Permafrost-related landslides in south and central Yukon

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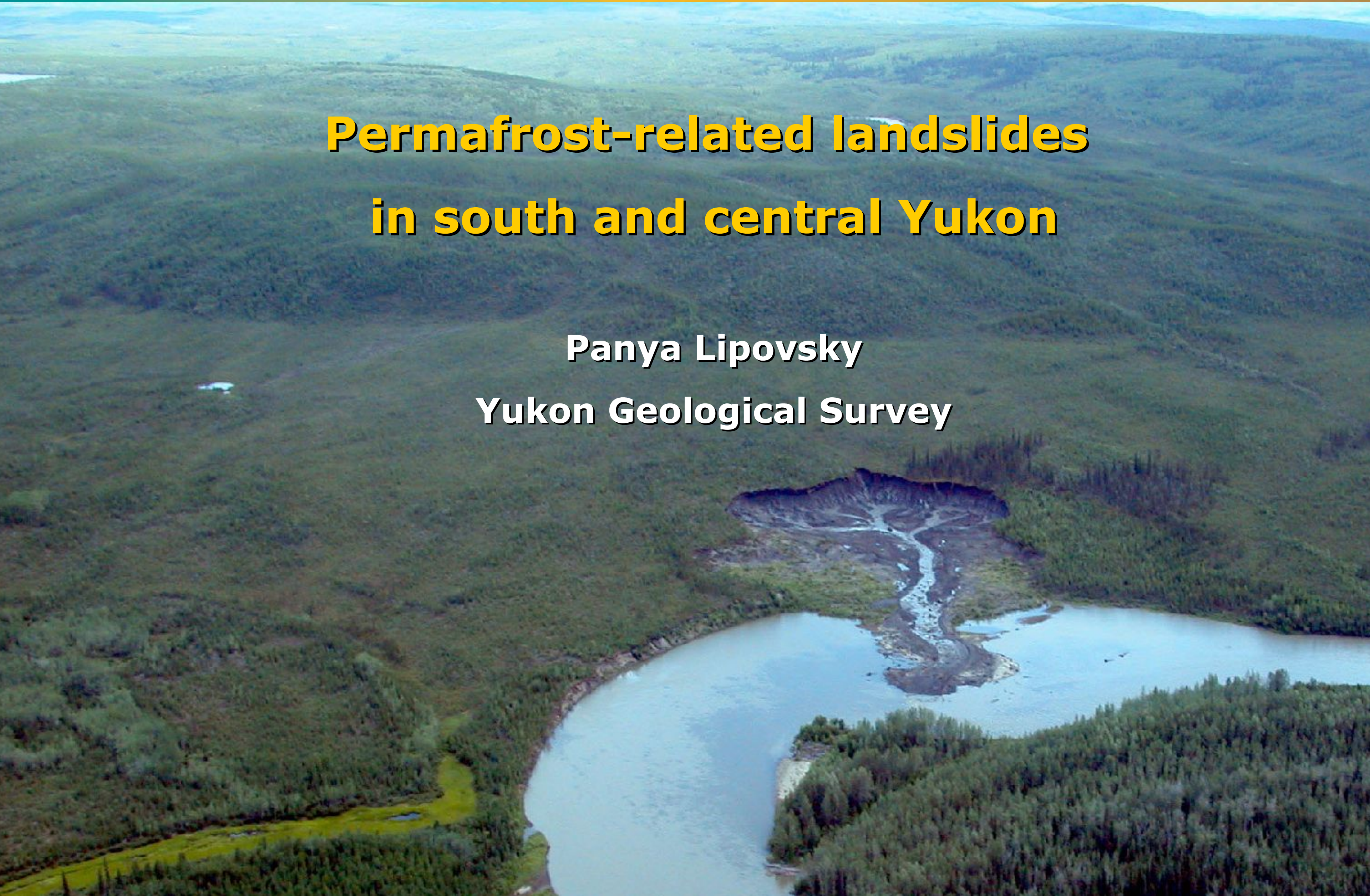
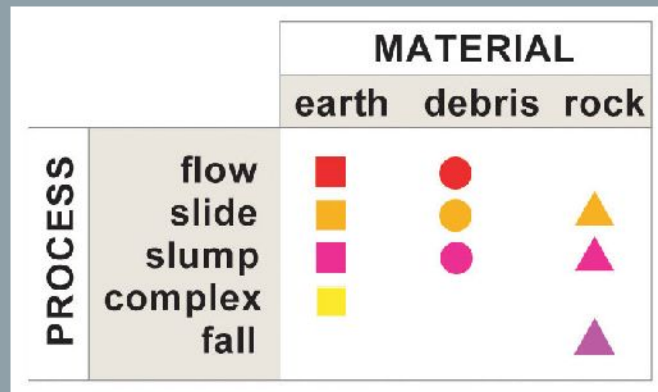
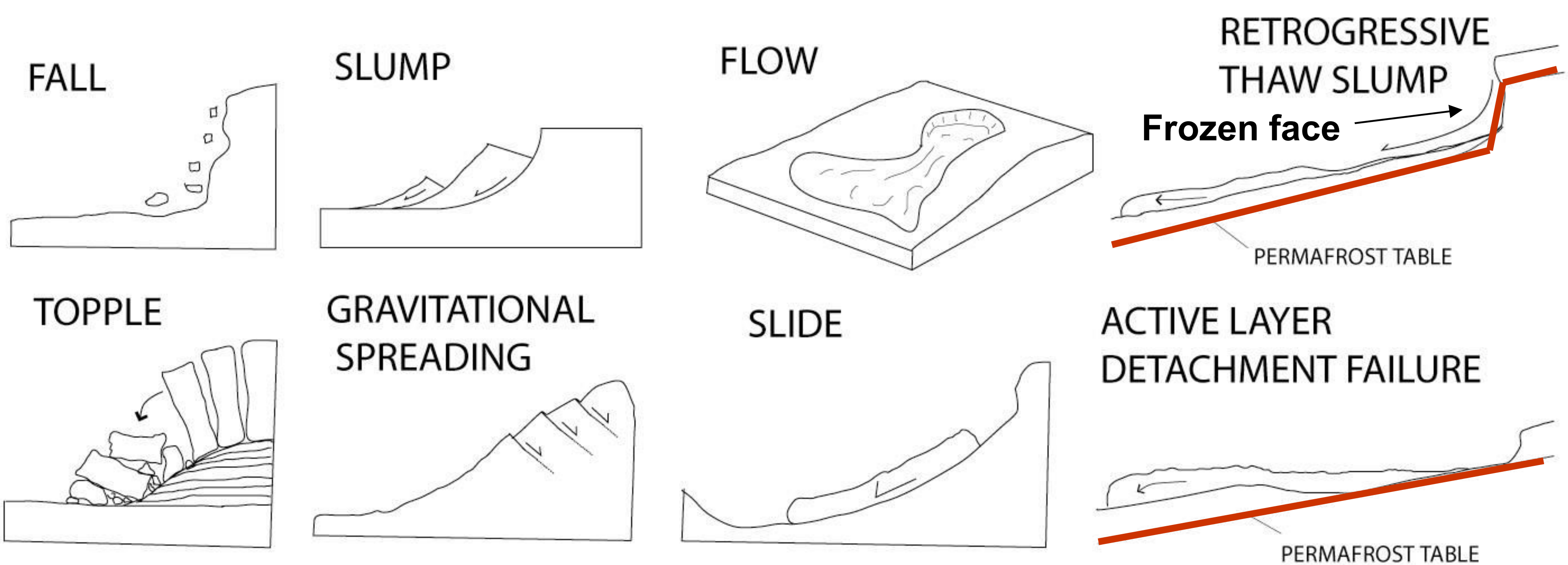
Yukon Geological Survey



