Surficial characteristics and the distribution of thaw landforms (1970 to 1999), Shingle Point to Kay Point, Yukon Territory

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Introduction

The Beaufort Sea coast, Yukon Territory, has been the subject of numerous studies documenting rates of coastal retreat and investigating geotechnical properties of materials in areas of proposed development. While these focused studies also assist in understanding coastal and offshore processes controlling erosion, sediment transport and the development of offshore permafrost, they do not address some key surficial characteristics which contribute to the geomorphology of the area. The surficial geology of the Yukon Coastal Plain, from the western Mackenzie Delta to Clarence Lagoon, including the area from Shingle Point to Kay Point, was mapped by Rampton (1982) at a scale of 1:125 000. Detailed surficial, subsurface and offshore material investigations were undertaken in the area immediately surrounding King Point (Hill 1990), Kay Point (Lewis 1975;) and Sabine Point (Harry et al. 1988). The surficial materials consist of pre-glacial marine and fluvial deposits, glacial-aged till, glaciofluvial deposits and post-glacial lacustrine, fluvial and marine deposits. These surficial materials, in places, contain significant amounts of ground ice which is exposed by retrogressive thaw failure and is associated with local coastal retreat of up to 7 m/a (e.g., Mackay 1963; Forbes and Frobel 1985; Hill 1990). Permafrost history and related origin of massive ice in sediments have been presented by Harry et al. (1988) at Sabine Point. They suggest that polycyclic thermokarst activity has been ongoing since the Wisconsinan, and is responsible for the hummocky topography east of King Point along with the presence of numerous lakes.

Field investigation in July 1999 revealed an abundance of thaw landforms along the immediate coast from Shingle Point to Kay Point. While thaw landforms are abundant in the form of active and relict retrogressive thaw flowslides (thawslides), what was most apparent in 1999, was the abundance of active-layer detachments. Therefore, it was important to document the occurrence of these landforms in 1999 in order to establish a baseline comparison to past and future years.

The objectives of this study are (1) to describe the surficial geology of the immediate coastline from Shingle Point to Kay Point with a view towards the geomorphic evolution of the area; (2) to document the locations of retrogressive thaw flowslides and active-layer detachments in this area; (3) to describe the relation between surficial materials and the distribution of these thaw landforms; and (4) to determine the changes in distribution and frequency of the thaw landforms for the period from 1970 to 1999.

Glacial history and physiographic setting

The morainal deposits identified by Rampton (1982) were emplaced during the Buckland Glaciation, a north-west advance of the Cordilleran Ice Sheet, proposed to be Early Wisconsinan in age, and a late Wisconsinan re-advance, termed the Sabine Phase. The limits of these advances are marked by morainal ridges to the south of the mapped area, along the Barn Mountains and by a morainal belt adjacent to Sabine Point. Retreat of this ice sheet was accompanied by the formation of lake basins and outwash complexes which cover much of the study area. Post-glacial thermokarst modification has resulted in extensive lacustrine deposits and the redeposition of material through retrogressive thaw failure. West of King Point, high-relief ridges dissected by gullies were formed during this Sabine re-advance. Glacial overriding has resulted in folded and faulted sequences of pre-glacial deposits.

Methods

Field investigations in July 1999 along the Yukon Beaufort Sea coast, from Shingle Point to Kay Point included detailed ground observations, and remote observations by boat and helicopter (Figure 1). Thaw landforms, namely retrogressive thaw flowslides and active-layer detachments, were classified according to their level of activity. These distinctions were based primarily on headwall and vegetation characteristics. This classification scheme was developed to clarify differences between active thaw landforms and those which had begun to stabilize, and to define the type of landform referred to when documenting the change in activity that had occurred in the area since 1970.

Detailed measurements of the dimensions of thawslides and active-layer detachments were also taken (Figure 2). *Width (w)* refers to the maximum length from one side of the failure to the other, parallel to the shoreline. The *length* of each side of the actively-eroding slump, denoted by s_1 and s_2, is measured perpendicular to *w*. The *perimeter (p)* defines the distance around the actively-eroding failure; where the *outlet width* (*o)* is the narrowest part of the debris flow outlet. The maximum height of the *headwall* (*hw*) is the height from debris in the bottom of the eroding face to the base of the vegetation mat at the top. The locations of each retrogressive thawslide and active-layer detachment observed on foot were recorded using a hand-held GPS. Those observed by boat and helicopter were located on 1985, 1:31 000 airphotos and coordinates obtained by referencing these photos to a digital base map obtained from Geomatics Canada.

