

1 Thermokarst landforms and associated conditions

1.1 Ice wedge and hillslope thermokarst landforms

1.1.1 Thermo-erosional gullies and deepened troughs

Thermokarst landforms associated with ice wedges include 1) deepened ice wedge troughs, 2) thermo-erosional gullies, and 3) ice wedge melt ponds. These features occur most commonly in the continuous permafrost zone, where ice wedges are most abundant (Chiasson and Allard, 2022; Kokelj et al., 2014; O'Neill et al., 2022). Based on the literature, these thermokarst landforms are also most strongly associated with hillslope thermokarst landscapes (Table S1). Ice wedge thermokarst landforms are recorded across the Arctic Archipelago on Banks (Burn et al., 2021; Farquharson et al., 2019), Prince Patrick (Farquharson et al., 2019), Ellef Ringnes (Farquharson et al., 2019; Liljedahl et al., 2016), Ellesmere (Becker et al., 2016; Ward Jones et al., 2020), and Richards Islands (Burn et al., 2021). Recorded observations of increasing trough ponds in Arctic terrain have also been mapped through analysis of trends in satellite imagery (Fraser et al., 2023).

Table S1. Permafrost terrain and ground ice conditions associated with ice wedge and hillslope thermokarst landforms based on frequency tables. Maximum (modal) values in **bold**, percentages $\geq 5\%$ in *italics*.

Thermokarst Landforms	Thermokarst Landscape^ H = Hillslope L = Lake W = Wetland (Olefeldt et al., 2016).	Permafrost zones (Heginbottom et al., 1995)	Biomes (Dyke et al., 2004)	Surficial Deposits (Fulton, 1995)**	% Peat Cover (Tarnocai et al., 2011)	Past Ground Ice* R = Relict S = Segregated W = Wedge	Modern Ground Ice* (O'Neill et al., 2022)	Holocene Ground Ice Loss
Deepened ice wedge trough	H <i>H</i> <i>H-W-L</i>	Continuous	Herb tundra <i>Shrub tundra</i>	Till blanket (f) <i>Weathered reg. ven.</i> <i>Colluvial (f)</i> <i>Marine offshore</i>	None <i>Very low</i>	R-W-S W-S-r r-s-w <i>S-W-r</i> <i>S-w-r</i>	R-S-W W-S s-w <i>S-W</i> <i>S-w</i>	R, S, W = Neg.
Thermo-erosional gully	H-w-l <i>H-l-w</i>	Continuous	Herb tundra <i>Shrub tundra</i>	Till blanket (f) Glaciofluvial Pl.	None	R-S-W <i>R-w-s</i>	R-S-W <i>R-S-w</i>	R, S, W = Neg.
Ice wedge melt pond	H-W-l <i>W-H-l</i> <i>L-H-w</i>	Continuous <i>Discontinuous</i>	Shrub tundra <i>Boreal forest</i> <i>Herb tundra</i>	Till blanket (f) <i>Lacustrine</i> <i>Glaciofluvial</i> <i>Hummocky till (f)</i>	Very low <i>Low</i> <i>None</i> <i>Negligible</i>	R-S-w <i>R-S-w</i> <i>none</i>	S-W-r <i>S-W-r</i> <i>w</i>	R = Most S = Neg.-Partial W = Neg.-Partial
Retrogressive thaw slump	H <i>W-H-L</i> <i>H-L-w</i>	Continuous	Shrub tundra <i>Herb tundra</i>	Till blanket (f) <i>Hummocky till (f)</i> <i>Till moraine (f)</i>	None <i>Very low</i> <i>Neg</i>	R-W-S <i>S-W-r</i> <i>R-S-W</i>	R-W-S <i>R-S-W</i> <i>S-W</i>	R = Neg.-Most S = Neg.