Types of Landslides





STRESSES ON SLOPE

Topography
Seismicity
River migration/incision
Recent glacial retreat
Human disturbance

LOSS OF MATERIAL STRENGTH

Weathered source materials
Intense rainfall and/or snowmelt events
Groundwater
Permafrost
Forest fires

Intense rainfall or snowmelt

Water saturates soil

- Increases weight on slope
- Leads to high pore water pressure and loss of friction

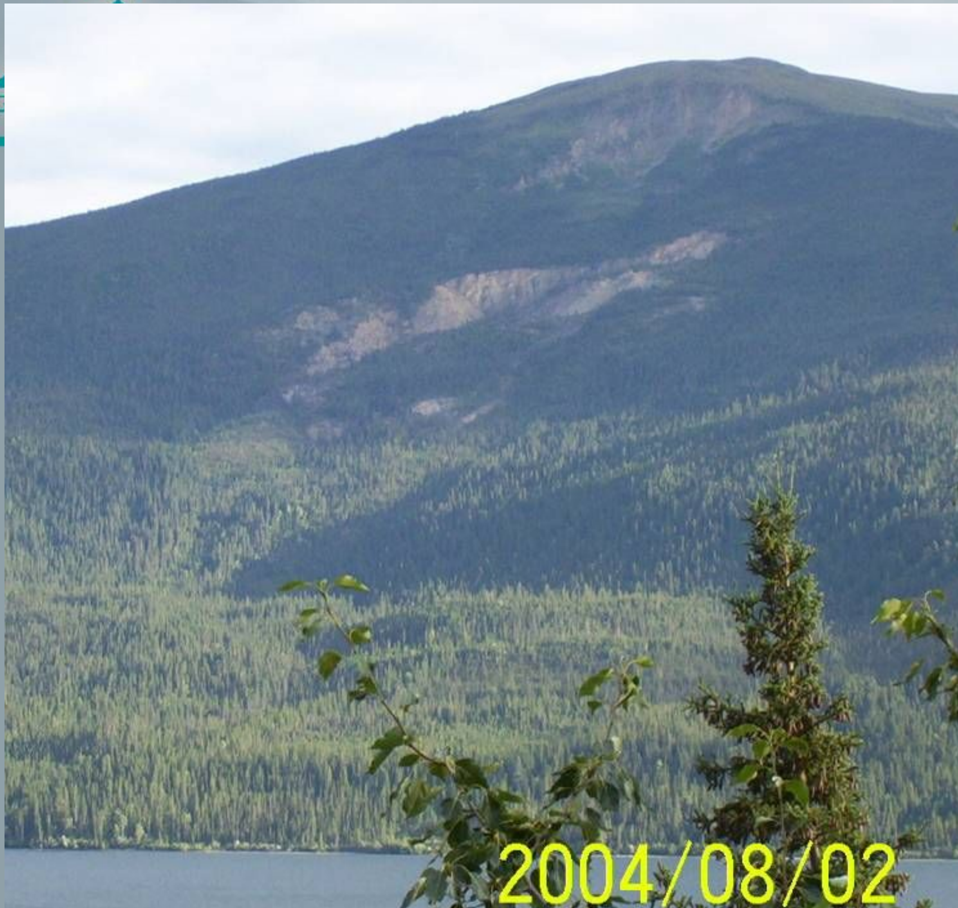
Affects areas where

- shallow permafrost or bedrock impede drainage
- groundwater or surface runoff concentrates

Photo by Ric Janowicz

July 8-15, 1988: 91.6 mm rain at Burwash Landing

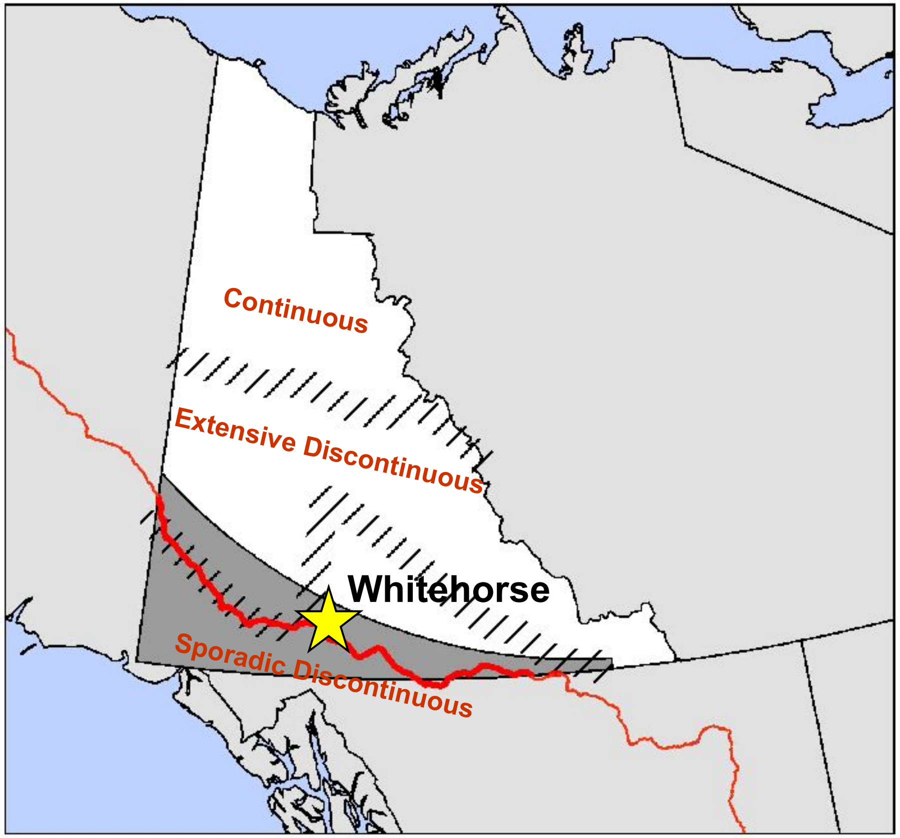
Alaska Highway blocked by debris flows and floods in 8 locations along Kluane Lake. (Evans & Clague, 1989)


2004/08/02


Little Salmon Lake
2008/09/01

Permafrost

- generally on north-facing slopes underlain by thick organic mats and silt-rich soils
- if present, restricts drainage
- if thaws, adds moisture and reduces strength



Permafrost Thickness/Temperature

- In SW Yukon, permafrost is generally up to ~20 m thick, below an active layer of 1-2 m.
- Up to 25-40 m thick near Mayo (Burn, 1992) and 20-60 m thick near Dawson
- Up to ~300 m thick in northern Coastal Plain.

