YUKON GEOLOGICAL SURVEY

Recent Permafrost-Related Landslide Investigations in South and Central Yukon

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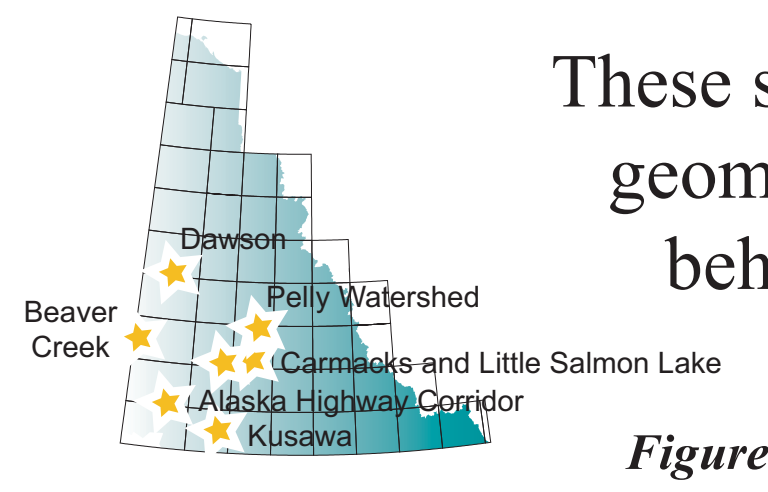
Introduction

Permafrost-related landslides are poorly documented in discontinuous permafrost regions.

There is growing concern for the potential effects of climate change and development on slope stability in permafrost terrain.

A number of studies (Fig. 1) have been conducted by the YGS since 2003 to improve our understanding of these failures.


Dawson
Beaver Creek
Pelly Watershed
Carmacks and Little Salmon Lake
Alaska Highway Corridor
Kusawa

These studies have focused on characterizing geomorphic settings, triggers and causes, behaviours, and potential impacts using a variety of investigation techniques.

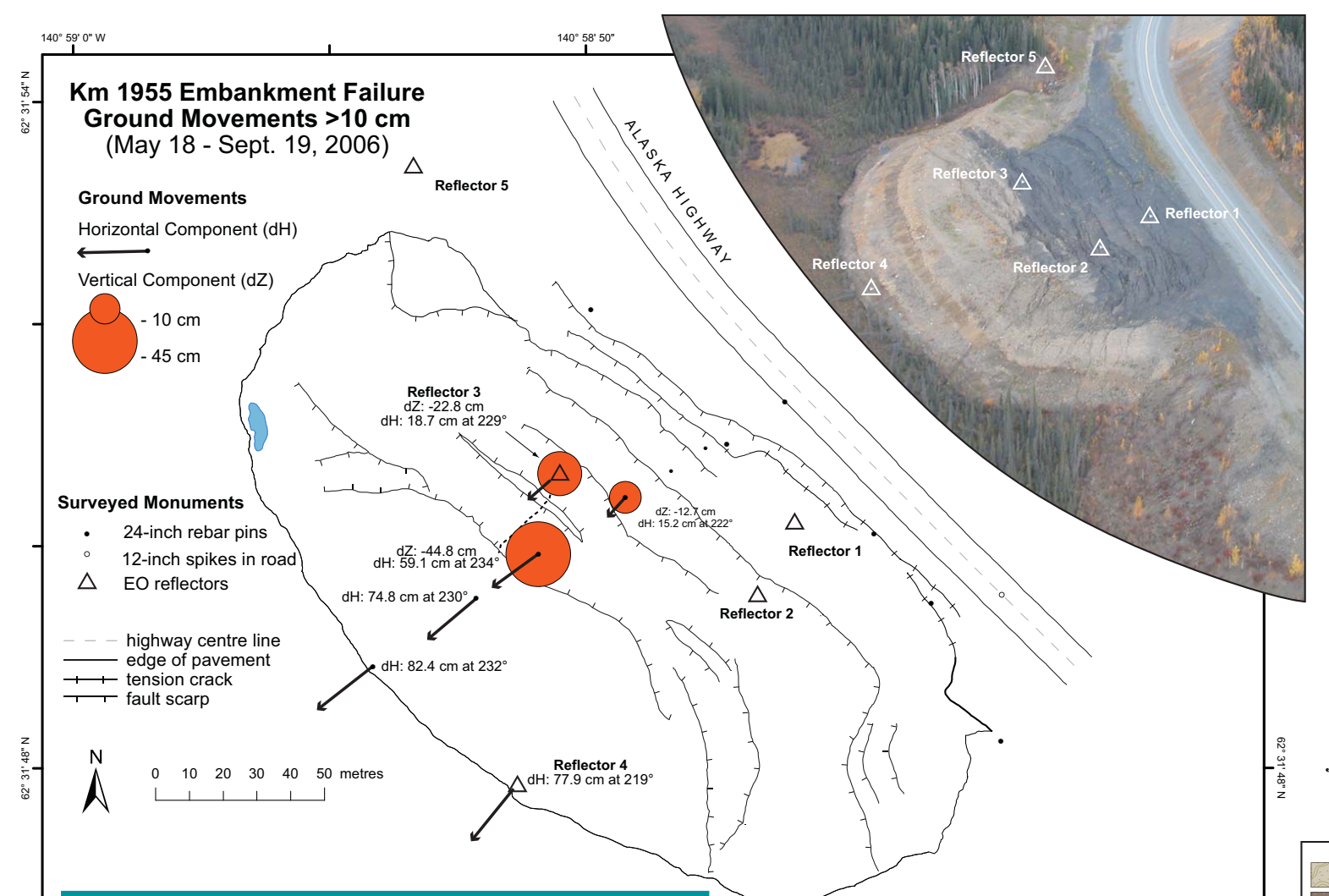
***Figure 1**. Locations of various study areas.*

Satellite Monitoring

In partnership with CCORE Engineering (St. Johns, NF) and the European Space Agency, five sites were monitored using RadarSAT imagery captured throughout the summer of 2006.