(RTS)	<i>H-w-l</i>		<i>Boreal forest</i>			<i>R-S-w</i>	<i>W-S</i>	W = Neg.- Partial
Active Layer Detachment Failure (ALDF)	H-L-w <i>h</i> <i>L-H-W</i> <i>H-w-l</i> <i>W-H-l</i>	Continuous <i>Discontinuous</i>	Herb tundra <i>Boreal forest</i> <i>Shrub tundra</i>	Colluvial (f) <i>Glaciomar. offsh.</i> <i>Till blanket (f)</i> <i>Weathered reg.</i> <i>Hummocky Till (f)</i> <i>Glaciolac. offshr.</i>	None <i>Low</i> <i>Negligible</i> <i>Very low</i>	S-W-r <i>s-w-r</i> <i>S-r-w</i> <i>R-S-w</i> <i>W-R-S</i>	S-W <i>R-S</i> <i>s-w</i> <i>r-s</i> <i>S</i> <i>S-w</i>	R = Most S = Neg. W = Neg.- Partial
Deep-seated permafrost landslide (DSPL)	W-l-h <i>none</i> <i>h-w-l</i> <i>W-h-l</i>	Discontinuous <i>Continuous</i>	Boreal forest	Till veneer (f) <i>Till blanket (f)</i>	Negligible <i>None</i>	s-r-w <i>R-S-w</i>	<i>s-w</i>	R = Complete S = Partial W = Partial

20 ^ Capitalization (H, L, W) represents thermokarst landscapes in medium-to-high abundance and lowercase (h, l, w) low to negligible abundance. The order of letters represents the relative dominance of each thermokarst landscape type.

*Capitalization (R, S, W) represents medium-to-high ground ice abundance and lowercase (r, s, w) low to negligible abundance. The order of letters represents the relative dominance of each ground ice type.

25 **The surficial dataset of Fulton (1995) was modified to parse out dominantly coarse (c) vs. fine-grained (f) till based on underlying bedrock geology as described in O'Neill et al. (2019)

Deepened ice-wedge troughs result from top-down melting of wedge ice and subsidence due to increasing thaw penetration (e.g., Farquharson et al., 2019). In contrast, thermo-erosional gullies are formed by runoff that rapidly melts ice wedges and contributes significant convective heat exchange to thawing (Fortier et al., 2007). These gullies may include retrogressive scarps within the eroded troughs (Fortier et al., 2007). Deepened troughs and thermo-erosional gullies occur in well-drained locations, with gullies acting as key surface drainage pathways (Fortier et al., 2007). Although deepened ice wedge troughs provide a conduit for ice wedge meltwater to drain through active layer materials (Burn et al., 2021), they are not typically associated with channelized or erosive overland flow, as in the case of thermo-erosional gullies.

1.1.2 Ice wedge melt ponds

Ice wedge melt ponds form in ice wedge troughs in topographic settings where drainage is impeded. The extent of ice wedge melt ponds is actively expanding across the Canadian Arctic in response to warmer air temperatures and progressive ice wedge degradation (Fraser et al., 2018, 2023). These ponds are associated with flat upland terrain (Fraser et al., 2018) but also form on hillslopes in troughs that are parallel to the elevation contour, provided the subsidence lowers the pond surface below permafrost in the downslope direction (Burn et al., 2021).

These thermokarst landforms are mainly associated with hillslope-dominated thermokarst
landscapes and secondarily in association with areas mapped as lake and wetland landscapes
(Table S1). They occur within the continuous permafrost zone (Chiasson and Allard, 2022;
Kokelj et al., 2014) in herb tundra and shrub tundra biomes, where peat cover is typically absent
or very low (Table S1). Nevertheless, thermo-erosional gullies may also occur locally at sites
with up to 30 cm of sandy peat (Gagnon and Allard, 2020). Fraser et al. (2018) documented
abundant ice wedge thermokarst on Banks Island, in the form of ice wedge melt ponds on
hilltops, which may further lead to the formation of high-centred polygons and thaw lakes. These
ice-wedge thermokarst landforms are mostly associated with fine-grained till blanket deposits,
with deepened troughs and ice wedge melt ponds also occurring within weathered regolith,
colluvial, and marine sediments (Table S1). Thermo-erosional gullies also occur on glaciofluvial
outwash plain sediments, and typically where modelled wedge ice abundance is medium to high.
Although these ice wedge thermokarst landforms are inherently tied to landscapes with well-
developed ice wedge polygons, segregated and relict ice may also be present in these cold
permafrost environments (Bernard-Grand'Maison and Pollard, 2018; Fraser et al., 2018).
Modelled Holocene ground ice loss associated with deepened ice wedge troughs and thermo-
erosional gullies is generally negligible, as they occur primarily in cold continuous permafrost
regions where ground ice has accumulated over time. In contrast, ice wedge melt ponds are
found in areas of greater predicted ground ice loss, including partial loss of segregated and
wedge ice and most loss of relict ice (Table S1).

