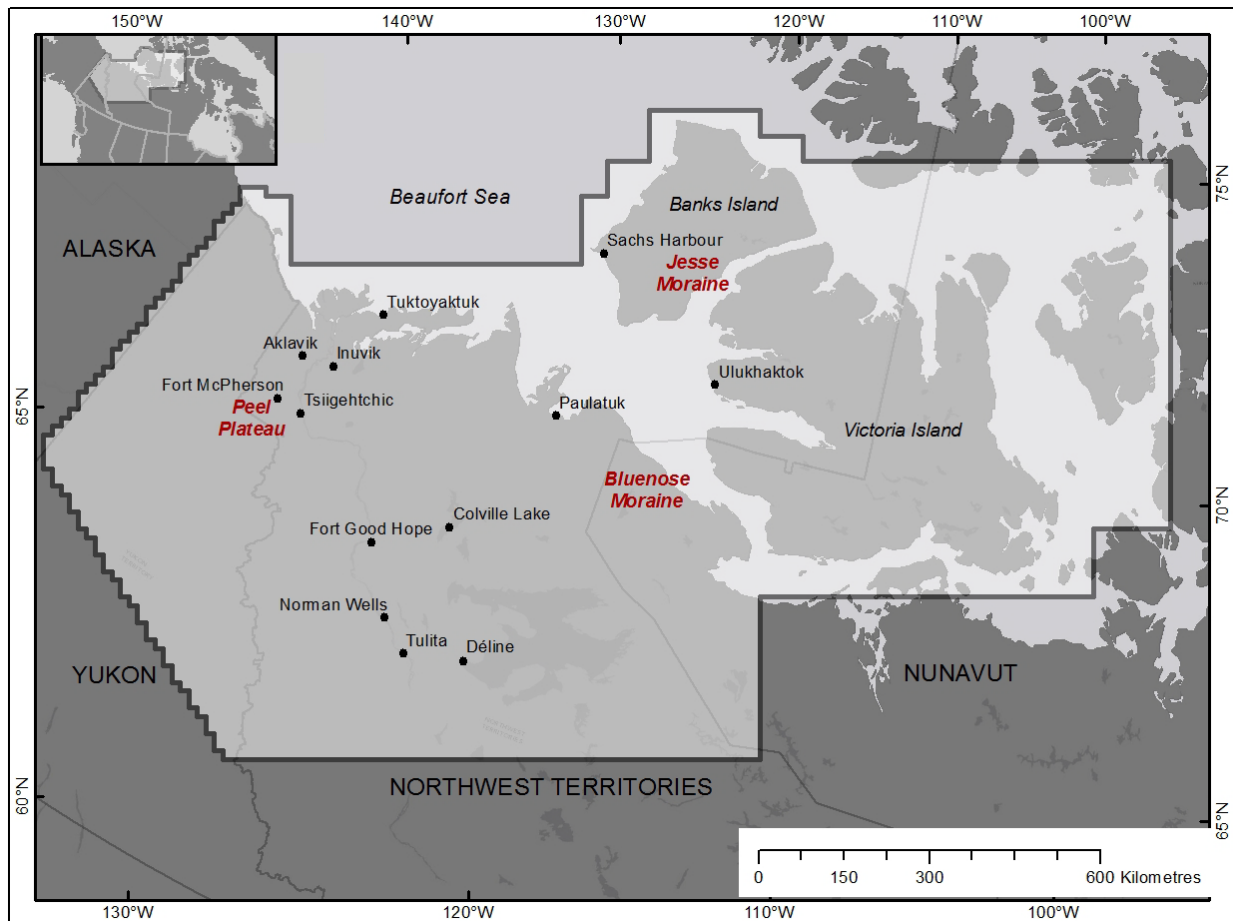


Figure 2. Map showing the study region (1,274,625 km²), including the northern Yukon and Northwest Territories, and western Nunavut. The inset at the top left shows the location of the study area in northern Canada.

Attributes recorded for each grid cell were: 1) slump density; 2) the primary slump-landscape associations (valley, lakeside, coastal); 3) area of the largest slump; 4) debris tongue presence; and 5) mapper name (Table 1). There was also an additional field for comments on unique observations or interpretation uncertainty. Interpretation instructions and attribute values are provided in detail in the following section. Data were compiled in ArcGIS (10.0-10.2).

Table 1. Attributes and inputs for the grid cell classifications.

Attribute	Descriptors
Terrestrial area	Y or N
Slump density	None, Low (1-5 slumps), Medium (6-14 slumps), High (15+ slumps), NA
Geomorphic context	Lakeside, Valley (=fluvial) and/or Coastal; NA
Secondary geomorphic context	Lakeside, Valley (=fluvial) and/or Coastal; NA
Maximum slump size	Regular (≤ 5 ha [$50\,000\text{ m}^2$] and <300 m scar length), mega slump (>5 ha, and scar length >300 m), NA
Largest slump area	In hectares (precise to 2 decimal places), or NA. This attribute was only recorded in grid cells with large slumps (>5 ha)
Debris flows present	Y, N, NA
Mapper	Name

The SPOT 5 and SPOT 4 imagery consulted had a pixel size of 10 m, and were viewed at a scale of between 1:20 000 and 1:30 000. This allowed mappers to confidently identify slumps as small as 0.75 ha. Active or recently active slumps were identified based on the presence of recently exposed sediments, absent or poorly-developed vegetation, and a well-defined headwall. To ensure that slumps were interpreted accurately, each grid cell was examined by at least one trained observer and one expert reviewer. Stable slumps were not considered in this analysis because of challenges associated with consistently identifying stable, revegetated slump scars across a range of landscapes using the SPOT 5 and SPOT 4 imagery. As such, the mapping products derived using this methodology represent conservative estimates of slump distribution. The full dataset and interpretation of mapping results will be made available in a future publication.