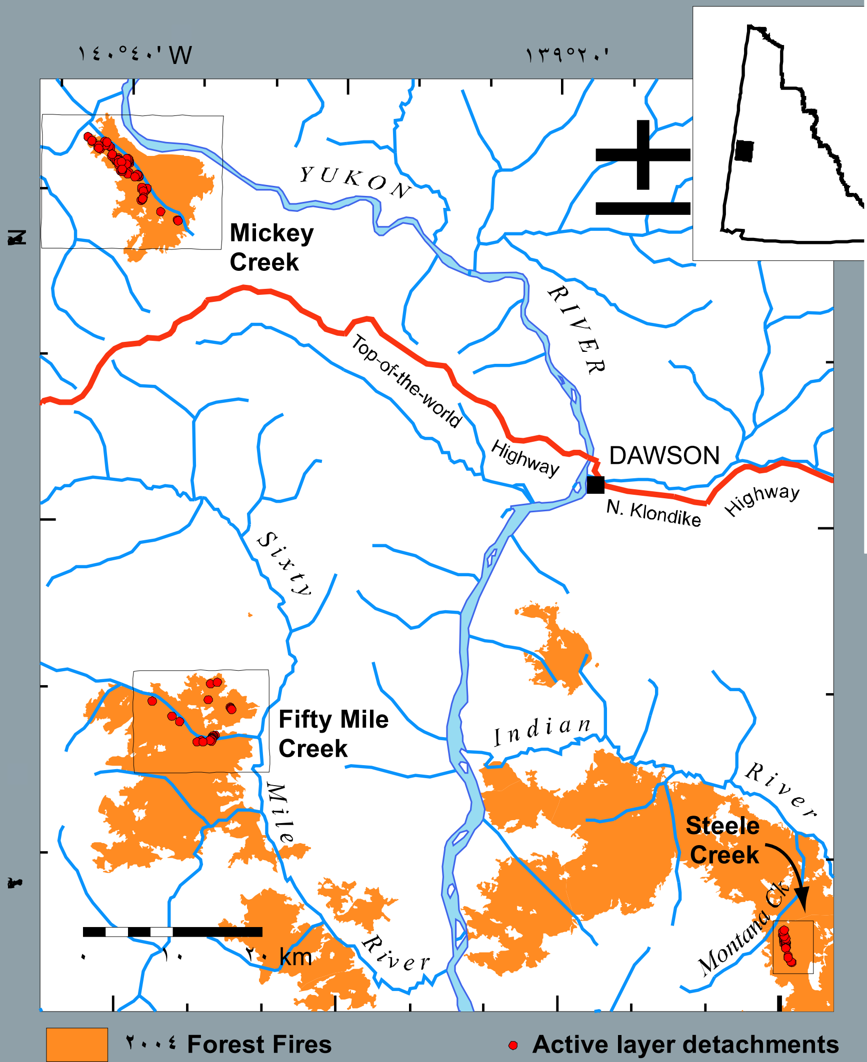
- In northern Alaska, permafrost is warming 0.25-1 °C/decade, mostly in response to increased snow depths (Osterkamp, 2007)
- In NWT (central/northern Mackenzie valley), permafrost is warming 0.3 to 0.6 °/decade in response to increasing air temperature (Smith, 2005)
- Permafrost in southern Yukon and NWT is considered “warm” (< -2 °C) and is not warming as fast.

Active Layer Detachments

- Generally long, narrow and shallow (<2 m).
- Can occur on very gentle slopes.
- Permafrost table restricts drainage and acts as failure plane.
- Usually triggered by forest fires or high rainfall/snowmelt.

Excell Creek, near Faro, after 2004 forest fire

2004 Forest Fires near Dawson

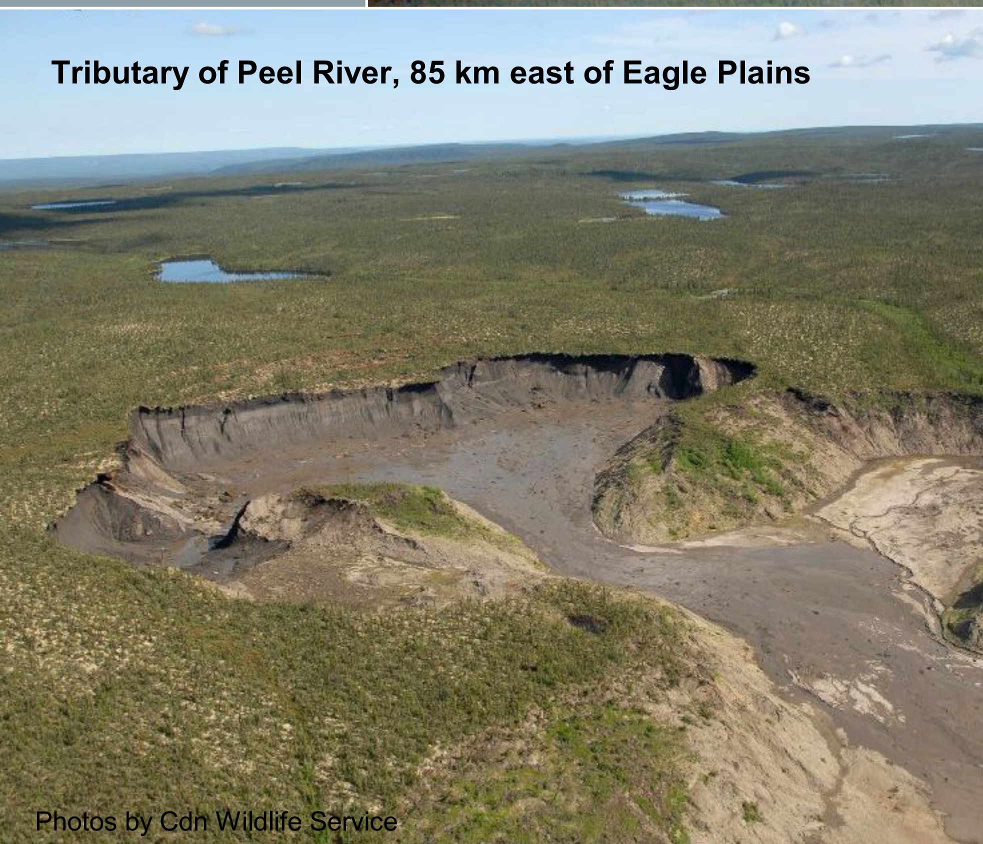


- Almost 150 active layer detachments occurred in three study basins within one year of forest fires.
- Failures initiated in silty colluvium, on gentle to moderate slopes (generally 5-25 degrees), on a variety of aspects, and commonly near a convex break in slope.
- Most failures were shallow (50-80 cm) and on the order of 5-20 m wide x 10-100 m long.
- Combined effects are a potentially significant source of sediment to local streams and has implications for new placer regulatory regime.

Lipovsky et al., 2006 and Coates' MSc, 2008

Retrogressive Thaw Failures

- Usually triggered by river erosion or disturbance of vegetation.
- Ice exposed in steep headscarp thaws and causes ongoing retreat.
- Material transported away in highly mobile flows that often travel several km.




Tributary of Peel River, 85 km east of Eagle Plains

Photos by Cdn Wildlife Service

Magundy River

- Ground ice contents exposed in headscarp up to 50% as thin veins < 1cm thick.
- Headscarp retreat rates averaged 30-40 m/yr between 1998 and 2004.