1.1.3 Retrogressive thaw slumps

Retrogressive thaw slumps (RTS) are slope failures in permafrost terrain that enlarge
progressively due to ablation of exposed massive ice or ice-rich sediments (Lewkowicz et al.,
2025). They are characterized by a retreating ice-rich headwall and a scar area transporting
thawed debris downslope (Lacelle et al., 2015). They may be initiated by coastal, river, or
lakeshore erosion, or by stream incision, and may also evolve from active-layer detachment
failures (ALDF) (Lewkowicz and Way, 2019). They occur predominantly in the western Arctic in
the Northwest Territories and Yukon Territory, with other observations in the central and high
Arctic. RTS are observed throughout the Canadian Arctic Archipelago, including on Banks

(Evans et al., 2021; French, 1974; Heginbottom, 1978; Rudy et al., 2017a; Segal et al., 2016),
75 Melville (Heginbottom, 1978), Bylot (Coulombe et al., 2019), Baffin (Hyatt et al., 2003),
Ellesmere (Campbell-Heaton et al., 2021; Smith, 1999; Ward Jones et al., 2019) and Axel
Heiberg Islands (Ward Jones et al., 2019). They are extensively mapped across the western
Arctic in association with coastal, valley, and lakeside geomorphic settings (Kokelj, 2017; 2021).
They are common on the Yukon Coastal Plains (de Krom, 1990; Harry et al., 1988; Lacelle et al.,
80 2004; Lenz et al., 2013; Lantuit and Pollard, 2008; Lantuit et al., 2012; Wolfe et al., 2001) and
Tuktoyaktuk Coastlands and extend southward into the Mackenzie Valley (Littlefair and Tank,
2018) and into central and southern Yukon Territory (Burn, 2000; Burn and Smith, 1990;
Huscroft et al., 2003).

RTS are dominantly associated with mapped hillslope thermokarst landscapes, though they also
85 occur in association with lake and wetland landscapes (Table S1). They occur primarily within
continuous permafrost, with very few observations in the discontinuous permafrost zone (Table
S1). They are mainly associated with herb tundra biome and extend into shrub tundra and boreal
forest biomes (Table S1). Peat cover associated with observed slumps is absent to low within
herb tundra biomes and ranges from negligible to low within shrub tundra and boreal biomes.

90 RTS are most common in areas of fine-grained till blanket, hummocky till, and till veneer
deposits (Table S1), but also in glaciomarine deposits, such as in the Fosheim Peninsula of
Ellesmere Island (Smith, 1999). Modelled ground ice conditions associated with RTS typically
include relict, segregated, and wedge ice in moderate to high abundance. Holocene ground ice
loss in areas with slumps is commonly negligible, as they occur mainly within continuous
95 permafrost. However, slump-affected regions within discontinuous permafrost may occur in
areas with segregated ice that have lost all relict ice and have had a partial loss of wedge ice
(Table S1).

1.1.4 Active layer detachment failures

100 Active layer detachment failures (ALDFs) are the resulting shallow translational landslides
formed by the rapid downslope movement of a thawing surface layer over frozen ground
(Lewkowicz et al., 2025). They occur following the development of high porewater pressures
either by the rapid melting of ground ice near the base of the active layer (Lewkowicz, 2007) or

due to high precipitation events. Observations of ALDF are abundant within the Mackenzie Valley, NT (Lewkowicz and Harris, 2005a and b), and central and southern Yukon Territory (Huscroft et al., 2003; Lipovsky and Huscroft, 2007), in the high Arctic, including Melville (Beamish et al., 2014; Paquette et al., 2020; Robson et al., 2021; Rudy et al., 2017b) and Ellesmere Island (Lewkowicz and Harris, 2005a, 2005b) and in the western Arctic on Hershel Island and the Yukon Coastal Plain (de Krom, 1990; Wolfe et al., 2001).