Using Interferometric Synthetic Aperture Radar (InSAR), the technique is capable of detecting mm-scale ground movements resulting from permafrost degradation.

Two sites near Beaver Creek (Figs. 2 & 3), as well as the Magundy (Fig. 15), Little Salmon Lake (Fig. 14) and 10 Mile Creek (Fig. 13) landslides near Carmacks were monitored. Results have not yet been processed.


140° 59' 0" W
140° 58' 50"
62° 31' 54" N
62° 31' 48" N
Km 1955 Embankment Failure
Ground Movements >10 cm
(May 18 - Sept. 19, 2006)
Ground Movements
Horizontal Component (dH)
Vertical Component (dZ)
- 10 cm
- 45 cm
Surveyed Monuments
24-inch rebar pins
12-inch spikes in road
EO reflectors
highway centre line
edge of pavement
tension crack
fault scarp
N
0 10 20 30 40 50 metres
ALASKA HIGHWAY
Reflector 5
Reflector 3
dZ: -22.8 cm
dH: 18.7 cm at 229°
dZ: -12.7 cm
dH: 15.2 cm at 222°
dZ: -44.8 cm
dH: 59.1 cm at 234°
dH: 74.8 cm at 230°
dH: 82.4 cm at 232°
Reflector 1
Reflector 2
Reflector 4
dH: 77.9 cm at 219°

Reflector 3

***Figure 2** (left). At a site near Beaver Creek, total station surveys were used to measure ground movements and provide validation for satellite monitoring.*

Inset shows reflector installed to provide ground control.

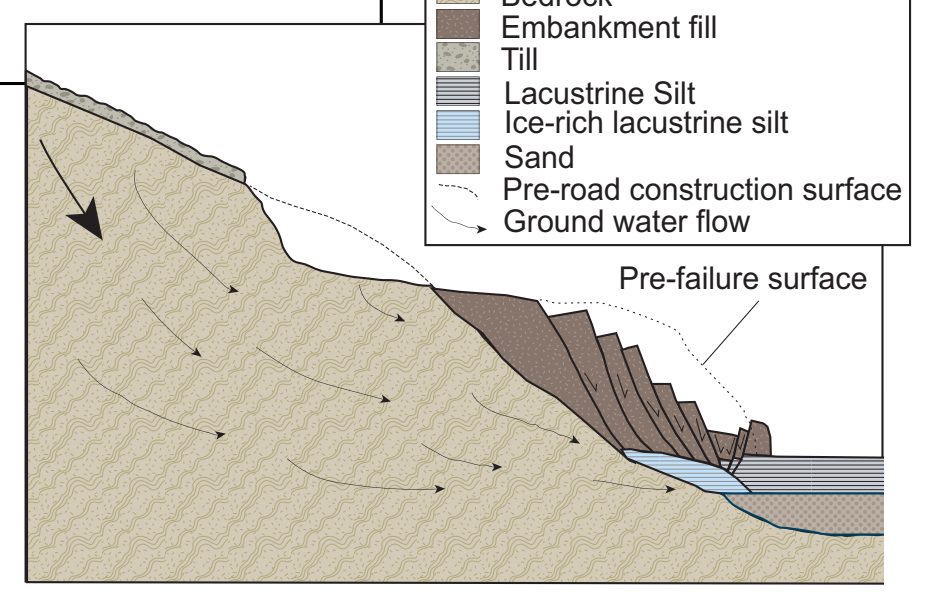

Bedrock
Embankment fill
Till
Lacustrine Silt
Ice-rich lacustrine silt
Sand
Pre-road construction surface
Ground water flow
Pre-failure surface

***Figure 3** (below). Sketch of proposed failure mechanism at Beaver Creek failure.*

2004 Forest Fires near Dawson

- 2005 study in collaboration with Jim Coates and Antoni Lewkowicz (U of Ottawa) focussed on three basins (Fig. 5) burned in 2004 forest fires.
- Almost 150 active layer detachments occurred within one year of the fires.
- Failures initiated in silty colluvium, on gentle to moderate slopes (generally 10-25°) with a variety of aspects, and commonly near a convex break in slope.
- Most failures were shallow (50-80 cm deep) and relatively small (5-20 m wide x 10-500 m long).
- The combined effects of widespread failures are a potentially significant source of sediment to local streams, where water quality is of critical importance to placer mining regulations.