Aspect = North

Source Area Slope = 12-13°

Elevation Drop = 335 m

Runout Length = 2200 m

Source Area Width = 350 m

Deposit Width = 1300 m

Area Impacted = 84 ha

Dates Active = 1996 to present

Takhini River

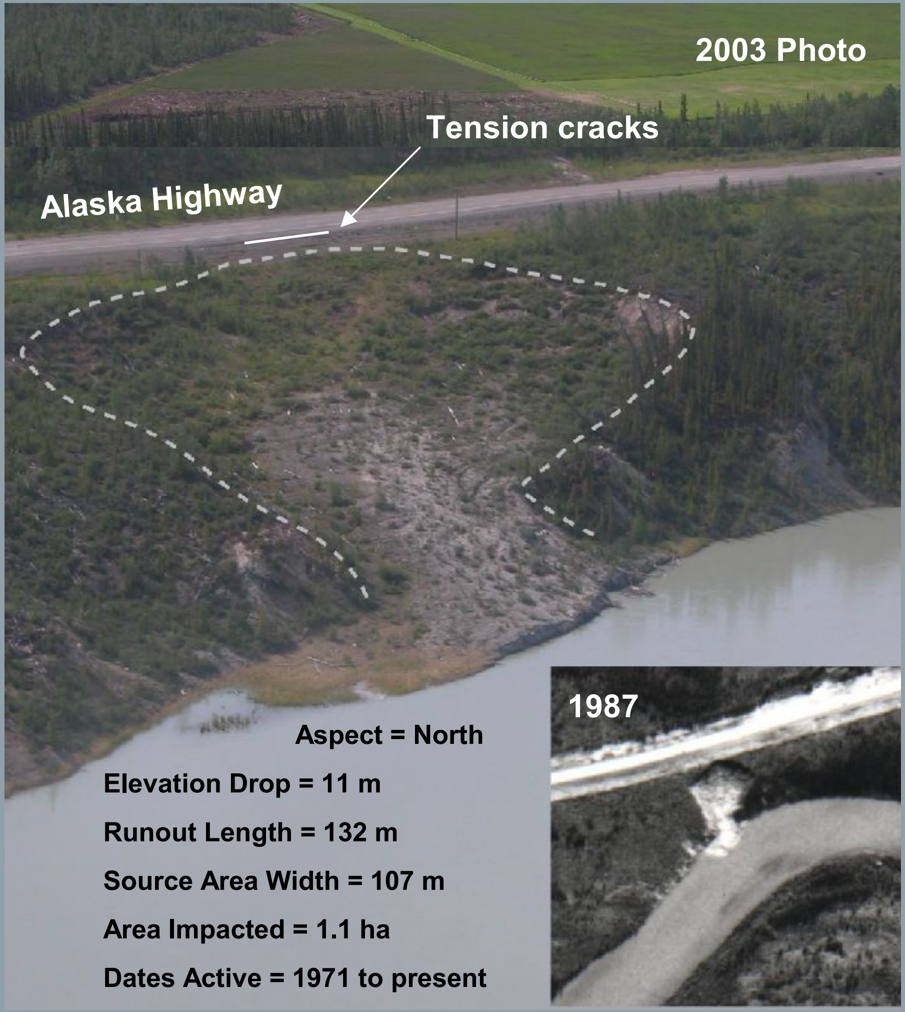
- River erosion exposed ice in glaciolacustrine terrace prior to 1971.

- Headscarp retreat rates:
  - 1971-1979: 25 m (3 m/yr for 8 years)
  - 1979-1987: 112 m (16 m/yr for 8 years)
  - 1987-present: a few meters

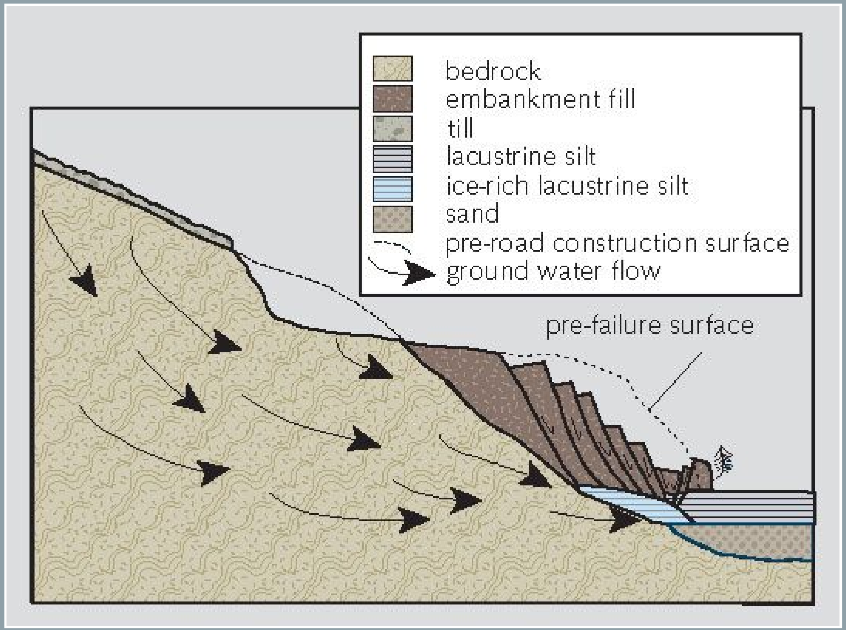
- Ongoing permafrost thaw related to thermal and hydrological disturbance from highway and nearby cleared fields.

- Buried utility lines rerouted above ground and ongoing highway maintenance required.

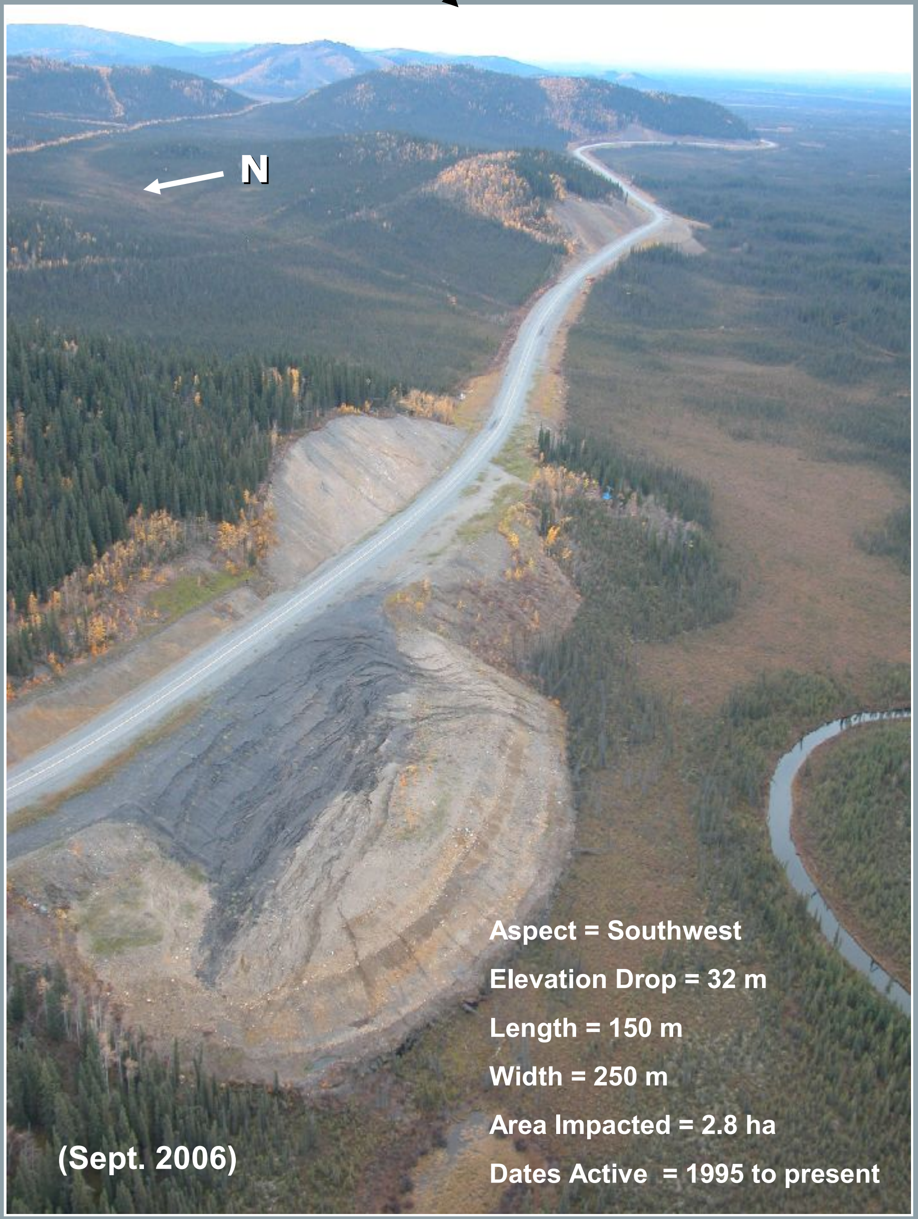
(from Huscroft et al., 2004)