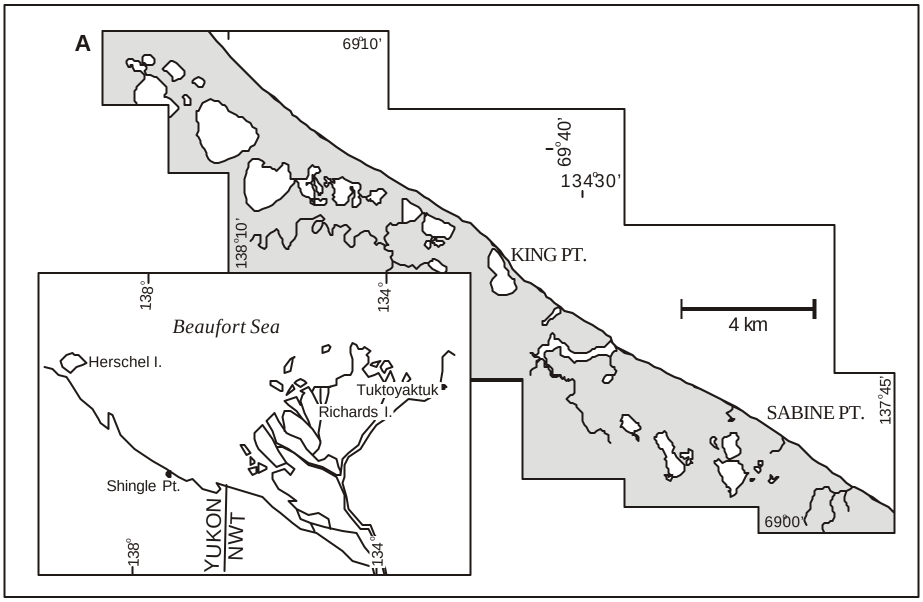
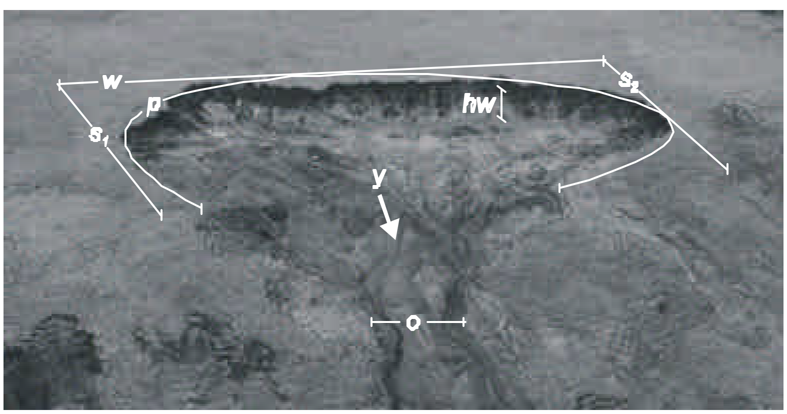


Figure 1: Study area showing area covered in detail by ground observations in 1999.



w: width of slump, parallel to shore
s1, s2: length of slump on each side, measured perpendicular to *w*
p: perimeter of slump face
o: width of narrowest part of outlet
hw: height of headwall
y: orientation of slump

Figure 2: Illustration of retrogressive thaw flowslide measurements taken.

Changes in the distribution and frequency of thaw landforms were documented by examining 1970 airphotos at a scale of 1:23 000, and 1985 airphotos, at 1:31 000. The minimum resolution (i.e. the smallest detectable landform) was selected at 1 mm. For the 1970 photos, this meant that any landform with largest dimension less than 23 m was not recorded, and for 1985 airphotos, any less than 30 m. To maintain consistency and to not bias comparison, any landforms in 1999 that had a largest dimension less than 30 m, were not included in the comparison study.

To accompany the detailed distribution and classification of thaw landforms, the surficial geology, as presented by Rampton (1982) was examined for the immediate coastline within the study area in order to evaluate the association of thaw landforms with surficial materials. Ground truthing was limited to the immediate coastline, and only where wave undercutting, block slumping or retrogressive thaw failure had exposed sediments in section. Additional units were added, to denote areas that appear to have been modified by modern (Holocene) thermokarst processes, ice-thrusted deposits which contain significant amounts of gravel, and an outwash channel.