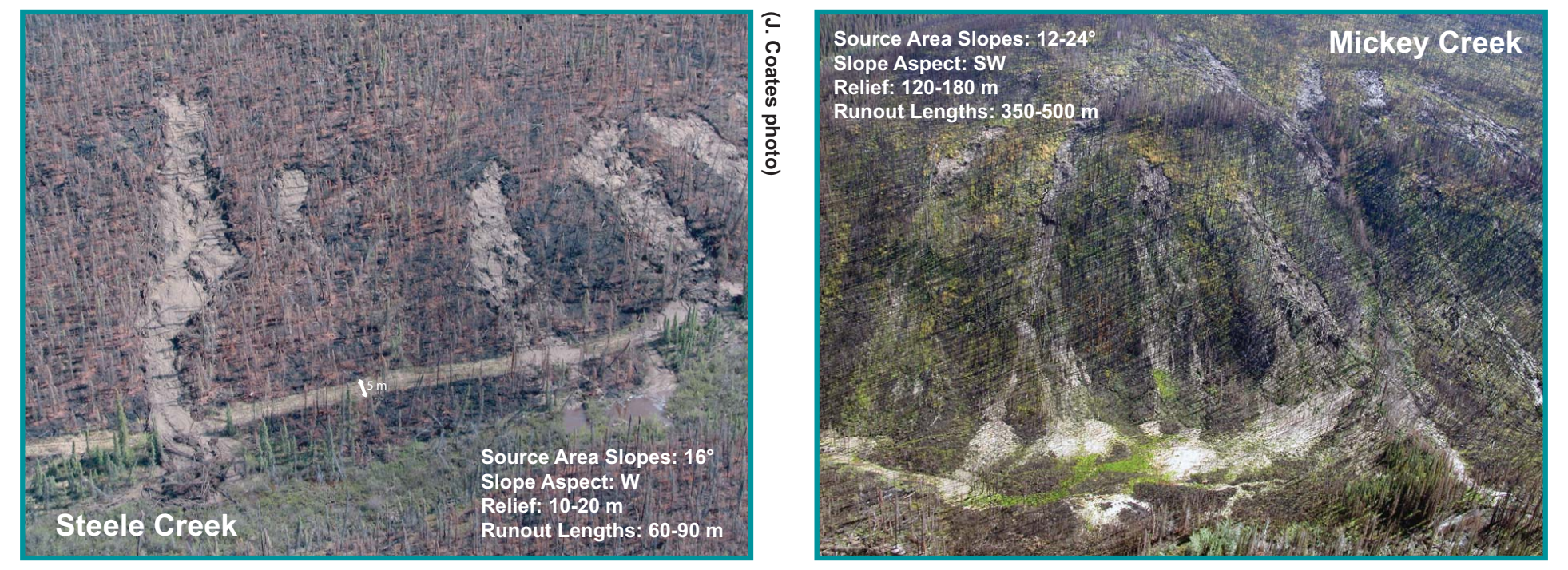

Steele Creek
Source Area Slopes: 16°
Slope Aspect: W
Relief: 10-20 m
Runout Lengths: 60-90 m
(J. Coates photo)
Mickey Creek
Source Area Slopes: 12-24°
Slope Aspect: SW
Relief: 120-180 m
Runout Lengths: 350-500 m

***Figure 4** (above). Characteristics of typical active layer detachments in two study basins. Note large amounts of fine sediment deposited onto valley bottom in both examples.*

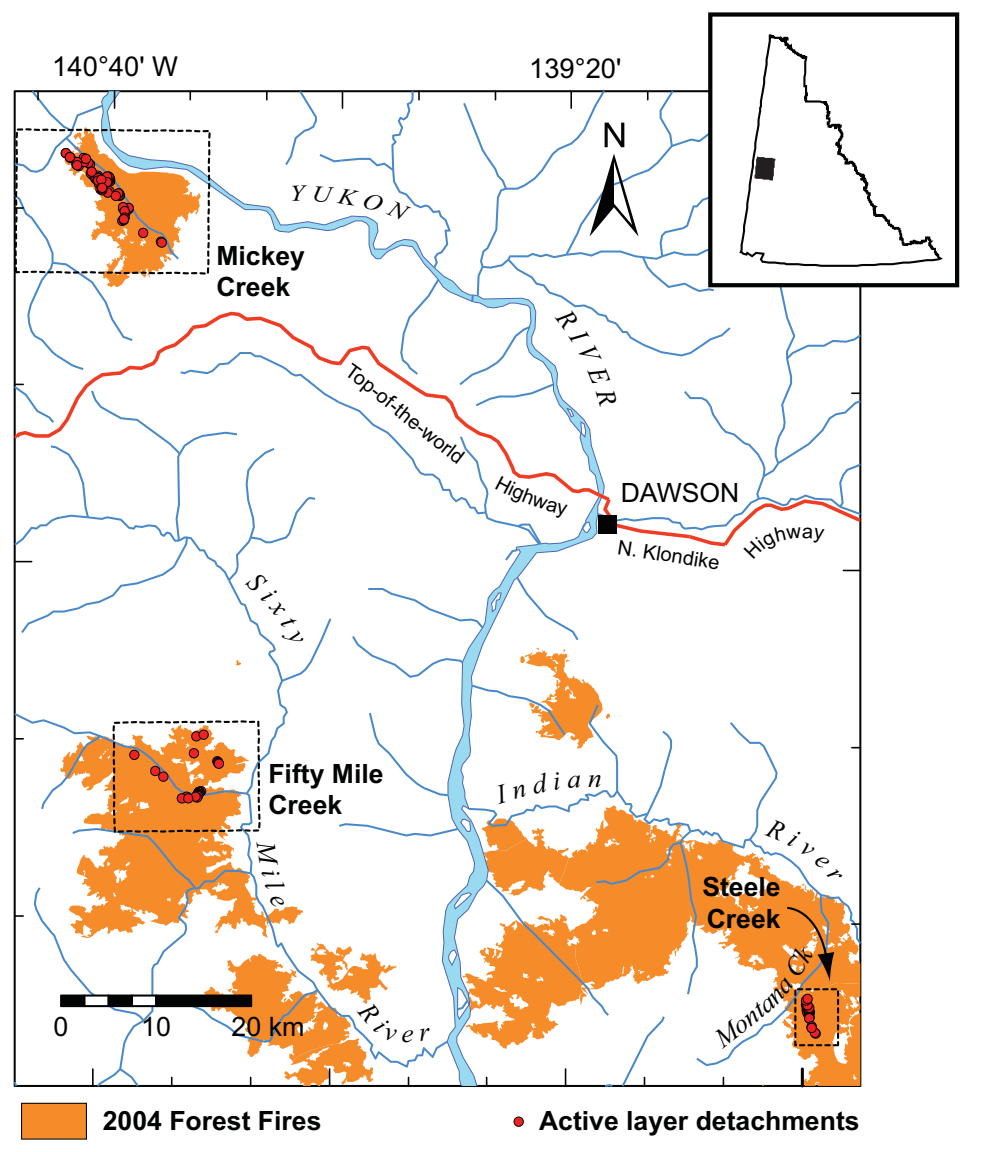

140°40' W
139°20'
64°20' N
63°40'
N
YUKON RIVER
Mickey Creek
Top-of-the-world Highway
DAWSON
N. Klondike Highway
Sixty Mile River
Fifty Mile Creek
Indian River
Steele Creek
Montana Cr.
0 10 20 km
2004 Forest Fires
Active layer detachments

***Figure 5** (right). Map showing locations of active-layer detachments within three study basins and distribution of 2004 forest fires.*

(For more information on this study, see Lipovsky et al., 2006)

Kusawa Lake Resistivity Surveys

- In 1981, an alpine landslide (Figure 7) triggered debris torrents that travelled 5 km down a creek (Figure 6) and severely damaged the Kusawa Lake campground, 300 m of its access road and adjacent private property.
- Permafrost likely played a role in initiating the landslide via its control on local pore pressures.
- Concern for the risk of similar events occurring in the future prompted Yukon Parks and YGS to conduct investigations in the Kusawa Fan basin to further characterize the hazard.
- Geophysical resistivity surveys were performed in June 2006 to determine the permafrost configuration above the headscarp (Figure 8).