Beaver Creek Embankment Failure



- Base of bedrock slopes is common setting for ground ice to form, due to converging groundwater flow into fine-grained valley bottom sediments.
- 1996 boreholes through embankment found 2.8 to 3.7 m ice-rich silt beneath 8-12 m gravel fill (Paine & Assc, 1997)
- Thaw of ice likely accelerated by:
  - disruption of underground creek at toe of failure
  - water ponded by grabens
  - thermal heat transfer from dark fill



Little Salmon Lake

Aspect = North

Adjacent Undisturbed Slope = 16°

Elevation Drop = 100 m

Length = 250 m

Width = 350 m

Area Impacted = 5.8 ha

Dates Active = pre-1989 to present

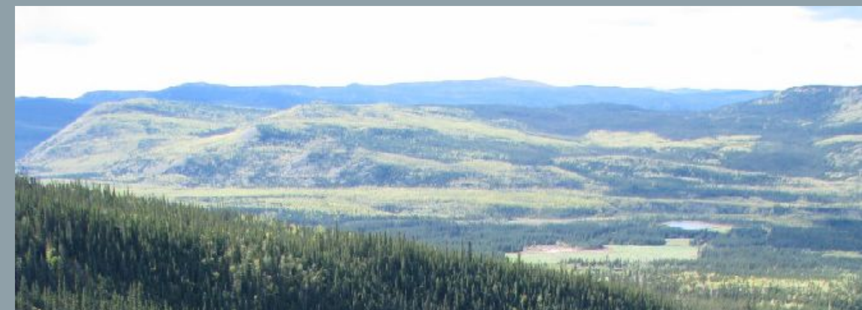
(Lyle, 2006)

- **Scarps developed between 1989 and 2004.**
- **Large block below low scarp disappeared into lake between 2004-2005.**
- **Causal factors:**
  - **- creep of “warm” ice-rich permafrost on slope**
  - **- high ice contents from groundwater flow through confined glaciofluvial sediments**
  - **- thermal erosion by lake**

10 Mile Creek

- Frozen till confined permeable glaciofluvial deposits during high snow melt, triggering massive debris flow.
- Debris flow travelled nearly 5 km at speeds up to 40 km/hr).

Yukon
Energy, Mines and Resources



<u>August 2008 record rainfall:</u>

- **Carmacks: 62 mm rain in 5 days**
- **Burwash: 120 mm in 4 days**

(Environment Canada)