ALDF are located within mapped hillslope thermokarst landscapes and are also associated with lake and wetland landscapes. They occur mainly within the continuous permafrost zone, but their distribution extends into discontinuous permafrost (Table S1). They are predominantly within herb tundra, and secondarily within shrub tundra and boreal forest biomes with little to no peat cover (Table S1). In the high Arctic, they are most common on fine-grained colluvium and are also found on other fine-grained marine, till, weathered regolith, and glaciolacustrine deposits. They occur predominantly on terrain containing moderate-to-high segregated and wedge ice, and on fine-grained glacial sediments that also contain relict ice (Table S1). Active layer detachment failures occur mainly where Holocene ground ice loss of segregated ice is negligible but extend into areas where partial to high ground ice loss of wedge or relict ice has occurred, such as the Mackenzie Valley and southern Yukon Territory (Huscroft et al., 2003; Lipovsky and Huscroft, 2007; Lewkowicz and Harris, 2005b).

1.1.5 Deep-seated permafrost landslides

Deep-seated permafrost landslides (DSPLs) are rapid slope failures within permafrost terrain that include the translocation of frozen soil below the active layer (Lyle et al. 2014). These features are observed in the southern Yukon Territory and Mackenzie Valley (Young et al., 2022).

DSPL are mainly associated with wetland-hillslope thermokarst landscapes. They occur primarily in discontinuous permafrost and extend into the southern portion of the continuous permafrost zone (Table S1). DSPL occur mostly within the boreal forest biome, in areas where peat cover is negligible to absent, and deposits are fine-grained till veneer or till blanket. They occur in areas with negligible to low modelled segregated and wedge ice and no relict ice.

Holocene ground ice loss includes the partial melt of segregated and wedge ice and complete loss of relict ice (Table S1).

135 **1.2 Lake thermokarst landforms**

1.2.1 Thermokarst lakes

A thermokarst lake is a body of water occupying a depression that formed, at least in part, by thermokarst processes, including ground settlement or expansion due to the thaw of ice-rich permafrost (Lewkowicz et al., 2025). They are observed in the high Arctic (Bouchard et al., 2020) and in the western Canadian
140 Arctic including the Tuktoyaktuk Coastlands (Burgess et al., 1982; Burn, 2002; Dallimore et al., 2000; Johnson and Brown, 1961; Olthof et al., 2015; Mackay, 1999; Marsh, 1990; Murton, 1996), Yukon Coastal Plains (Lenz et al., 2013; Plug and West, 2009), and Old Crow Flats (Bandara et al., 2020; Labrecque et al., 2009; Lantz and Turner, 2015; MacDonald et al., 2012; Roy-Léveillé et al., 2017). They are prominent in discontinuous permafrost in the Great Slave Lowlands (Morse and Rudy, 2022),
145 central Yukon (Burn and Smith, 1990; Burn, 1998), and range from continuous permafrost in the western Hudson Bay Lowlands (Dyke and Sladen., 2010; Sannel and Brown, 2010; Halsey et al., 1997; Sannel and Kuhry, 2011) to discontinuous permafrost in northern Quebec and Labrador (Dionne, 1978; Narancic et al., 2017). Lateral thermokarst lake expansion and shoreline collapse relate to the melt of relict, segregated and wedge ice, which can also initiate shoreline RTS (Kokelj et al., 2009).

150 Thermokarst lakes are associated primarily with lake-wetland-hillslope thermokarst landscapes and occur in continuous and discontinuous permafrost terrain, mainly within shrub tundra and boreal forest biomes (Table S2). They mainly occur on terrain with low to negligible peat cover but do occur across a range of peat cover from moderate to low. Thermokarst lakes are mostly associated with both coarse- and fine-grained till blanket deposits, as typified by the western Canadian Arctic, but also with other fine-grained
155 tills and alluvial, glaciofluvial, and lacustrine deposits (Table S2). Associated ground ice is mainly segregated ice in association with wedge ice and, to a lesser extent, relict ice. Holocene ground ice loss associated with thermokarst lakes included partial loss of segregated and wedge ice and typically the loss of most relict ice.

160 **1.3 Wetland thermokarst landforms**

1.3.1 Collapse ponds

Collapse ponds are ponds that have typically formed from permafrost degradation in palsa, peat plateau, or lithalsa terrain (Breton et al., 2009). With continued subsidence and loss of permafrost, they may transition into fens and bogs within unfrozen areas (Carpino et al., 2018).

165 The ponds are observed in Nunavut (Martini and Morrison 2014; Leblanc et al., 2020), Northwest Territories (Mamet et al., 2017; Wolfe et al., 2014), Yukon Territory (Harris, 2002; Zoltai and Tarnocai, 1975), Alberta (Zoltai, 1993), Manitoba (Halsey et al., 1997), Quebec (Bouchard et al. 2011, 2014; Breton et al., 2009; Dionne, 1978; Laberge and Payette 1995; Payette et al., 2004), and Newfoundland and Labrador (Way et al., 2018).