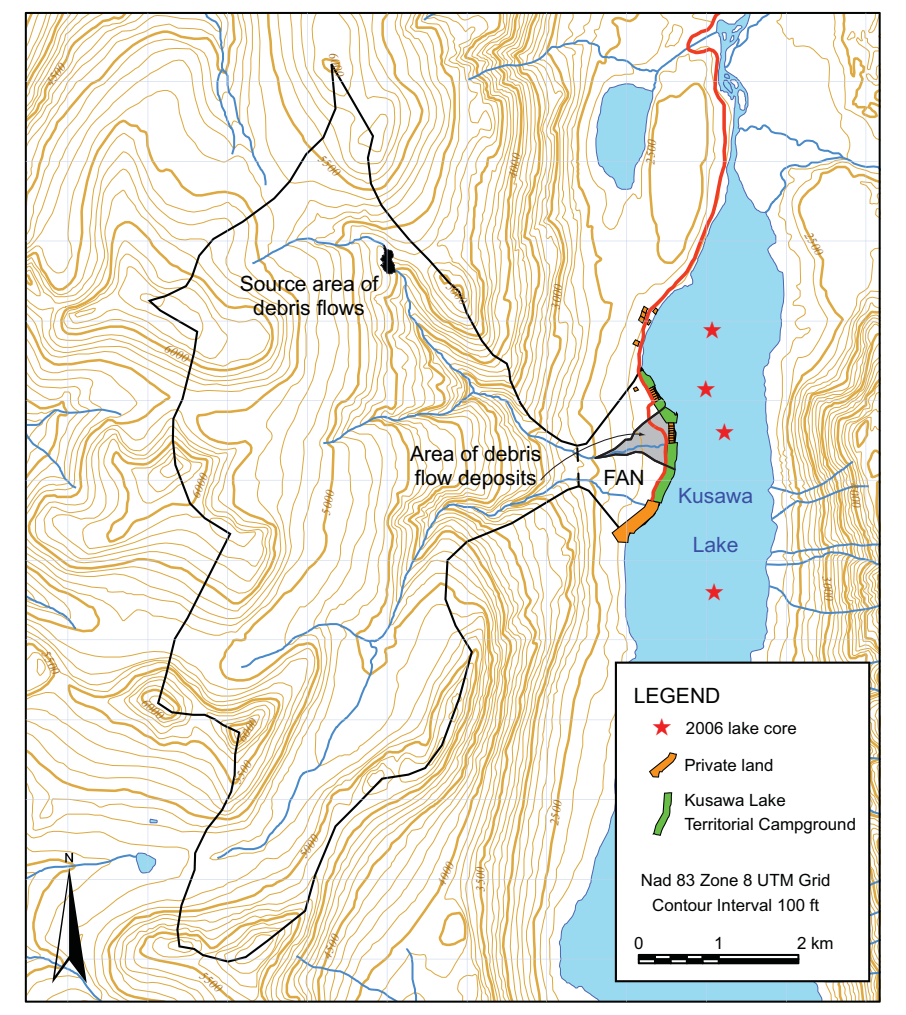

Source area of debris flows
Area of debris flow deposits
FAN
Kusawa Lake
LEGEND
2006 lake core
Private land
Kusawa Lake Territorial Campground
Nad 83 Zone 8 UTM Grid
Contour Interval 100 ft
0 1 2 km
N

***Figure 6**. Kusawa Fan drainage basin and location of landslide source area that triggered debris flows.*

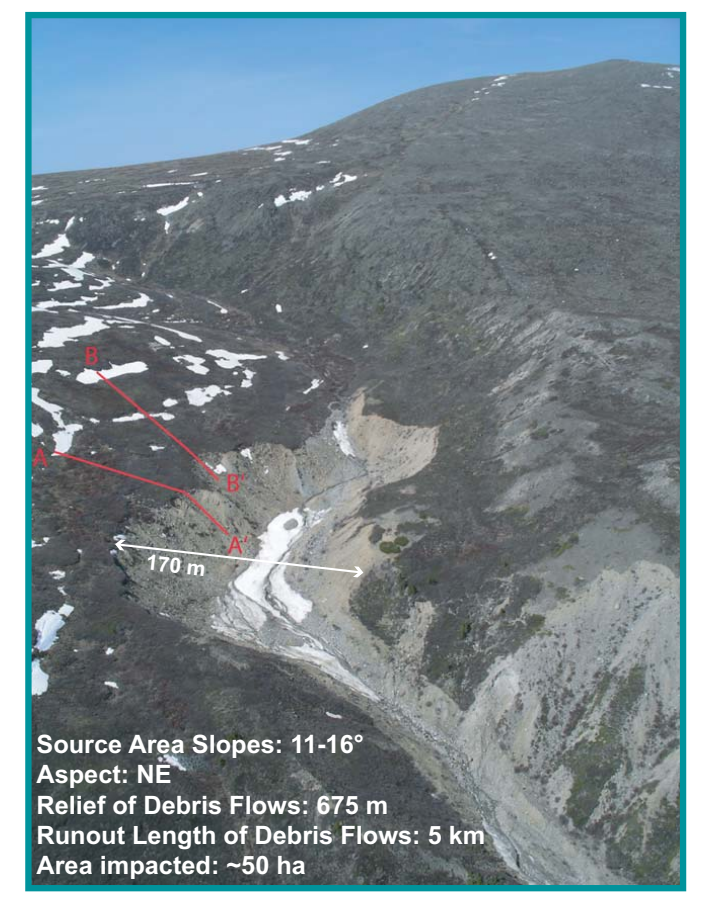

170 m
Source Area Slopes: 11-16°
Aspect: NE
Relief of Debris Flows: 675 m
Runout Length of Debris Flows: 5 km
Area impacted: ~50 ha