ACKNOWLEDGEMENTS

This work was supported by the Government of the Northwest Territories, the NWT Cumulative Impacts Monitoring Program, the Canada Foundation for Innovation, the Climate Change Impacts and Adaptation Program, and the Natural Science and Engineering Research Council of Canada. The project was made possible by collaboration between the NWT Geological Survey, Department of Industry Tourism and Investment, the NWT Cultural Places Program, Prince of Wales Northern Heritage Centre, Department of Education, Culture and Employment, the Centre

for Geomatics, Informatics Shared Services, Government of the Northwest Territories and the School of Environmental Studies, University of Victoria. The authors would also like to thank John Ketchum and Tom Andrews for supporting this initiative, Will Tyson and Gillian Harvey for GIS technical support, and Chanda Brietzke, Abra Martin, and Emily Cameron for scientific support and helpful discussions. Critical comments by Phillipe Normandeau and Steve Wolfe improved the quality of this report.

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APPENDIX A. MAPPER INSTRUCTIONS: BROAD-SCALE MAPPING OF TERRAIN IMPACTED BY RETROGRESSIVE THAW SLUMPING IN NORTHWESTERN CANADA

1. MAP INTERPRETATION

1.1 Accessing the online map.

Go to the NWT Geomatics Spatial data warehouse

Portal http://apps.geomatics.gov.nt.ca/SilverlightViewer_SDW/Viewer.html?Viewer=Spatial%20Data%20Warehouse&Project=669c355a-a72f-4585-a65a-f16287b614a6.

There is a 15 km by 15 km grid (black) overlaying the mosaicked SPOT imagery of NWT and northwestern Canada. The SPOT 5 and SPOT 4 layer may appear as numerous green outlines until you zoom in closer than 1:12000000). The 15 x 15 km² grid cell is labeled using letters and numbers: column 1 is the most westerly and row A is most northerly.

1.2 Basic map functions.

To zoom in, use the scroll wheel of your mouse, or the “Zoom In” and “Zoom Out” buttons under the tab “Getting Around.” Click and drag to move side to side (you may need to select the “Pan” button under “Getting Around”).

1.3 Excel Document Setup.

The slump characteristics of each grid cell will be determined by the mappers and recorded in an Excel Worksheet (Figure A1). Each grid box has a unique identity that is displayed online, and is found under the column “PageName” in the Excel Workbook. Each row in the excel worksheet corresponds to a unique grid cell. (Note: the excel file will only contain the labels of the grid cells that have been assigned to the particular mapper).

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	FID_	PageName	PageNumber	Map	Density	Geomorph	Geomorph2	Size_	Size_Large	DebrisFlow	Confidence	Mapper	Notes	
2	0	A131	1											
3	1	A132	2											
4	2	B131	3											
5	3	B132	4											

Figure A1. Excel worksheet fields (columns). The green coloured fields should be filled in on this sheet. These indicate which grid cells the individual is responsible for mapping. The empty cells (columns D to M) are to be populated by the mapper as they examine each grid cell.

The fields (columns) that mappers must fill in for each grid cell are described briefly in Table A1, **and in more detail in Section 2.2**. The fill-in options are also available through a drop-down menu that appears when Excel cell is clicked (Figure A2).

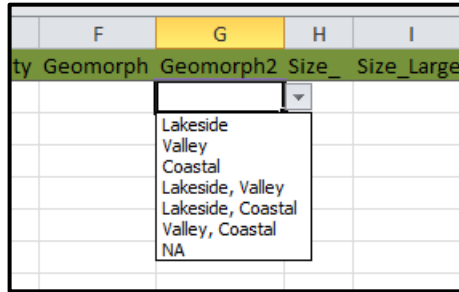


Figure A2. Example drop-down menu in the Excel Worksheet.

Table A1. Scored attributes and values for broad-scale slump grid cell classification. See Section 2.2 for more detail.

Attribute	Values
Map	Y or N
Density of slumps	None, low (1-5), medium (6-14), or high (15+), NA
Geomorphic context	Lakeside, Valley (=fluvial), Coastal, (or a combination), NA
Secondary geomorphic	Lakeside, Valley, Coastal, (or a combination), NA
Maximum slump size	Regular (≤ 5 ha ($=50\,000\text{ m}^2$) in area and ≤ 300 m scar length), mega (> 5 ha, and scar length > 300 m), NA
Largest slump area	In hectares (precise to 2 decimal places), or NA. (NOTE: only required for mega slumps)
Debris flows present	Y or N, NA
Image Quality	Good, Poor
Mapping confidence	Low, High
Mapper	Name
Notes	Document important notes or observations; reasons for low image quality or low mapper confidence; indicate if the density or size of slumps is unusually high, or has resulted in some notable phenomena. Indicate if there is only one slump present.