Landform classification and description

Retrogressive thaw flowslides

A total of seventy-three active retrogressive thaw flowslides were identified along the coast from Shingle Point to Kay Point in 1999. Of these, 30 were studied in detail and classified according to the scheme presented in Figure 3. The classification was designed to differentiate between currently active landforms (1^{o}), those that have begun to stabilize (2^{o}), and those that are

RETROGRESSIVE THAW FLOWSLIDE

1°

Exposed, icy headwall, thickest at maximum extent of slump and decreasing sideways; no established vegetation in slump.

2°

Some headwall, but sloughed in; green vegetation, often mastodon plant.

3°

No headwall, grass dominates slump.

ACTIVE LAYER DETACHMENT

1°

Failure to depth of active layer, consistent thickness around failure; no exposed icy headwall, push debris; flow follows topography; no established vegetation.

2°

Established vegetation, form of failure preserved.

Figure 3: Classification scheme used for retrogressive thaw flowslides and active-layer detachments.

no longer active (3^{o}). From oblique aerial photographs taken in 1999 at 400 - 600 m elevation, it is apparent that 1^{o} thawslides greatly outnumber 2^{o} thawslides, and that the headwalls of many of these active thawslides are located beyond the old headwall locations of stabilized, 3^{o} thawslides. In addition, 3^{o} thawslides are larger than 1^{o} or 2^{o} thawslides, because the trace of the headwall of a stabilized slump often represents the maximum extent of several thawslides that have encroached upon one another, and may have been active during different times. Where a solitary thawslide occurs, it is considered *simple*, whereas several thawslides which share a common outlet are considered to be *compound*. Compound slides were measured as individual thawslides since they were separated by a point consisting of dry talus.

Active-layer detachments

Eighty-nine active-layer detachments were identified along the coast in 1999. Twenty-five of these were studied in detail, observing their level of activity and dimensions. These were classified according to the scheme in Figure 3. In some cases, it was difficult to differentiate between a 2^{o} active-layer detachment and a small 2^{o} thawslide. In these cases, the decision was often based on the presence or absence of a push lobe of material at the base of the slide (as opposed to a track of debris) and the height of the relict headwall. The active-layer detachments were typically smaller than thawslides, with an average width of 24 m, the largest being 55 m and the smallest 8 m wide.

Surficial geology

The distribution of surficial materials for the area is described by Rampton (1982) along with detailed stratigraphic information and glacial history. Surficial units are divided into Buckland and post-Buckland (including modern) deposits.

<u>*Buckland-age deposits*</u>

*Ice-thrusted deposits (**Mr, Mt**)*

Rampton (1982) refers to a unit of ice-thrusted deposits along the coast from just west of King Point to just south of Kay Point. This unit consists of pre-Buckland-aged marine silts and clays, rusty gravels and crossbedded sands and silts interbedded with organic material that were deformed and uplifted by overriding Buckland ice. This unit is sub-divided to reflect differences in deposit characteristics.

The segment of coastline just west of King Point designated as **Mr**, consists of folded marine silts with abundant shell fragments, sand and gravel in repetitive sequences, forming NW-SE-trending ridges up to 70 m above sea level. Where exposed in section, the material in this unit has an abundance of well-sorted gravel resembling fluvial material. Isolated, simple retrogressive thaw thawslides expose deformed beds of massive ice at least 12 m thick below 2 -3 m of icy sand and gravel (Figure 4).

The rest of the ice-thrusted deposits are designated as **Mt**, which has been identified to reflect the till cover overlying the marine and fluvial sequences. This unit rises from 30 to 40 m elevation at its southeastern limit, to 60 m at its northwesternmost limit, where steep-sided

Figure 4: Gravelly ice-thrust till (Mr) west of King Point.

Figure 5: Active thawslide at King Point. Deformed massive ice (A) underlain by icy till with reticulate ice (B).

gullies expose folded and repetitive strata. Simple and compound retrogressive thaw flowslides expose 2 - 10 m of massive ice. Evidence of thrusting, in the form of resistant, vertical beds is present well-inland, where the unit is truncated by the Babbage River and its tributaries. The coastal segment of this unit is retreating at a rate of 1 to 3 m/a (Lewis 1975; Forbes and Frobel 1985).