***Figure 7**. Landslide source area in thick till deposit. Bowl is 370m long and up to 28m deep. Locations of resistivity profiles are shown in red.*

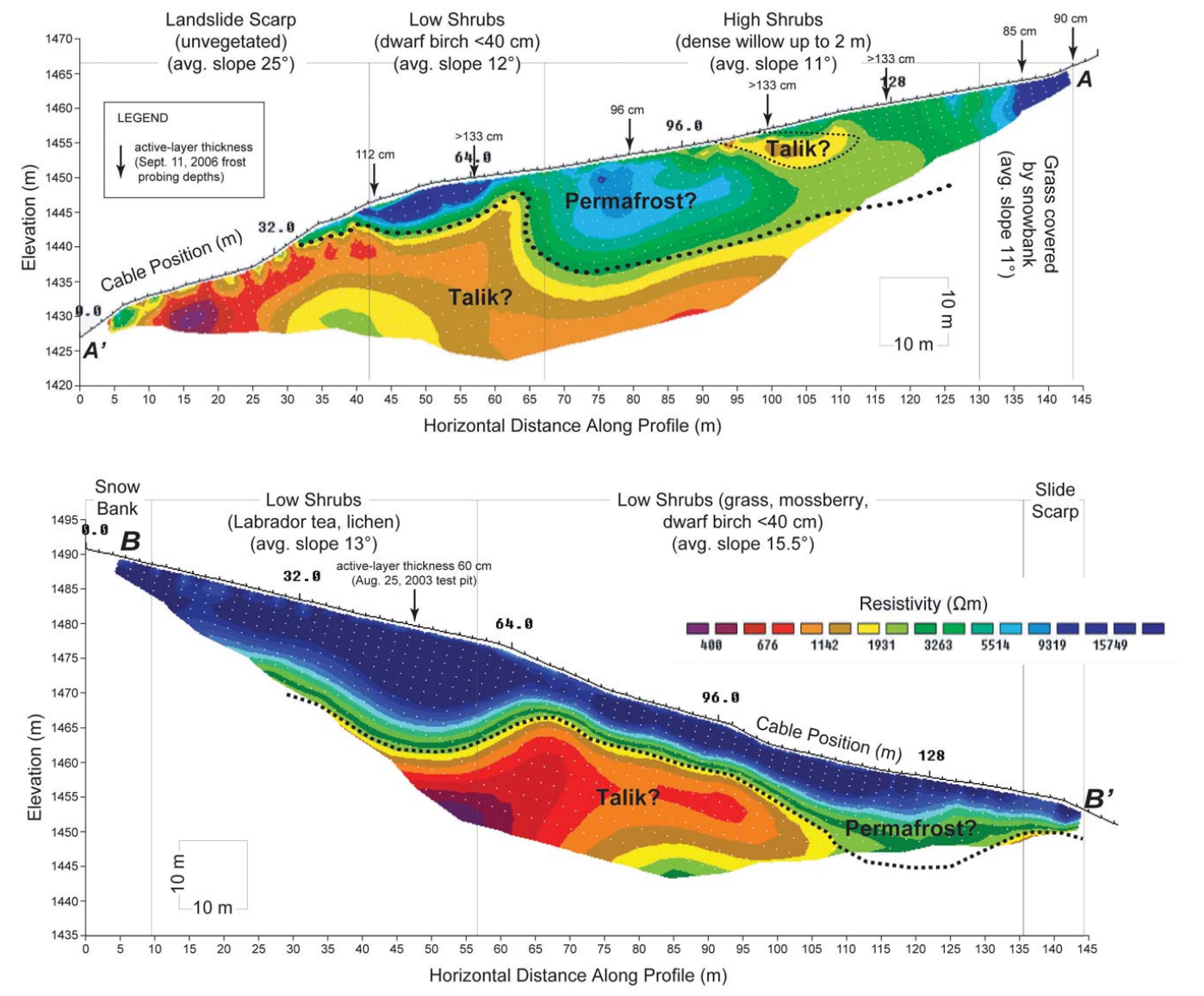


***Figure 8.** Resistivity results suggest that permfrost in the landslide source area has considerable ground ice content (high resistivity values) and that thicknesses vary between 7 and 18 m.*

Pelly Watershed Inventory

- In response to concerns raised by Selkirk First Nation regarding deteriorated water quality in the Pelly River in recent years, a reconnaissance inventory of permafrost landslides was completed along the Pelly and MacMillan Rivers in 2006.
- Air photo interpretation, satellite imagery, a fixed wing flight and GIS analysis were used to locate over 100 landslides (Fig. 9).
- Several examples illustrate some key features unique to permafrost-related landslides:
  - generally occur on northerly-facing slopes, but can occur on south-facing slopes (Fig. 11).
  - initiate on gentle slopes (Fig. 12), usually between 10 and 20º.
  - can impact extremely large areas up to 200 ha (Figs. 11, 12 and 15).
  - can initiate debris flows that travel long distances up to 5 km downslope (Figs. 6 and 13).
  - can remain active for decades (Fig. 12).