1.4 To Map:

The mapper must use the viewer and go to the grid square that is to be assessed. Using the Excel Workbook, the mapper must go to the corresponding row and populate fields defined in Table A1. An example of two completed rows describing cells BN68 and BN71 is shown in Figure A3.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
	FID	PageName	PageNumber	Map	Density	Geomorpl	Geomorpl	Size	Size_Larg	DebrisFlo	Image_Qu	Confiden	Mapper	Notes	
a)	3022	BN68	3023	Y	Medium	Coastal	Lakeside	Mega		9 Y	Good	High	Becky		
b)	3025	BN71	3026	Y	None	NA	NA	NA	NA	NA	Poor	High	Becky	cloudy	

Figure A3. Examples of completed Excel rows: a) corresponds to a grid cell (BN68) that contains slumps, and b) corresponds to a grid cell (BN71) that does not contain slumps.

The mappers continue by selecting grid cells and filling in the Excel document accordingly. Periodically save the work in Excel.

The Geospatial warehouse viewer has low-level oblique photographs of the NWT landscape available, which may be used to better assess the terrain in a particular mapping area. Mappers are encouraged to browse these photographs prior to mapping the grid cells. The photographs cannot be viewed at the same time that the grid is being displayed, unless a second viewing window is open. Photographs can be viewed by going to “Map Layers,” found in the information pane on the left-hand side of the screen (Figure A4). If the map layers are not visible, click on the arrow to the left of the “Search, Print Maps, Training & Explore the North...” icon and select the “NWT Ecosystem Classification Flight Lines and Photos” option from the dropdown menu beside “Map Theme”. Once this layer is loaded, flight lines will show when the map is zoomed out, and orange triangles (marking locations with photographs) will become visible when zoomed in. To view the photos, click on the orange triangles.

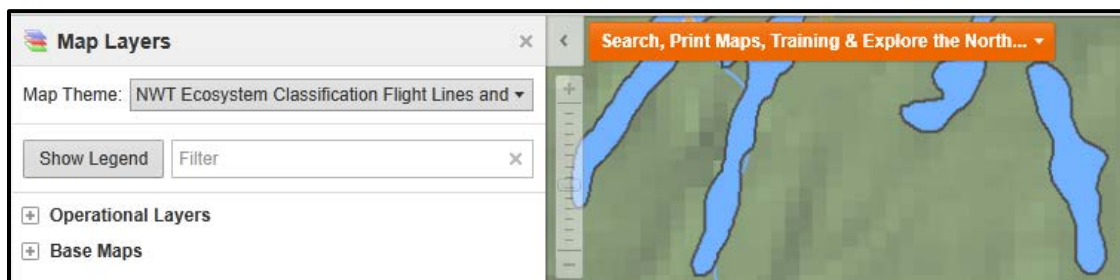


Figure A4. How to access the NWT Ecosystem Classification Flight Lines and Photos.

NOTE: Do not change the column order or titles in Excel, as they need to be standardized between mappers so that the data can be combined at a later date.

1.5 Scale for Mapping.

To ensure consistency between trained technicians, the SPOT 5 and SPOT 4 imagery must be viewed at a scale of 1:25 000 (zooming between 1:20 000 and 1:30 000 is OK). Zoom level can be selected by clicking on “Getting Around” and then typing in the “Map Scale” box. Note: the SPOT imagery cannot be viewed when zoomed in greater than 1:20 000.

1.6 Begin the Trial Section.

There are several regions that will be used for practice interpretation by all technicians. These regions are found in the “NA_SLUMPS_Trial_Areas_yourname.xlsx” document. In this file there are some grid cells that have already been assessed; these should be viewed for practice and familiarization with slump attributes. Mappers should fill in the assigned Excel worksheet and email the completed Excel document to the mapping coordinator (Becky Segal). All excel files will be reviewed by Steve Kokelj and Becky Segal and inconsistencies amongst the results will be determined and discussed. After the trial section, mappers will receive another Excel document indicating designated grid cells for interpretation.

2. ATTRIBUTE VALUES: Definitions and clarification

2.1 Recognizing retrogressive thaw slumps.

Thaw slumps form when ice-rich permafrost on slopes is exposed and begins to thaw (Figure B1). They possess a headwall which defines the upslope boundary of a slump, a scar area, and a debris tongue. Sometimes, a debris tongue of mud and sediment can be seen extending downslope or downvalley, away from the slump. In coastal and lakeside slumps the mass flow is often truncated by the adjacent water body.

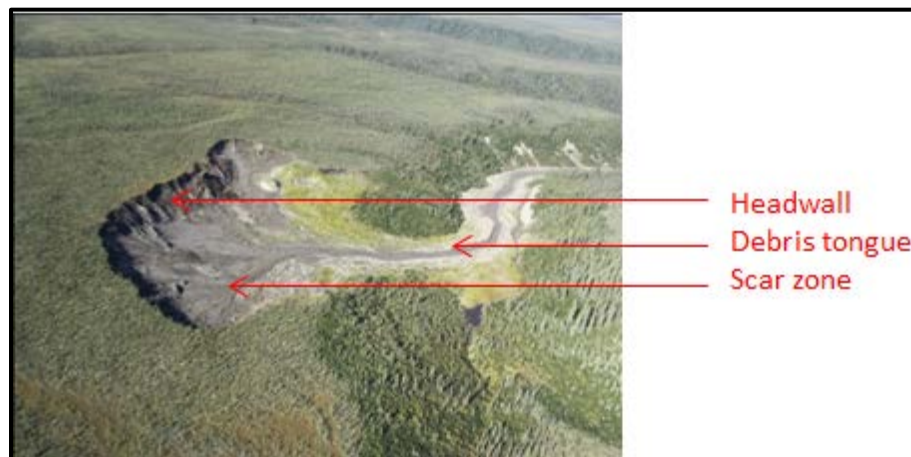


Figure B1. A retrogressive thaw slump with labeled features.