Yukon Geological Survey

Kusawa Lake Fan

Yukon Energy, Mines and Resources

Source Area Aspect = Northeast

Slope Above Source Area = 11-16°

Debris Flow Elevation Drop = 675 m

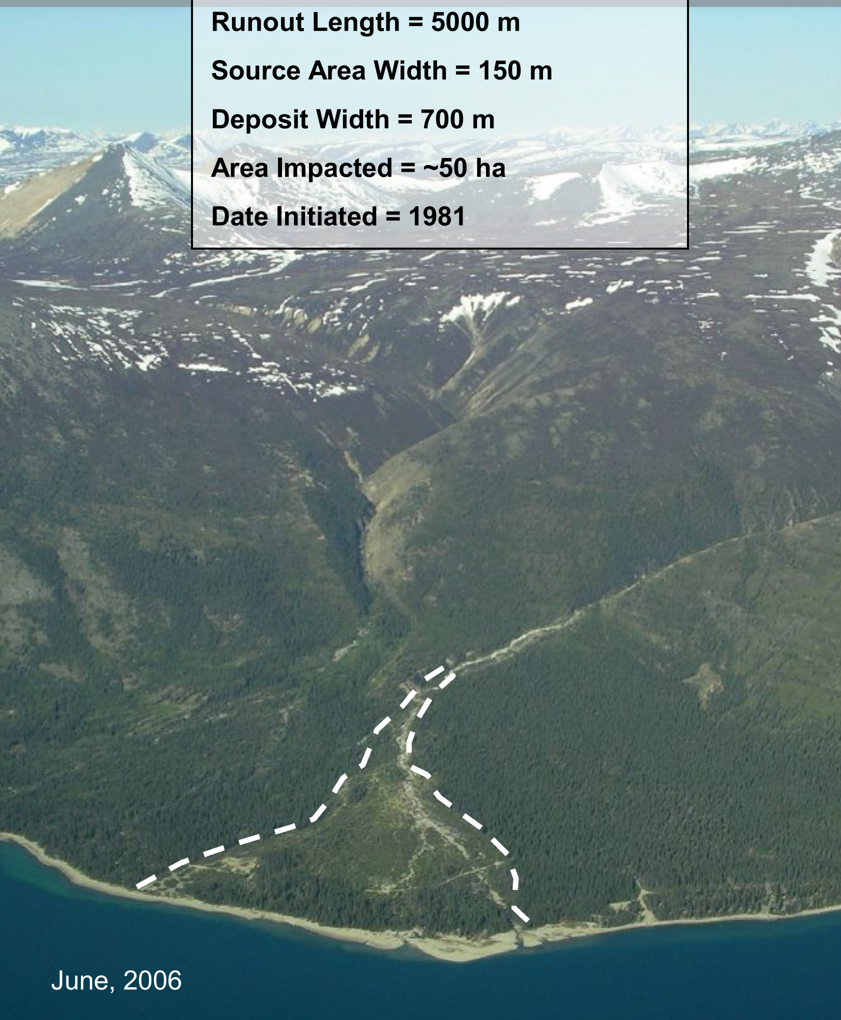
Runout Length = 5000 m

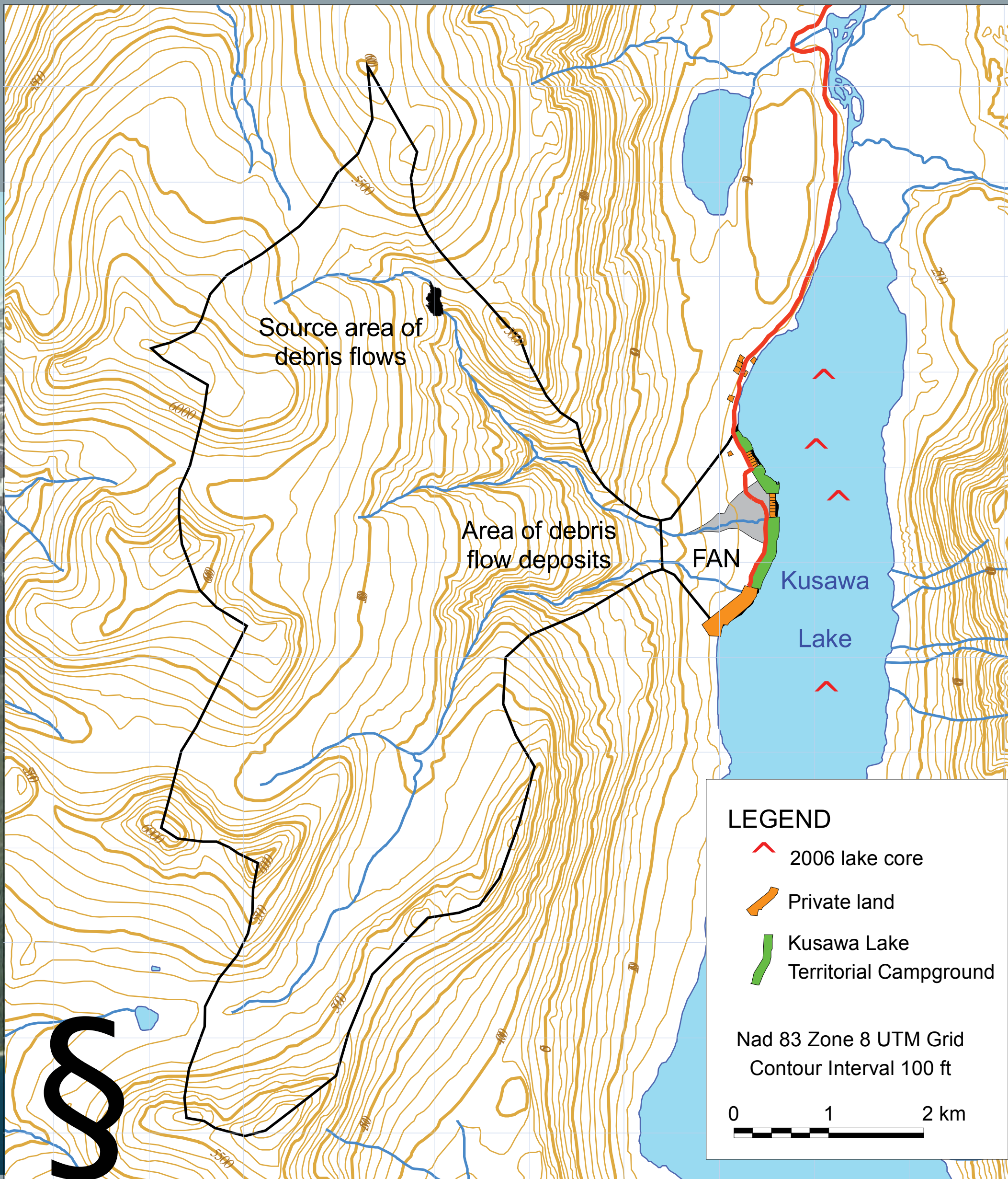
Source Area Width = 150 m

Deposit Width = 700 m

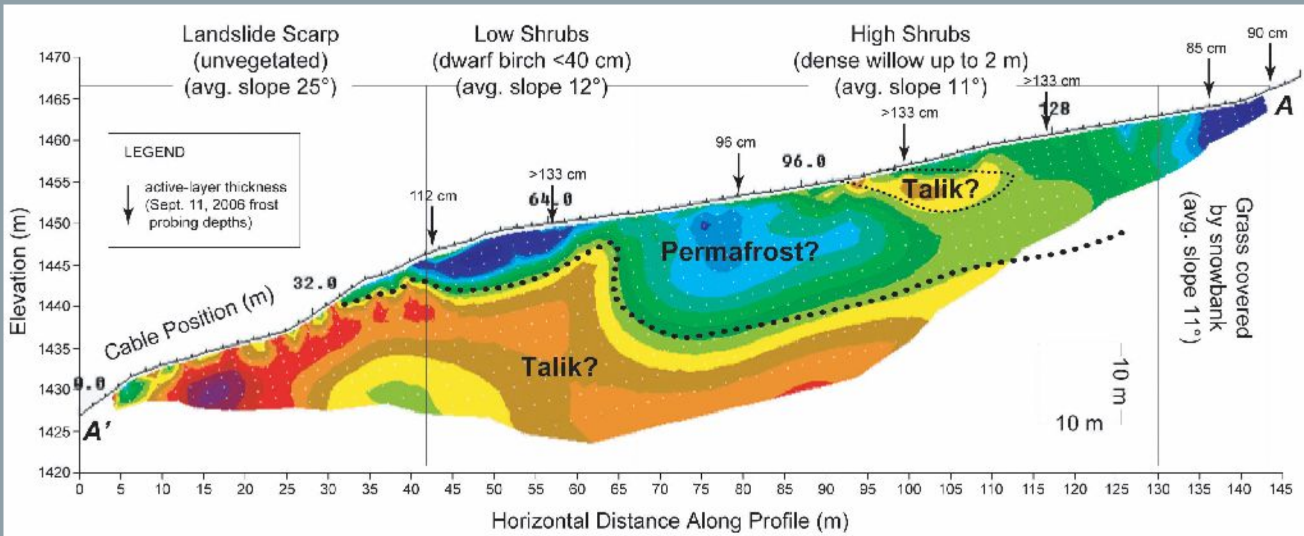
Area Impacted = ~50 ha

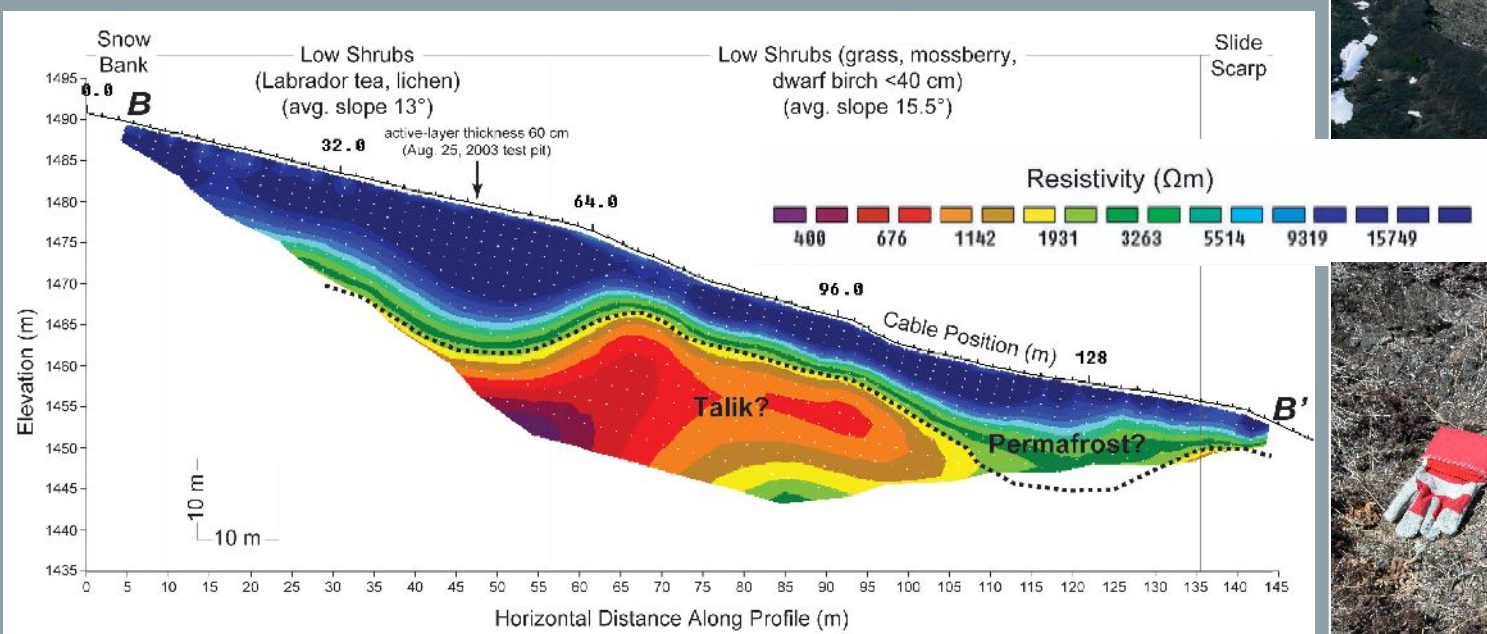
Date Initiated = 1981

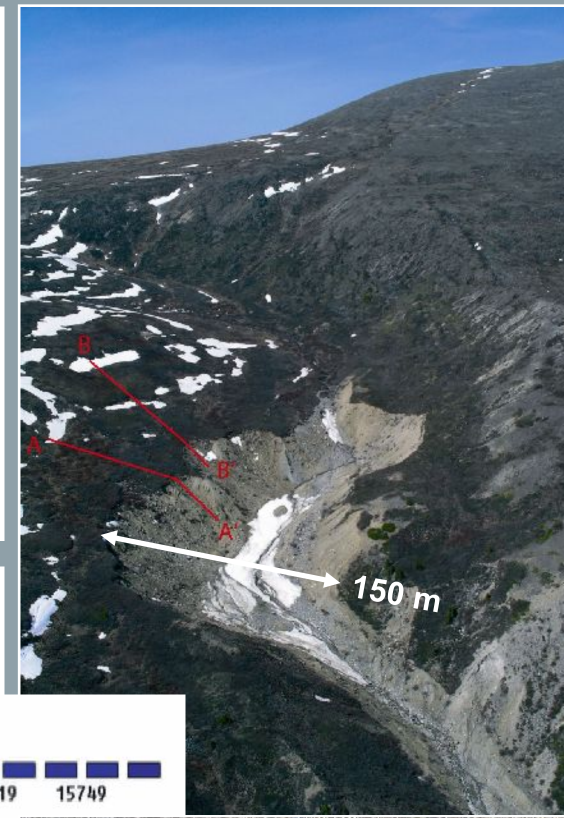




Kusawa Lake Fan





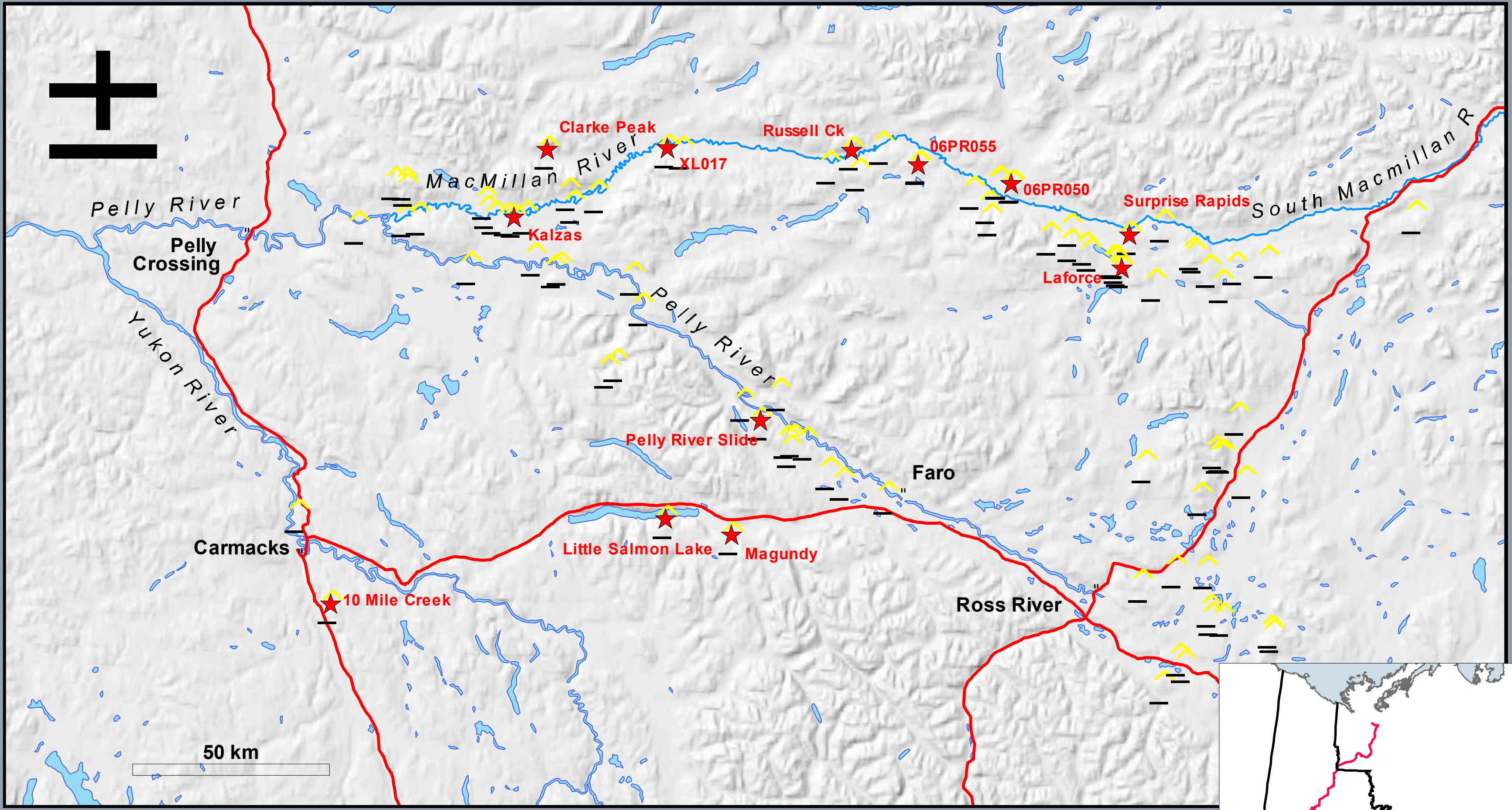


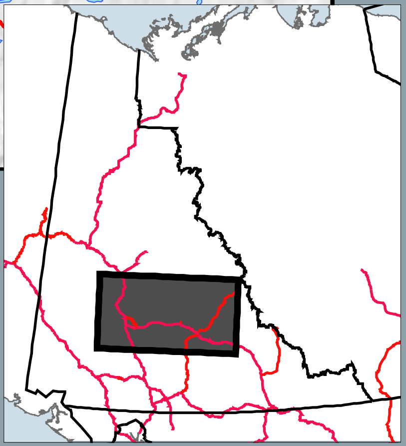
Kusawa Lake Fan

1981/1982 rainfall

- **High, but not unusual, rainfall was recorded in Whitehorse and Otter Falls in the weeks prior to the 1981 and 1982 events.**
  - may not be representative of conditions at higher elevation at Kusawa
  - intensity, duration and antecedent conditions are important
- **In the 2 weeks prior to the Aug. 31, 1981 event:**
  - Whitehorse: < 1 mm on 4 scattered days, ~1 cm rain on Aug. 31
  - Otter Falls: Aug. 26 – 6 mm, Aug. 31 – 8 mm
- **In the 2 weeks prior to the Sept. 16, 1982 event:**
  - Whitehorse: Sept. 1 (4 mm), Sept. 2 (5 mm), Sept. 8 (11 mm)
  - Otter falls: Sept. 1 (11 mm), Sept. 2 (1 mm), remainder: dry
- **Thresholds values on the order of 1-7 mm/hr for durations <1 day have been documented in literature to trigger landslides**