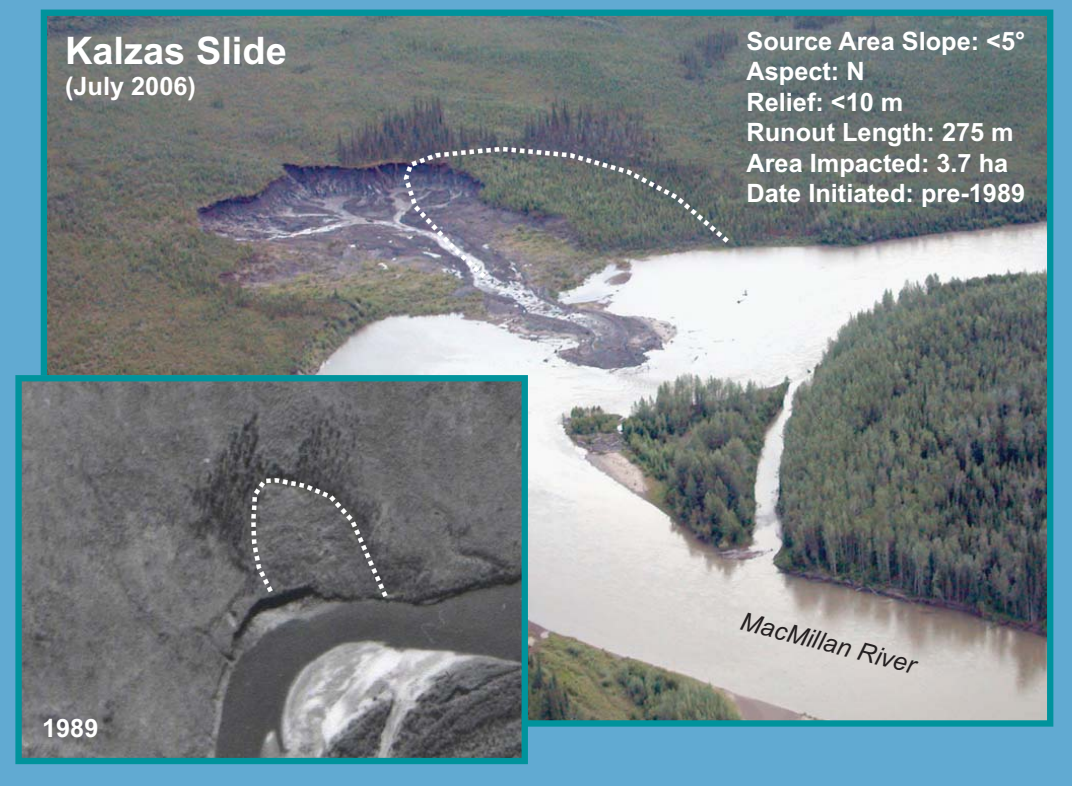

Kalzas Slide
(July 2006)
Source Area Slope: <5°
Aspect: N
Relief: <10 m
Runout Length: 275 m
Area Impacted: 3.7 ha
Date Initiated: pre-1989
MacMillan River
1989

***Figure 10**. This textbook retrogressive thaw failure has dammed 3/4 of the MacMillan River for at least the last 3 years. Since 1989, headscarp retreat rates have averaged 10 m per year. The failure occurs adjacent to the scar of an older one, shown by the dotted lines.*

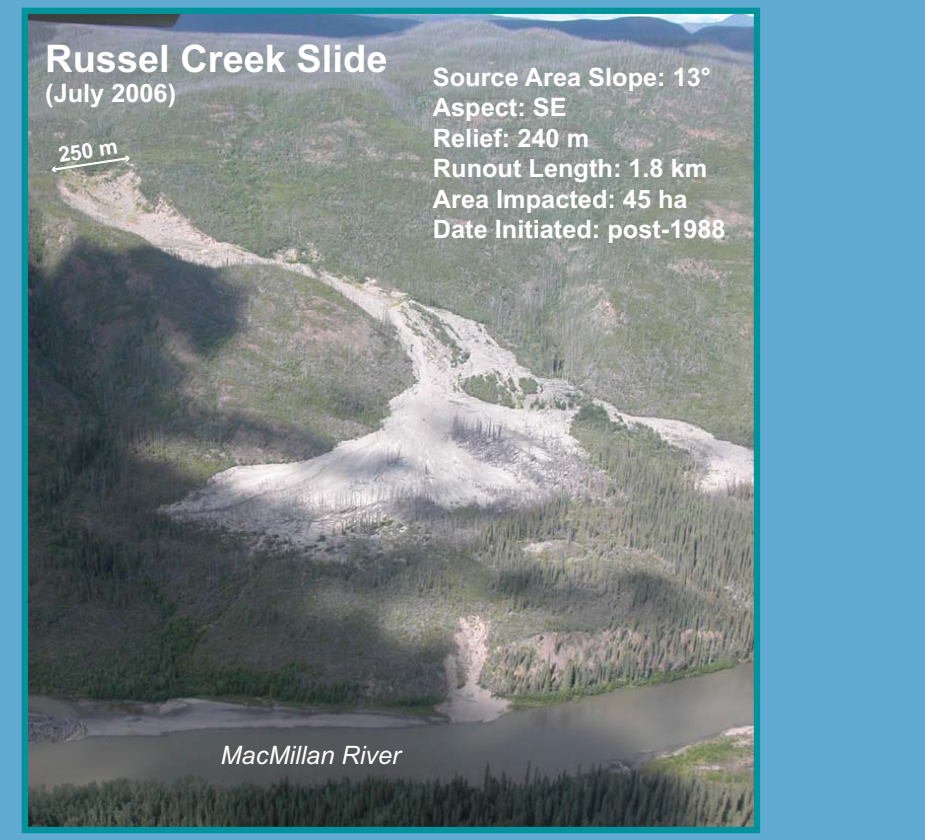

Russel Creek Slide
(July 2006)
250 m
Source Area Slope: 13°
Aspect: SE
Relief: 240 m
Runout Length: 1.8 km
Area Impacted: 45 ha
Date Initiated: post-1988
MacMillan River

***Figure 11**. The large Russel Creek landslide was likely triggered by a forest fire in 1989. Its southerly aspect is unusual for permafrost-related landslides.*