Slumps occur alongside coastlines, lakeshores, and rivers/streams/valleys. The morphology and appearance of slumps vary in different geomorphic settings (see Section 2.3). The headwall, or upslope end, of an enlarging thaw slump is typically crescent shape. The debris tongue may be wide or narrow, depending on the surrounding landscape. Thaw slump debris tongues may extend downslope and infill small valleys (Figure B1), or they may be absent due to an adjacent lakeshore or coastline.

Slumps can be identified on SPOT imagery. While some slumps are too small to see, larger slumps are readily visible. The sample SPOT image below (Figure B2) shows a

region with many large thaw slumps present. Figure B3 shows a stream that has eroded a small canyon, forming small cliffs with cusped tops. These may appear to be retrogressive thaw slumps but they are not.

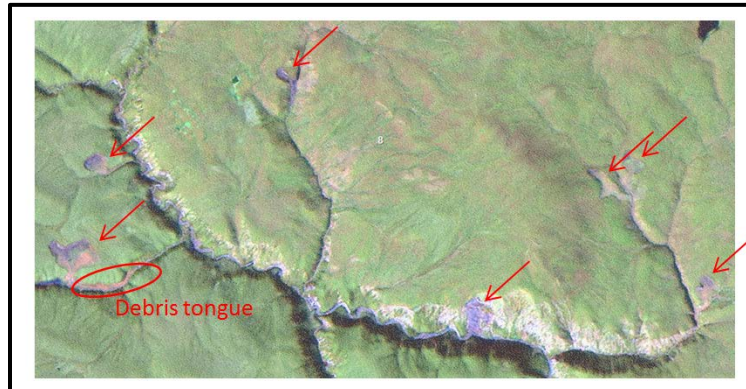


Figure B2. SPOT imagery sample showing a region containing marked thaw slumps (viewed at 1:30 000).



Figure B3. SPOT imagery showing part of Tetlit Creek. The meandering creek has eroded a canyon, creating small cliffs with cusped tops, which could be mistaken for slumps.

When mappers are inspecting images, exposed soils and scar areas of active slumps may look similar to other areas of erosion as they will be characterized by similar colours on the SPOT imagery. Furthermore, eroding valley sides or lakes that have decreased in area may also have a similar shape to lakeside slumps (Figure B4a). Disturbances adjacent to roads may be quarries or other kinds of anthropogenic developments, rather than slumps (Figure B4b). Thaw slumps may look different between SPOT images acquired during different times of the summer, or between different landscape types. It is important to consider where a feature is located on the landscape, and whether the location is typical of where a thaw slump could develop. For contrast with bare soils that are not slumps, Figure B4c shows lakes with numerous slumps that have developed on slopes adjacent to their shores.