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Table S2. Permafrost terrain and ground ice conditions associated with thermokarst landforms in lake and wetland thermokarst landscapes. Maximum values in **bold**, percentages $\geq 5\%$ in *italics*.

Thermo-karst Landforms	Thermokarst Landscape H = Hillslope L = Lake W = Wetland (Olefeldt et al. 2016)	Permafrost Zones (Hegginbottom et al. 1995)	Biomes (Dyke et al., 2004)	Surficial Deposits (Fulton, 1995)	% Peat Cover (Tarnocai et al., 2011)	Past Ground Ice R = Relict S = Segregated W = Wedge	Modern Ground Ice (O'Neill et al., 2022)	Holocene Ground Ice Loss
Thermo-karst lakes	L-W-h <i>L-W-H</i> <i>W-L-h</i>	Discontinuous <i>Continuous</i>	Boreal forest <i>Shrub tundra</i>	Till veneer (c) <i>Till blanket (f)</i> <i>Alluvial Hummocky till (f)</i>	Negligible <i>Very low</i> <i>Low</i> <i>Moderate</i>	s-r-w <i>R-S-w</i>	none <i>Srw</i> <i>rsW</i> <i>sw</i>	R = Most-complete S = Part.-complete W = Most-complete
Collapse ponds	w-l-h	Discontinuous	Boreal forest <i>Forest tundra</i>	Till veneer (c) <i>Till blanket (c)</i> <i>Glaciomarine ven.</i> <i>Glaciomar. offshr.</i>	Negligible	s-r-w	none <i>sw</i> <i>Sw</i> <i>RSW</i>	R = Complete S = Complete W = Complete
Collapse scar	w <i>W-l</i> <i>W</i>	Sporadic <i>Isolated</i> <i>Discontinuous</i> <i>Continuous</i> <i>Unfrozen</i>	Boreal forest <i>Forest tundra</i>	Till blanket (f) <i>Glaciolac. offshr.</i> <i>Glaciomar. offshr.</i> <i>Hummocky till (f)</i> <i>Till veneer (f)</i> <i>Glaciomar. ven.</i>	High <i>None</i> <i>Moderate</i> <i>Low</i> <i>Very low</i> <i>Negligible</i> <i>Very high</i>	S-r-w <i>s</i> <i>R-S-w</i> <i>s-r-w</i> <i>none</i>	s-w <i>none</i> <i>s</i> <i>S-w</i>	R = Complete S = Most-Partial W = Part.-complete
Bog-to-fen transition	W-l <i>w-l</i> <i>W-L</i> <i>w</i>	Sporadic <i>Isolated</i> <i>Continuous</i> <i>Unfrozen</i>	Boreal forest <i>Forest tundra</i>	Till blanket (f) <i>Glaciomar. offshr.</i> <i>Glaciomar. ven.</i> <i>Glaciolac. offshr.</i>	High <i>Moderate</i> <i>Low</i> <i>Very low</i> <i>Negligible</i> <i>None</i>	s-r-w <i>R-S-w</i> <i>S-r-w</i> <i>r-s-w</i> none	s-w <i>none</i> <i>s-w</i>	R = Complete S = Neg.-Most W = Part.-complete
Internal lawns	W	Isolated <i>Unfrozen</i>	Boreal forest	Till blanket (f) <i>Organic</i> <i>Hummocky till (f)</i> <i>Glaciolac. offshr.</i>	Moderate <i>High</i> <i>Low</i> <i>Very low</i>	R-S-w r-s-w s-r-w	s <i>none</i>	R = Complete S = Part.-complete W = Complete

*Capitalization (R, S, W) represents ground ice amounts in medium-to-high abundance and lowercase (r, s, w) represent ground ice abundance in low to negligible abundance.