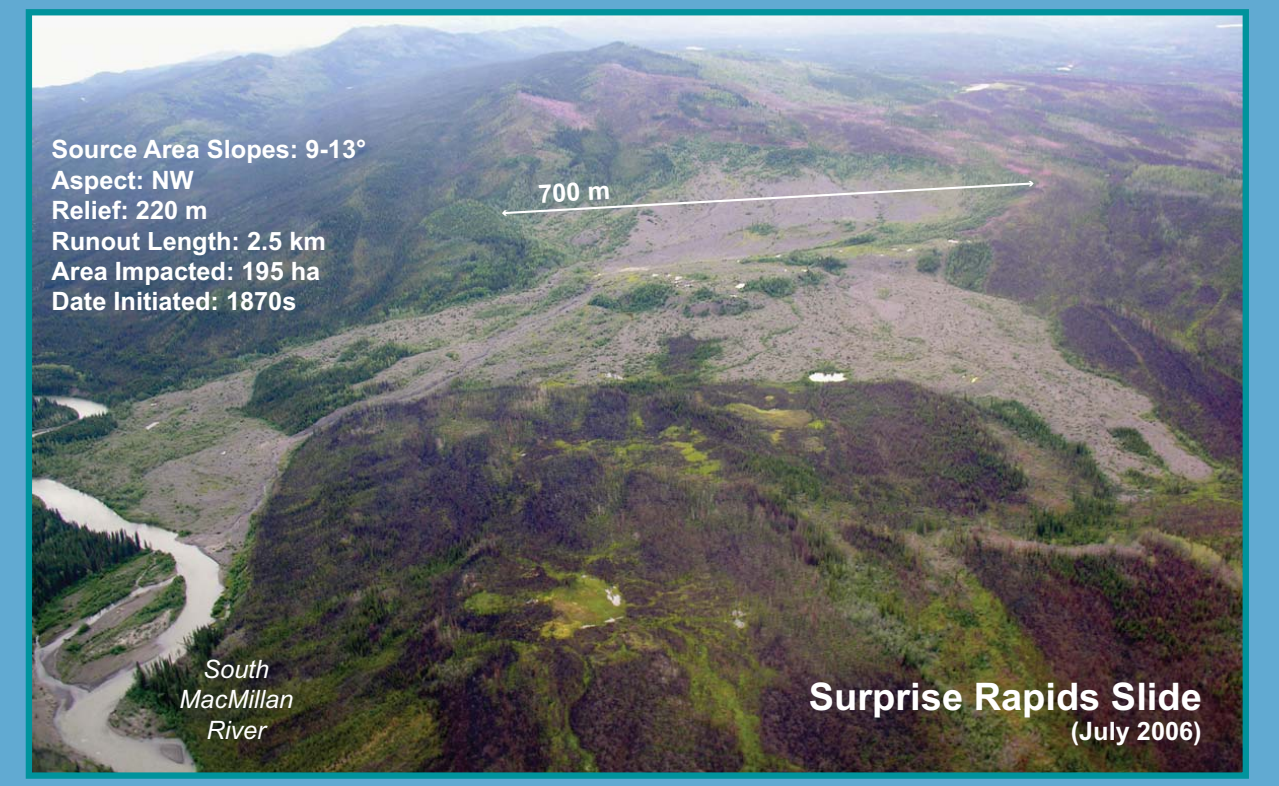

Source Area Slopes: 9-13°
Aspect: NW
Relief: 220 m
Runout Length: 2.5 km
Area Impacted: 195 ha
Date Initiated: 1870s
700 m
South MacMillan River
Surprise Rapids Slide
(July 2006)

***Figure 12**. The Surprise Rapids landslide is one of the largest retrogressive thaw failures in central Yukon. It was likely triggered by a forest fire in the 1870s and has been reactivated several times since then (Ward et al., 1992).*