*Other till terrain (**Mh, Mb**)*

Hummocky till (**Mh**), occurs southeast of King Point, as isolated, steep-sided hills surrounded by lacustrine deposit and as undulating plateaus which are locally stream-dissected. Rampton (1982) suggests that this till was emplaced during a re-advance of Buckland ice, termed the Sabine Phase. The material is largely composed of silt and clay-rich diamict (O'Connor and Associates 1986). Both Harry et al. (1988) and Rampton (1982) have suggested that the terrain within this "hummocky moraine" is cored by massive ice, and that the topography is due to thermokarst activity. Retrogressive thaw flowslides are simple and compound, and reveal up to 10 m of highly deformed massive ice in their headwalls. The top of the massive ice (2 -3 m below surface) is truncated by a thaw unconformity, above which the till contains reticulate ice to within about 1 m of the surface (Figure 5). While deformed icy beds are obvious below the thaw unconformity, they are difficult to trace above it where the till is mottled and clasts are iron-stained. In one exposure, near Sabine Point, the massive ice is overlain by clear ice, suspected to be segregated in origin (Harry et al. 1988). The true thickness of this unit (ice included) is unknown. Coastal retreat within this unit is up to 7 m/a (e.g., Mackay 1963).

The area designated as till blanket (**Mb**), occur towards the southeast end of the mapped area. It has lower relief, and where retrogressive thaw flowslides have exposed deposits they appear to have less massive ice at depth, suggested by the lower height of the headwalls.

*Glaciofluvial deposits (**Gf**)*

High-level outwash terraces (**Gf**) are found west of King Point, and an outwash channel dissects ice-thrusted deposits approximately 11 km west of King Point. Ice-wedge polygons are well-developed on terraces. Along the coast, south of Kay Point, thermo-mechanical erosion of these polygons has resulted in block slumping and erosion rates of up to 5 m/a (Lewis 1975).

<u>Post-Buckland deposits</u>

*Lacustrine deposits (**Lp**)*

Lacustrine plains (**Lp**) are thick, flat-lying, fine-grained and may be underlain by till of unknown age (Rampton 1982). They have a thick peat cover and exhibit well-developed ice-wedge polygon networks. Some of these areas may include a lacustrine veneer where post-Buckland lakes developed during a time of higher lake levels than at present. These deposits may be less than 1 m thick, as they are not flat-lying but mantle underlying topography. Lacustrine areas showing thermokarst terrain are also denoted. These areas are flat-lying, wet, and often contain modern lakes. These areas were likely covered by post-Buckland lakes, but may have represented areas which were deeper. As permafrost aggraded into surrounding deposits, these basins may have remained as taliks. Today, however, they are frozen, and contain ice-wedge polygons. This unit may also represent areas where hummocky till has been thermally eroded and the locations of present lakes are remnants of larger lakes which resulted from this erosion.

*Fluvial deposits (**Ft, Ap**)*

Fluvial deposits of the Babbage River occur as higher-level terraces (**Ft**), and the modern floodplain (**Ap**). Their ice content is unknown, but is presumed low.

*Marine sediments (**ms**)*

The long spit at the end of Kay Point, and those which close breached lakes west of King Point are composed of silt, sand and gravel, < 2 m high. Driftwood is abundant along the crests of these spits and onto the backshore.

Landform distribution

Figure 6 shows the surficial geology and the distribution of 1^{o} active-layer detachments and retrogressive thaw flowslides along the coast. Thawslides are found mostly adjacent to the coastline, with some along the shores of inland lakes and rivers. They occur in ice-thrusted deposits west of King Point, and in hummocky till east of King Point. Smaller thawslides occur in till blanket material just west of Shingle Point. No active thawslides were found in glaciofluvial or lacustrine materials in 1999, but isolated thawslides can be seen within glaciofluvial and lacustrine units on 1985 airphotos. Abundant thawslides within the hummocky till and ice-thrusted deposits are testament to their high ice content. Headwalls of active failures expose up to 12 m of massive ice (deformed icy till), which may be thicker since meltout debris at the base of active failures conceals the base of the ice. The dominantly coastal occurrence of these landforms is likely due to the removal of slump debris once it reaches the shoreline, which aids in maintaining a steep gradient. In addition, wave activity along the shoreline permits undercutting and continuous removal of debris (e.g., Mackay 1986). Although thawslides do not require a removal of material from their base to continue melting, removal of this material certainly accelerates this process (Mackay 1966). Since slump debris with high water content tends to move downslope as a fluid mudflow, and is more likely to reach the shore where it can be eroded, thawslides in materials with high ice contents propagate faster than those with lower ice contents and drier talus material. The occurrence of thawslides along the shores of drowned lakes, particularly the drowned valley east of King Point (Rampton 1982) means either that local wave activity may be of significance in the initiation of thawslides, or that lake levels periodically rise so that thermo-mechanical erosion of the shoreline and the initiation of thawslides is possible. The latter hypothesis is supported by the fact that thawslides along this lake in particular occur along both sides; this would not likely be the case if there was a dominant wind direction during a storm event. Alternatively, since the spit which separates the lake from the ocean is < 2 m high, and driftwood is abundant within the lake itself, a storm surge could cause a rise in water levels accompanied by waves and currents, promoting thawslide activity.