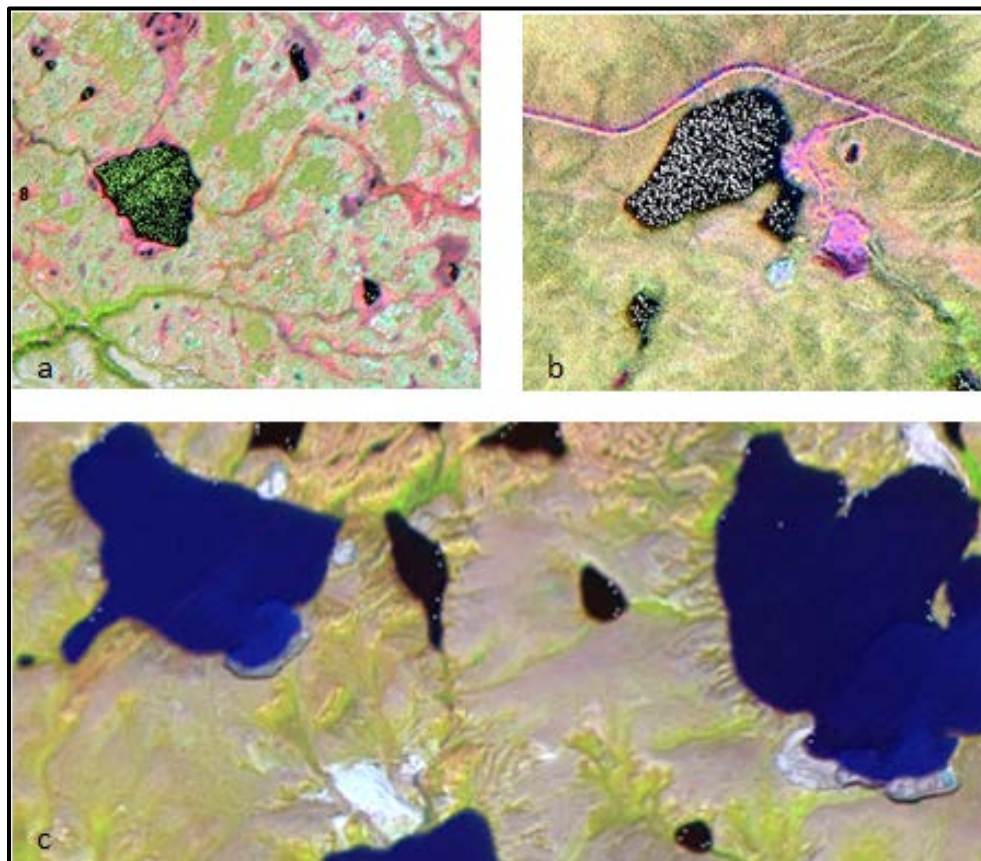


Figure B4. SPOT imagery showing a) a lake that is not surrounded by slumps, but has decreased in size and exposed lake bottom, which now surrounds it's margins, b) a disturbance from a road, including a large quarry and cleared area, and c) several lakes (near Bluenose lake) that are surrounded by numerous large slumps. The distinct colour of some slump-impacted lakes is likely due to suspended sediments in the water column. However, not all lakes showing this colour are affected by slumping.

2.2 Clarification of attributes and values.

The attributes to be recorded in the data table are described in detail below. NA (not applicable) can be used to fill in attribute values where appropriate.

2.2.1 **Map.** Mappers should identify if the grid cell can be mapped? If yes, select “Y”. The mapper should indicate no (N) if there is no available imagery to cover this grid cell, or if the area is 100% water. Note: many of the grid cells underlain by water have already been removed from the database.

2.2.2 **Density of Slumps.** This attribute refers to the number of slumps within a given grid cell. Options include: none, low (1-4), medium (5-14), or high (15+). The mapper should select NA if there is no area to map (i.e., if the grid cell is 100% water). If there is only one slump in a grid cell, this should be indicated in the “Notes” field.

2.2.2.1 It can be sometimes difficult to determine whether slump disturbances consist of a single slump or if they represent multiple features. For this project, **slumps are defined by their occupation of a distinct slope or portion of slope.** In some cases, a debris tongue may connect multiple features, but if individual slumps can be differentiated by distinct lobes on a slope, and do not coalesce on the slope, then they should be considered for this project as individual features. In some cases, polycyclic slumping (slumping followed by stabilization and then re-initiation of slumping) will cause slumps of varying ages to overlap. In such instances, polycyclic slumps can be considered a single feature.

For example, Figure B5a shows four slumps, connected by a mass flow deposit. Figure B5b shows three slumps. The indicated area has lobes on both sides of the valley (on two separate slopes), and counts as two separate slumps. There is another complex feature to the left that has coalesced and is therefore considered one slump. Figure B5c shows two slumps. The disturbance that appears above the stream has merged and is counted as a single slump, and there is also a small slump on the other side of the stream (which is on the opposite slope). Figure B5d shows three slumps. There is one slump on the right-hand slope (made up of two that coalesced to count as one slump), one slump on the opposite side of the valley, and a third at the top of the panel along a separate gulley system. Figure B5e shows two (polycyclic) slumps – one on either side of the stream valley.