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Unlike ice wedge trough ponding and thermokarst lakes, which occur within the continuous permafrost zone, collapse ponds are most common in discontinuous permafrost (Table S2). Collapse ponds are observed primarily in forest tundra and boreal forest biomes. They are commonly found on terrain without peat cover, but also across a range of peat covers from low to negligible (Table S2). Collapse ponds are mostly found within till veneer and blanket deposits and are also associated with glaciomarine and offshore marine deposits. Present-day ground ice associated with collapse ponds is commonly segregated and wedge ice in moderate to low abundance (Table S2). They are associated with partial loss of segregated and wedge ice, but complete loss of relict ice. When in association with till deposits, they notably include the complete loss of relict and wedge ice (Zoltai and Tarnocai, 1975; Table S2). These observations suggest that collapse ponds are typically associated with mineralogical plateaus (i.e., lithalsas) and peat plateaus (Bouchard et al., 2011; Dionne, 1978; Wolfe et al., 2014), as well as thaw of till terrain with former higher abundances of ground ice, including relict ice (Leblanc et al., 2020). They are associated with lithalsas (Morse and Rudy, 2022) in the Great Slave Lowlands, which have undergone glacial lake inundation followed by aggradation of permafrost hosting segregated ice. The association with glaciomarine deposits is also due to the abundance of collapse ponds observed within the former limits of the Tyrell Sea that extended inland of present-day Hudson Bay, following recession of the Laurentide Ice Sheet (Bouchard et al. 2011; Dionne 1978).

1.3.2 Collapse scars

Collapse scars result from the collapse of peat plateaus and palsas (Mamet et al., 2017), which are peat-covered permafrost mounds with layers of segregated ice and peat or mineral soil material, and with lithalsas (Calmels et al., 2008) that typically lack the peat cover or segregated ice layers at depth. Collapse scars are typically formed by vertical subsidence and lateral thaw of the plateau sides and can lead to the transformation of forested peat plateaus into wetlands, bogs, and fens. These landforms are observed in sporadic permafrost in the Northwest Territories (Beilman and Robinson, 2003; Carpino et al., 2018; Liblik et al., 1997), Yukon Territory (Coulthick and Lewkowicz 2003; Harris 2002), northern Alberta (Prater et al., 2007), Manitoba (Bubier et al., 1995; Camill 2005; Camill and Clark, 1998), and Ontario (Pironkova, 2017). They

also extend into isolated permafrost in Alberta (Beilman and Robinson, 2003; Zoltai, 1993), Saskatchewan (Beilman et al., 2001; Beilman and Robinson, 2003), and Quebec (Thibault and Payette, 2009). They are also noted within discontinuous and continuous permafrost in the
210 Northwest Territories (Beilman and Robinson, 2003; Mamet et al., 2017; Zoltai and Tarnocai, 1975), Yukon (Zoltai and Tarnocai, 1975), and northern Manitoba (Camill and Clark, 1998; Dredge and Nixon, 1979; Halsey et al., 1997; Sannel and Brown, 2010; Sannel and Kuhry, 2011), Ontario (Kirkwood et al., 2019), and Quebec (Worsley et al., 1995).

Collapse scars occur mainly within wetland and wetland-lake thermokarst landscapes of the
215 sporadic permafrost zone but extend into most other permafrost zones (Table S2). They occur mainly within the boreal forest and extend into forest tundra, most commonly on fine-grained till blanket deposits, as well as on other fine-grained tills and on glaciolacustrine and glaciomarine deposits (Table S2). Peat cover is typically high but ranges in thickness from moderate to none. Ground ice associated with collapse scars is segregated ice, and segregated-wedge ice in low
220 abundance (Table S2). Holocene ground ice loss in areas with collapse scars includes complete loss of relict ice, partial to complete loss of wedge ice, and partial to high loss of segregated ice. These associations are tied to the differences in initial landform types, with palsas and peat plateaus associated with underlying till deposits and thick peat cover in sporadic permafrost, with ground ice consisting of segregated ice within peat plateaus and palsas and, additionally, wedge
225 ice within polygonal peat plateaus (Dredge and Nixon, 1979). Lithalsas, in contrast, are more commonly associated with glaciolacustrine or marine deposits, thin peat cover, and segregated ice in discontinuous permafrost (Calmels et al., 2008; Wolfe et al., 2014).

1.3.3 Bog-to-fen transition

230 Bog-to-fen transitions are associated with organic soils and peatlands. Bogs are peat-forming wetlands fed primarily by rainwater, whereas fens form within mineral-rich groundwater. Fens tend to be less acidic than bogs, which support grasses and sedges, in addition to mosses and ericaceous shrubs adapted to acidic environments. In terms of thermokarst landscapes, fens may develop from the thawing of peat plateaus and palsas. Permafrost may persist within raised
235 portions of bogs and within ridges developed within string fens (Harry et al., 1988).