Thawslides occurring on the shores of higher elevation lakes are removed from oceanic influence. Therefore, these thawslides may be attributed to microclimatic effects, as many are south-facing and therefore subject to thermal erosion by solar insolation.

Active-layer detachments are also most common along the coast, with fewer inland occurrences. Their distribution is similar to thawslides, but they are more common in ice-thrusted deposits and do not appear to occur in glaciofluvial or lacustrine deposits. These landforms also very commonly occur within older, 3^o thawslides. There are numerous reasons why these revegetated slump bowls may be favourable to active-layer detachment development. There may be more ice at the base of the active layer, there may be steeper slopes associated with former slump bowls, the active layer may be more poorly insulated due to vegetation differences, or the slump bowls may favour snow accumulation, resulting in deepening of the active layer. Certainly, the hydrological properties of the active layer in and outside the bowls of old thawslides deserve more study to determine their influence on active-layer detachment distribution. The lack of annual observations makes it difficult to make associations between active-layer detachments and thawslides, but it is possible that detachments initiate the development of thawslides, especially where there is no direct coastal undercutting. In many places, particularly along the ice-thrusted coast west of King Point, active-layer detachments and thawslides occur at elevations as high as 60 m, well back from the shoreline. The removal of surface material through detachment and exposure of underlying permafrost may be sufficient to initiate thawslides in these areas.

Changes in distribution (1970 - 1999)

Although a distinction between 1^o, 2^o and 3^o thawslides has been made, without annual observations it is not possible to determine the time period that elapses before a 1^o thawslide becomes a 2^o thawslide. Mackay (1966) suggested that the re-establishment of vegetation in the base of the slump depends on the retreat rate and angle of the slump face while it is active, as it influences whether hummocks falling from the top land right-side up, favouring revegetation, or up-side down. For this reason, only the distribution of active (1^o) thawslides is compared.

Figure 6 shows the distribution of *all* thawslides and detachments identified in the study area, regardless of size. As mentioned previously however, only landforms larger than about 30 m were detectable on 1985 photos, and only those larger than about 23 m on 1970 photos. It is reasonable, then, to expect that significantly more of these landforms are displayed in 1999, where no such restrictions exist. To illustrate, from ground observations in 1999, 28 % of thawslides (7 of 28) had a largest dimension smaller than 30 m. If the average size of these landforms is more or less constant for the observation period, then 1970 and 1985 thawslides and detachments are under represented in Figure 6. Likewise, in 1999, 62% of detachments measured on the ground were smaller than 30 m, indicating that their distribution as documented by airphoto observation is underestimated as well. Nevertheless, by comparing just the number of landforms which meet the resolution criteria, there has been an increase in the number of thaw landforms in the study area from 1970 to 1985 to 1999. Twenty-seven active (1^o) thawslides and 30 active (1^o) detachments were identified in the area in 1970. In 1985, 51 thawslides and 44 detachments were identified, and in 1999, thawslides numbered 64, and detachments 67 (inset graph, Figure 6). This increase in distribution may be due to changing climate in the area. Wolfe et al. (2000) reported, from limited climatic data available from Environment Canada, that in 1998 (the year preceding observation) the average annual surface temperature was 4^oC higher than any previous year on record. Although speculative, lacking precipitation data, it may be this increase in surface temperature which has resulted in the increase in detachment and thawslide activity. In addition to an increase in number of these landforms, there are also changes in their distribution, namely in the area surrounding the drowned valley. This, as mentioned previously, could be linked to storm surge activity.

Summary

Detailed observations of surficial geology, and the distribution of thaw landforms may be useful in identifying areas which are susceptible to thermal erosion. Ice-thrusted deposits and hummocky till have high occurrences of thawslides and detachments. The detailed documentation of the locations and physical characteristics of these landforms may be useful in understanding their development and evolution. Although observations indicate an increase in the number of these landforms from 1970 to 1985 to 1999, annual observations are necessary to determine the cyclicity of these landforms and strengthen the association between coastal and coastland processes. Detailed geotechnical observations are required to investigate the relation, if any, that exists between active-layer detachment and thawslide occurrence.

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