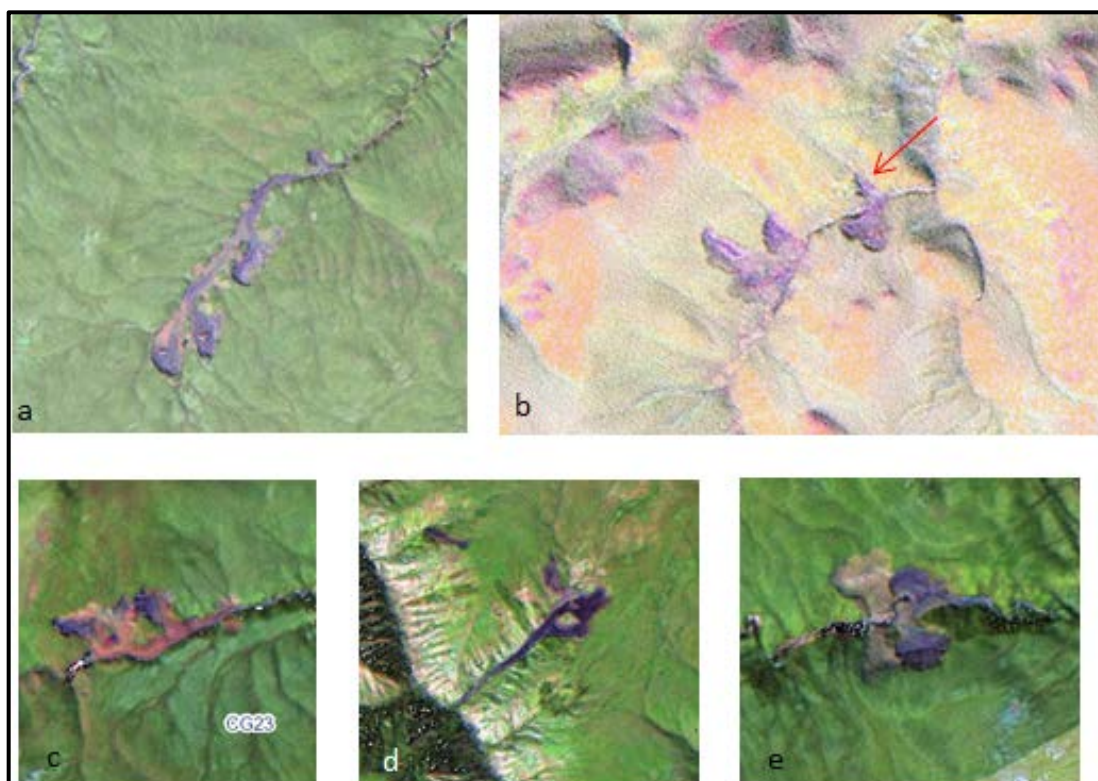


Figure B5. Illustration of when thaw slump disturbances are counted as single or multiple slumps: a) shows four distinct slumps (connected by a debris flow), b) shows three slumps: the area indicated by the arrow has two slumps (on two slopes), and the other disturbance has merged to count as one slump, c) shows two slumps: one large coalesced feature on the upper (north) side of the valley, and one small slump on the opposite (south) side of the valley, d) shows three slumps: one complex comprised of two merged slumps on the right-hand side of the gully, a second slump on the opposite side of the gully, and a third slump in the upper part of the image on another gully system, and e) shows two polycyclic slumps: one on the upper side of the stream and one on the lower side of the stream. The varying colour of the slumps indicates the features on the left have begun to stabilize and revegetate and the two features to the right are active.

2.3 Geomorphic context (Geomorph and Geomorph2). Indicate whether the **majority** of slumps in a given grid cell have formed adjacent to a lake, (Figure B6), river/stream/or valleyside (Figure B7), or along a coastline (Figure B8). The options for this attribute include lakeside, valley, or coastal, a combination of these three, or NA. If slumps are found to be associated with multiple environments within one grid cell, the most common association should be indicated under “Geomorph”, and the other slump-landscape association(s) should be indicated under a secondary geomorphic category, “Geomorph2.” If, however, there are multiple landscape types that are highly impacted (have at least 15 slumps each), those landscapes should be entered under the primary “Geomorph” category. If a grid cell has the same number of slumps within multiple geomorphic contexts, assign the primary geomorphic context to the larger slumps if it is clear (or the ones in which you have more confidence). There are geomorphic categories in the dropdown menu that allow the mapper to select multiple geomorphic units.

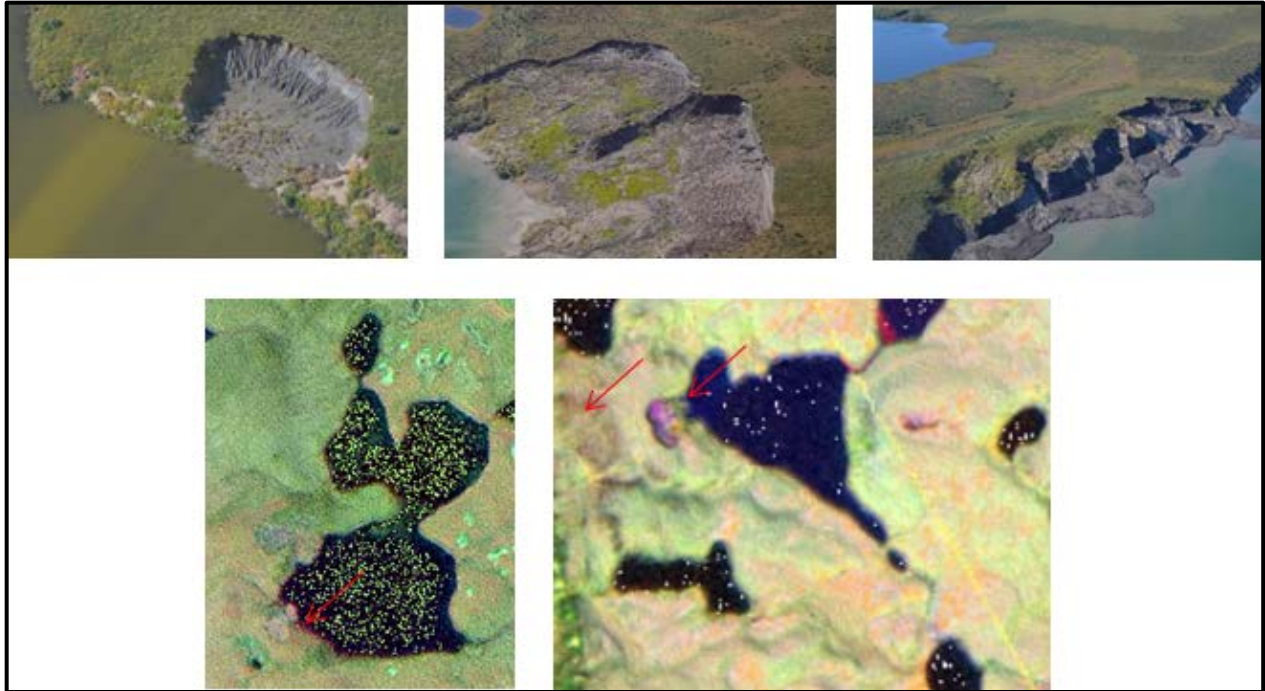


Figure B6. Images of retrogressive thaw slumps adjacent to lakes. Bottom: SPOT imagery. The arrows show slumps.