Thermokarst associated with the bog-to-fen transition occurs in wetlands, most commonly in sporadic permafrost but also within continuous permafrost, isolated patches, and unfrozen ground (Table S2). They are mainly found in the boreal forest and forest tundra biomes and are primarily associated with fine-grained till blanket deposits, as well as glaciomarine and glaciolacustrine deposits (Table S2). Peat cover is usually high but can range from moderate to none. They are associated with segregated ice and wedge ice, though in low abundance. Holocene ground ice loss is significant, with complete loss of relict ice, partial to complete loss of wedge ice, and partial to extensive loss of segregated ice (Table S2). Based on the co-occurrence of peat plateaus and bog-to-fen transition within areas of high peatland cover, the collapse of peat plateaus often leads to the formation of collapse ponds and fen-dominated thermokarst landscapes (Halsey et al., 1997; Thibault and Payette, 2009; Zoltai, 1993), whereas the collapse of lithalsas generally results only in collapse ponds (Dionne, 1978; Harris, 2002; Wolfe et al., 2014).

1.3.4 Internal lawns

Internal lawns are recently thawed areas with herbaceous vegetation cover, surrounded by densely forested frost mounds (Beilman and Robinson, 2003). Observations are mainly limited to the southern limits of permafrost within Alberta, Saskatchewan, and Manitoba. Internal lawns occur in wetland thermokarst landscapes, primarily within isolated permafrost in boreal forests (Table S2). They occur mostly on fine-grained till blanket deposits and on organic terrain, hummocky till glaciolacustrine deposits. They occur primarily within terrain with modelled negligible segregated ice, due to the small fraction of the landscape underlain by permafrost. These areas have otherwise lost all relict, segregated, and wedge ice over the Holocene (Table S2).

2 Thermokarst domains and associated conditions

Table S3 summarizes the dominant thermokarst and permafrost terrain conditions associated with each permafrost zone and subdivided into areas of lower and higher organic peat cover. These subdivisions are presented here as thermokarst domains, within which specific types and

265 associations of thermokarst landforms occur. Table S4 shows the distribution of thermokarst
landforms across the thermokarst domains, as indicated by the percentage of observations in each
domain.

270 Table S3. Summary of thermokarst domains showing the relative abundance of thermokarst
landforms and associated conditions for biomes, peatland cover, thermokarst landscape, ground
ice type, and relative Holocene ground ice loss.