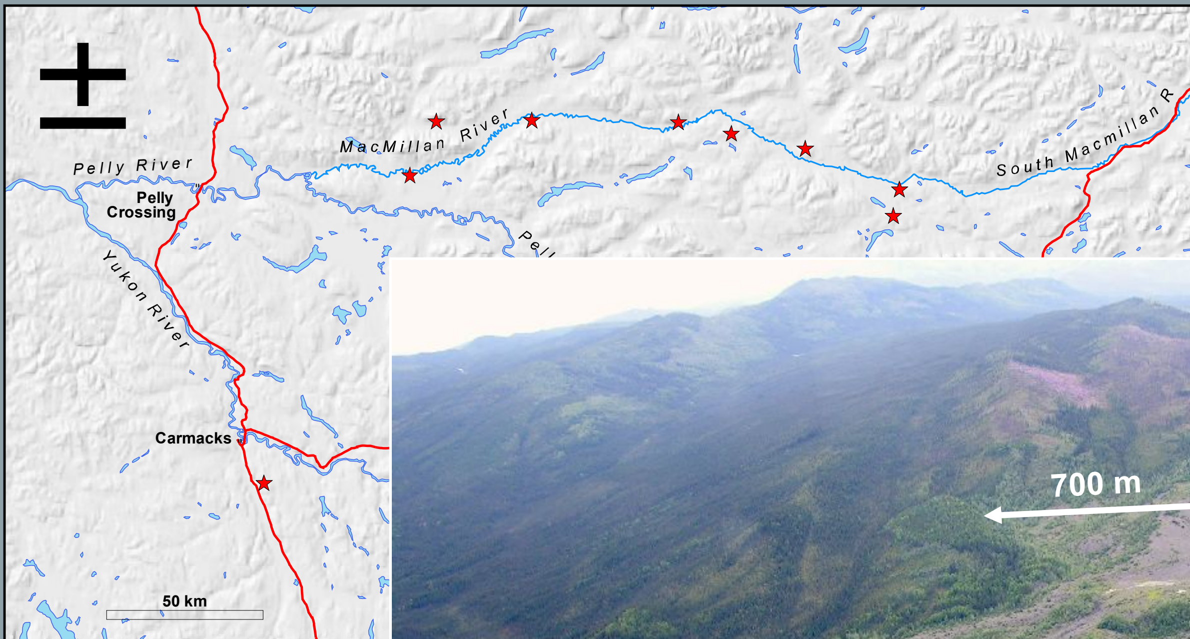
Pelly Watershed





Lipovsky et al., 2007

Surprise Rapids



- Initiated from gentle slopes.
- Very large runout length, deposit width and area impacted.
- Very little recovery after 130 years

Aspect = Northwest

Source Area Slope = 9-13°

Elevation Drop = 220 m

Runout Length = 2500 m

Source Area Width = 700 m

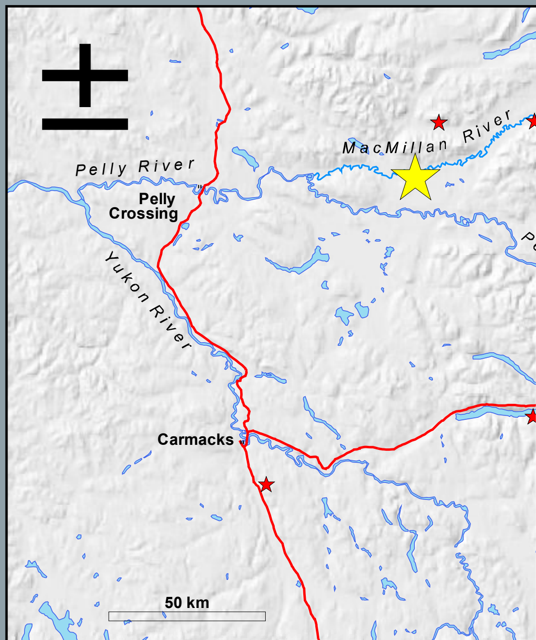
Deposit Width = 1700 m

Area Impacted = 195 ha

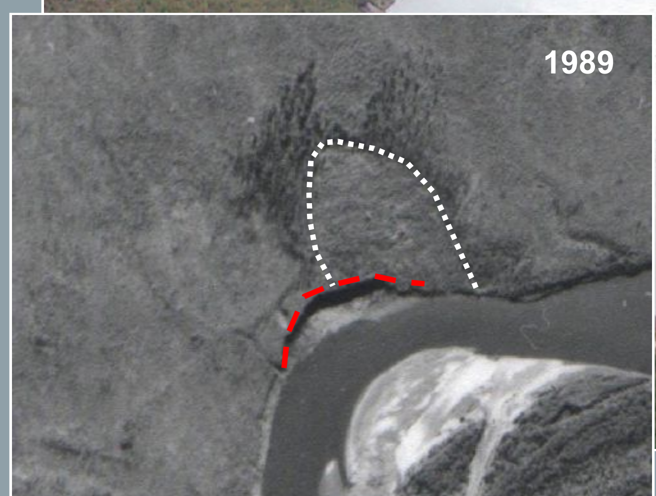
Dates Active = 1870s to present

(Ward et al., 1992)

Kalzas Slide



- Has retreated about 10 m/yr for last 17 years.
- Older overgrown slide just adjacent.
- Small slide, but capable of damming ¾ of MacMillan R. since at least 2003.



Aspect = North

Adjacent Undisturbed Slope = <5°

Elevation Drop = <10 m

Runout Length = 275 m

Width = 250 m

Area Impacted = 3.7 ha

Date Initiated = pre-1989

Summary

- Infrastructure, property and water quality have been significantly impacted by permafrost-related landslides in the past.
- Permafrost-related landslides can be far-reaching, can remain active for decades, can occur on gentle slopes of all aspects, and can impact large areas up to 200 ha.
- They can be triggered by human and natural causes including road construction, river erosion, forest fires, heavy rainfall and confined groundwater flow.
- Basin characteristics and surficial material stratigraphy several km upslope of any area targeted for development should be evaluated for permafrost landslide risk.
- Development on fans should carefully consider the risk of debris flows.
- The design of stream crossings should incorporate the potential for debris torrents to occur.
- Maps/models of permafrost distribution and hydrological parameters (rainfall intensity thresholds for critical levels/rates of infiltration, saturation and runoff) would greatly benefit landslide susceptibility modeling and risk management.