Figure B7. Images of retrogressive thaw slumps with large debris flows that have formed on valley sides adjacent to small streams. The image on the right shows multiple slumps, a large one on the right and a smaller one on the left side of the valley. The debris flow can make these features look like one individual feature, but since there are crescent-shaped headwalls on opposite sides of the valley, there must be two distinct slumps. (There is actually a third slump up-valley of the small feature on the left side, but it is difficult to see). Note: images of fluvial slumps on SPOT imagery can be seen in Figure B5.

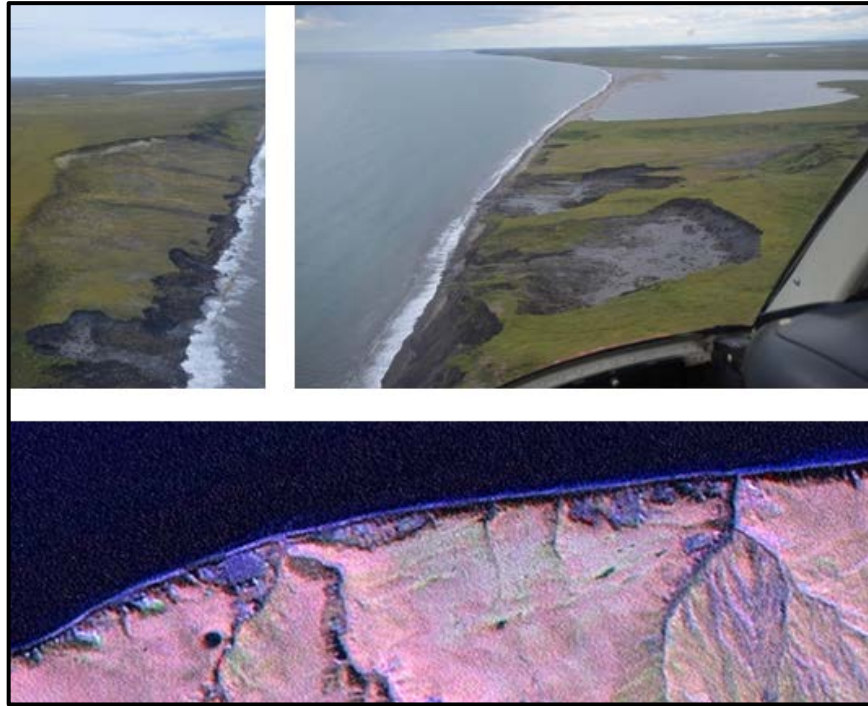


Figure B8. Images of retrogressive thaw slumps adjacent to ocean. The top left photo shows a polycyclic slump. The large, old slump scar may not be visible on SPOT imagery, but if it can be detected, the slump should be mapped as one broad polycyclic slump. In this case, the active portions of the slump are merged together and should be mapped as one slump. The top right photo shows multiple slumps. Bottom: SPOT imagery showing multiple slumps.

2.4 Maximum slump size. This category allows the mapper to determine if large slumps are present within the grid that is being mapped. Very large slumps, here termed “mega slumps” have a scar length >300 m AND a disturbance area of >5 ha ($50\,000\text{ m}^2$). Regular slumps are smaller (<300 m in scar length and ≤ 5 ha in disturbance area).

Measurements of scar length can be made using the “Measure Distance” tool. Scar length is measured parallel to the slope (Figure B9a and B9b), or perpendicular to the water body/valley to the point of the headwall which has progressed furthest upslope. The linear distance between the base of the slope (valley, lakeshore or coastline) and the maximum headwall extent is to be measured. Some slumps, including those shown in Figures B9a and B9b, have multiple headwalls – choose the scar that will give you the maximum scar length. Figure B10 shows an INCORRECT measurement of scar length.

A disturbance area measurement is illustrated in Figures B9c and B9d. To measure disturbance area, click on the “Measure Area” tool and then click to outline the slump; double click to finish. The area should appear in the Measurement Info section. To change the units to hectares use the drop-down menu under “Units.” Disturbance area should be recorded in hectares, to a precision of 2 decimal places.