TK Domain	PF Zone*	Thermokarst Landforms	Percent Landform in Domain	Modern Biome**	Organic Peat Cover	Dominant TK Landscape	Ground Ice *** Types	Holocene Ground Ice Loss
I	Cont.	Gullies Deepened troughs Melt-ponds RTS ALDFs Thermokarst lakes	87.5 66.7 8.9 36.0 54.3 0.2	HT (and throughout Holocene)	None None Very low None-Low None-Low None-Low	Hillslope Hillslope Hillslope Hillslope Hill-Lake Hillslope	R-W-S W-S R-W-S R-W-S W-S R-W-S	Negligible Negligible Negligible Negligible Negligible Negligible
II	Cont.	Gullies Deepened troughs Melt Ponds RTS ALDFs DSPLs Thermokarst lakes Collapse ponds Collapse scars	12.5 33.3 89.9 61.2 33.9 19.0 24.3 0.9 1.7	ST HT-ST HT-ST-BF HT-ST-BF ST-BF BF ST-FT-BF ST ST-FT	None None None-Low None-Low None-Low None None-Low None-Neg. None-V low	Hillslope Hillslope Hillslope Hillslope Hill-Wet Wetland Lake Wetland Hillslope	R-W-S R-W-S R-W-S R-W-S R-W-S W-S R-W-S R-W-S R-W-S	Negligible Negligible Partial Partial-High Partial-High Partial Partial-High Negligible Negligible
IIp	Cont.	Melt ponds ALDFs Thermokarst lakes Collapse scars Bogs-to-fens	1.6 0.2 0.1 8.3 14.3	ST BF ST-BF FT-BF BF	Medium Medium Medium Med-High Moderate	Lake Lake Wetland Wetland Wetland	R-W-S R-W-S R-W-S R-W-S S-S	Negligible Partial-High Partial-High Partial-High Partial
III	Disc.	Melt ponds RTS ALDFs DSPLs Thermokarst lakes Collapse Ponds Collapse Scars	1.2 1.5 9.9 78.5 74.9 96.1 8.3	ST BF BF BF ST-BF FT-BF FT-BF	Very Low Neg-Low None-Low None-Neg None-Low Negligible Neg-None	Hillslope Wetland Wetland Wetland Lake Wetland Wetland	W-S W-S W-S W-S R-W-S W-S W-S	Negligible Partial-Comp Partial-Comp Partial-Comp Partial Partial Partial-Comp
IIIp	Disc.	RTS ALDFs Thermokarst lakes Collapse Scars Bogs-to-fens	0.02 0.1 0.6 6.7 3.6	BF BF BF-ST BF BF	High High Moderate Med-V high Negligible	Wetland Wetland Wetland Wetland Wetland	W-S W-S W-S W-S S	Partial Partial Partial Partial-Comp Negligible
IV	Spor.	RTS ALDFs DSPLs Thermokarst lakes Collapse ponds Collapse scars Bogs-to-fens	0.01 0.1 2.5 0.1 1.9 25.0 10.7	BF BF BF ST-FT-BF FT-BF FT-BF FT-BF	None None None-V low None-Low None-Low None-Low V low-Low	None None Wetland Wetland Wetland Wetland Wet-Lake	W-S W-S W-S W-S W-S W-S W-S	Partial-High Partial-High High Partial-High High Partial-High High
IVp	Spor.	Thermokarst lakes Collapse scars Bogs-to-fens	0.1 30.0 39.3	FT BF BF	Medium Med-V high Med-High	Wetland Wetland Wetland	W-S W-S W-S	Partial-High Partial-High Partial-High

V	Iso.	Thermokarst lakes	0.1	BF	None-Neg	Wetland	S	High
		Collapse ponds	0.7	FT-BF	None-Low	Wetland	W-S	High
		Collapse scars	15.0	BF	None-Low	Wetland	S	High
		Bogs-to-fens	17.8	BF	Neg-Low	Lake	S	High
		Internal lawns	33.3	BF	V low-Low	Wetland	S	Partial
Vp	Iso.	Collapse scars	1.7	BF	Med-high	Wetland	S	High
		Bogs-to-fens	3.6	BF	High	Wetland	S	Complete
		Internal lawns	33.4	BF	Med-High	Wetland	S	Partial
Thawed	None	Collapse ponds	0.5	BF	Low-Med	NA	S	Complete
		Collapse scars	3.3	BF	V low-Med	NA	S	Complete
		Bogs-to-fens	10.7	BF	Med-High	NA	S	Complete
		Internal lawns	33.3	BF	Low-Med	NA	S	Complete

*Permafrost zones: Cont.=Continuous; Disc.=Discontinuous; Spor.=Sporadic; Iso.=Isolated patches

**Biomes: HT=Herb tundra; ST=Shrub tundra; BF=Boreal forest; FT=Forest tundra

275 ***Ground ice types: R = Relict; S = Segregated; W = Wedge

Table S4. Distribution of thermokarst landforms across Thermokarst Domains.

Thermokarst landform	Thermokarst Landscape	Percentage of observations by Domain									
		I	II	IIp	III	IIIp	IV	IVp	V	Vp	No permafrost
Thermo-erosional gully	Ice Wedge	87.5	12.5								
Deepened ice wedge trough		66.7	33.3								
Ice wedge melt pond		8.9	89.9		1.2						
Retrogressive thaw slump	Hillslope	36.0	61.2		1.5	0.02	0.01				1.3*
Active layer detachment failure		54.0	34.5		9.9	0.1	0.1				1.4*
Deep-seated permafrost landslide			19.0		78.5		2.5				
Thermokarst lake	Lake		24.4		74.9	0.1	0.1	0.1	0.1		
Collapse pond	Wetland		0.9		96.1		1.9		0.7		0.5
Collapse scar			1.7	8.3	8.3	6.7	25.5	30.0	15.0	1.7	3.3
Bogs-to-fen				14.3		3.6	10.7	39.3	17.8	3.6	10.7
Internal lawn									66.7		33.3

* Outside of study boundaries.

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