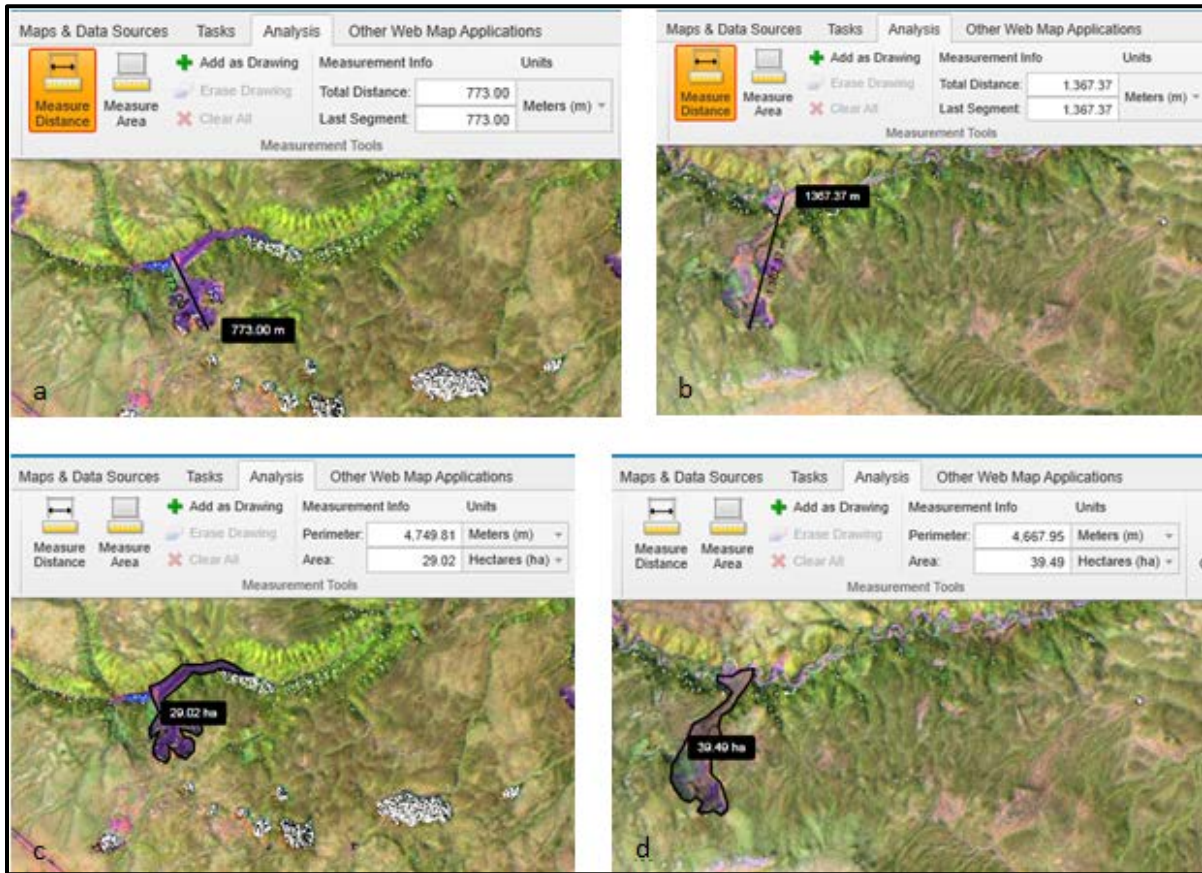


Figure B9. Measurements for classifying slump sizes. Both a) and b) show how to measure slump scar length correctly. These measurements were taken across the thickest section that is near perpendicular to the water body (or valley). Image c) and d) shows how to measure slump area (the debris tongue down the valley was not included in this measurement).



Figure B10. Incorrect measurement of slump scar length. This measurement was taken across the slope.

- 2.4.1 **Measurement of Largest Slump Area (Size_Large).** If there is/are mega slump(s) present, measure the largest slump area using the “Measure Area” tool (as shown in Figure B9c and d). Measure the area, including the debris flow, and record your findings to the nearest hundredth hectare (2 decimal places).
- 2.4.2 **Debris Flow.** Indicate if a significant debris tongue is present and if it extends into a water body or valley bottom. Slump debris tongues consist of material (mud, etc.) from thaw slumps that have flowed downslope. In Figure B9a (above), the debris tongue has developed in the valley and extends to the right of the slumps. Recent debris tongue deposits can also be seen on SPOT imagery in Figures B5a, c and d and on photographs in Figure B7.
- 2.4.3 **Image Quality.** Indicate here whether the image quality is “good” or “poor.” On poor quality imagery (Figure B11), slumps may be present but could be obscured by image quality. This imagery may also have clouds, be very dark, or have been taken during a season when slumps are hidden.

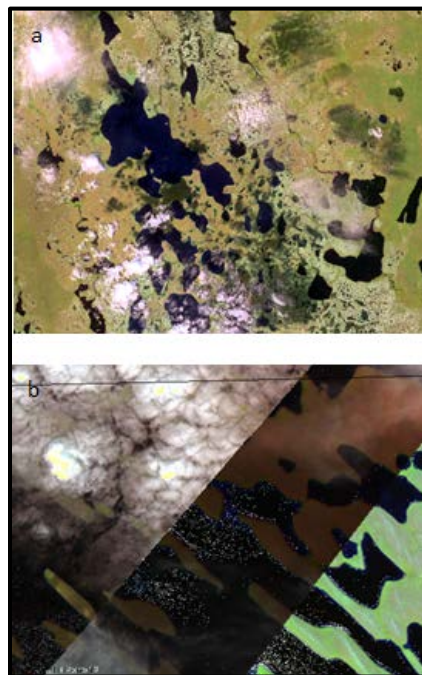


Figure B11. a) A SPOT image where clouds obscure some of the landscape, and b) part of a grid cell that should be flagged as having poor quality SPOT imagery.

- 2.4.4 **Interpretation confidence.** This field allows the mapper to indicate how confident they are in their assessment of the grid cell. Options are low or high confidence. Factors that can affect confidence include slump size (if they are small, they can be more difficult to identify), and landscape (there may be features that look similar to slumps). Grid cells that are flagged with low confidence will be examined closely by

expert reviewers.

2.4.5 **Map Interpreter.** The first name of the mapper must be entered in this column (formerly referred to as “Mapper”)

2.4.6 **Notes.** This section should be used (sparingly) to indicate anything unusual or important. If a grid cell has been flagged with low confidence or poor imagery quality, the reasons for this assessment may be entered here. Also, this section can be used to identify any grid cells that have an extremely high density of slumps (at least 25 slumps), or only one slump.