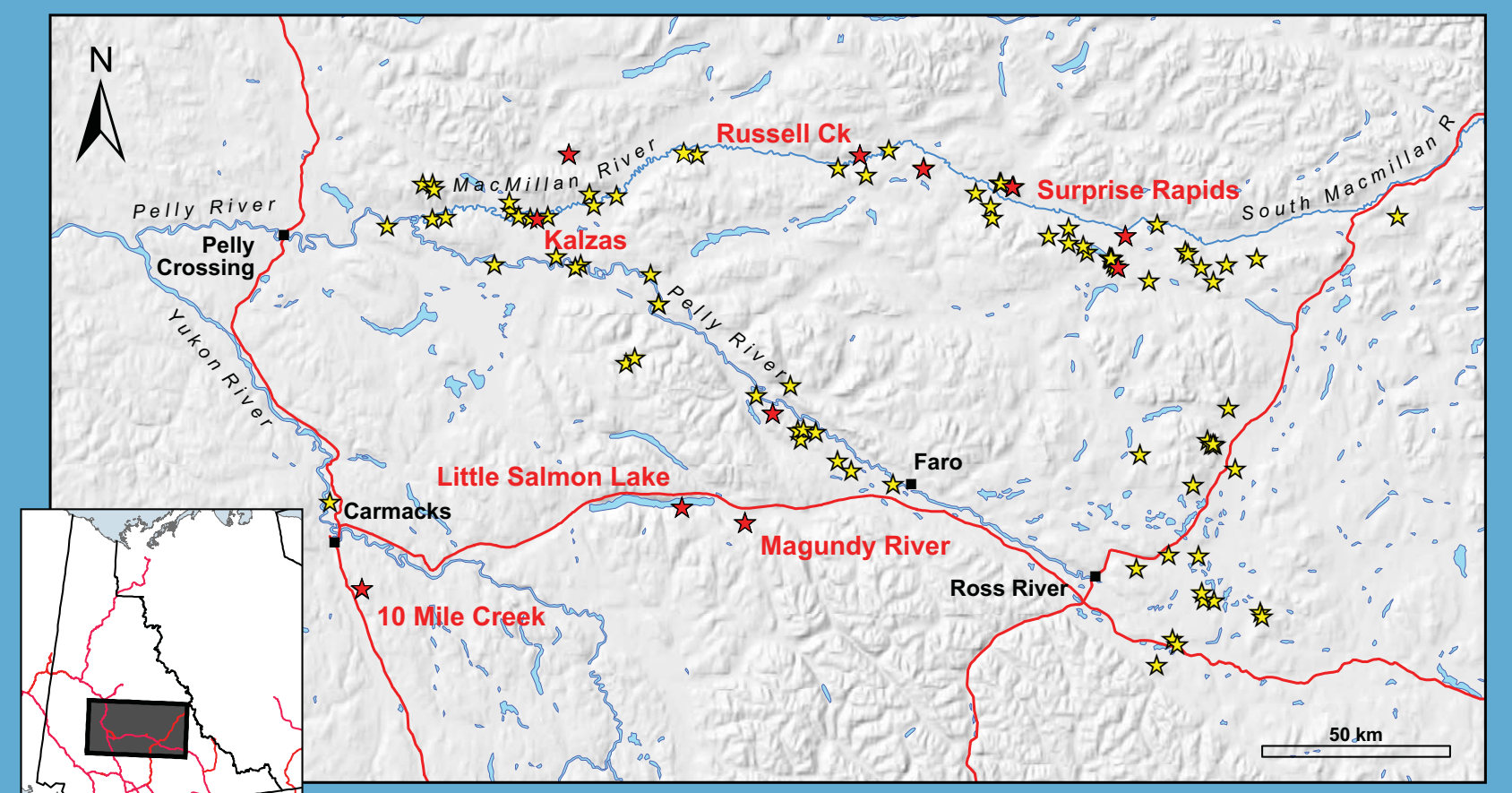

N
Pelly River
Pelly Crossing
Yukon River
MacMillan River
Russell Ck
Kalzas
Surprise Rapids
South Macmillan R.
Pelly River
Faro
Little Salmon Lake
Carmacks
Magundy River
Ross River
10 Mile Creek
50 km

***Figure 9**. Locations of permafrost-related landslides (shown by stars) in the Pelly River Watershed.*

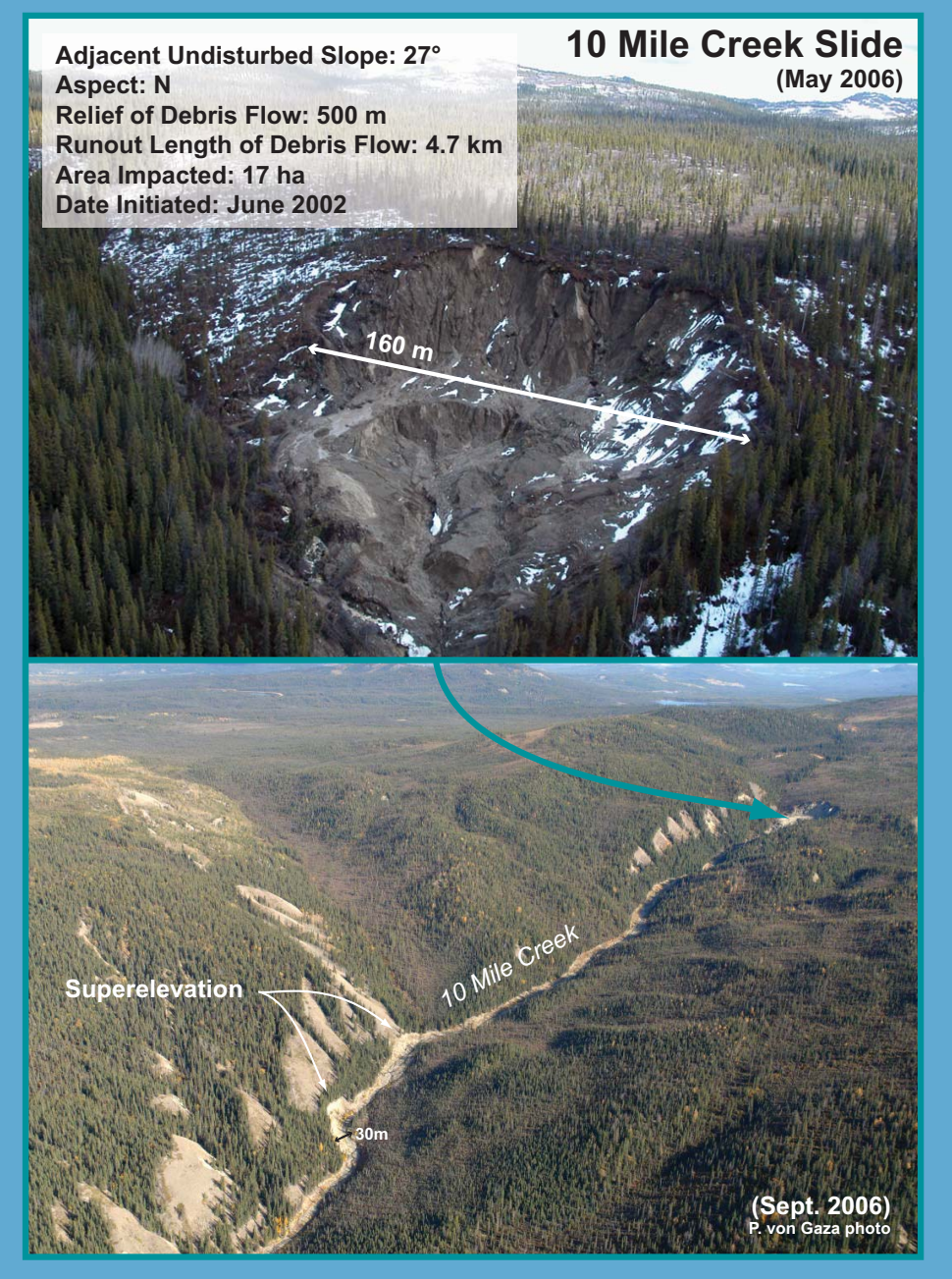

Adjacent Undisturbed Slope: 27°
Aspect: N
Relief of Debris Flow: 500 m
Runout Length of Debris Flow: 4.7 km
Area Impacted: 17 ha
Date Initiated: June 2002
10 Mile Creek Slide
(May 2006)
160 m
Superelevation
10 Mile Creek
30m
(Sept. 2006)
P. von Gaza photo

***Figure 13**. 13 km SE of Carmacks, high pore pressures beneath the permafrost caused a large detachment failure (top photo). The failure then triggered a massive debris flow that travelled 5 km down 10 Mile Creek to the Klondike Highway. The torrent travelled at speeds of up to 40 km/hr and cleared a swath (shown in photo above) averaging 30 m wide. Note superelevation (sloshing) of debris flow around bends in the channel.*

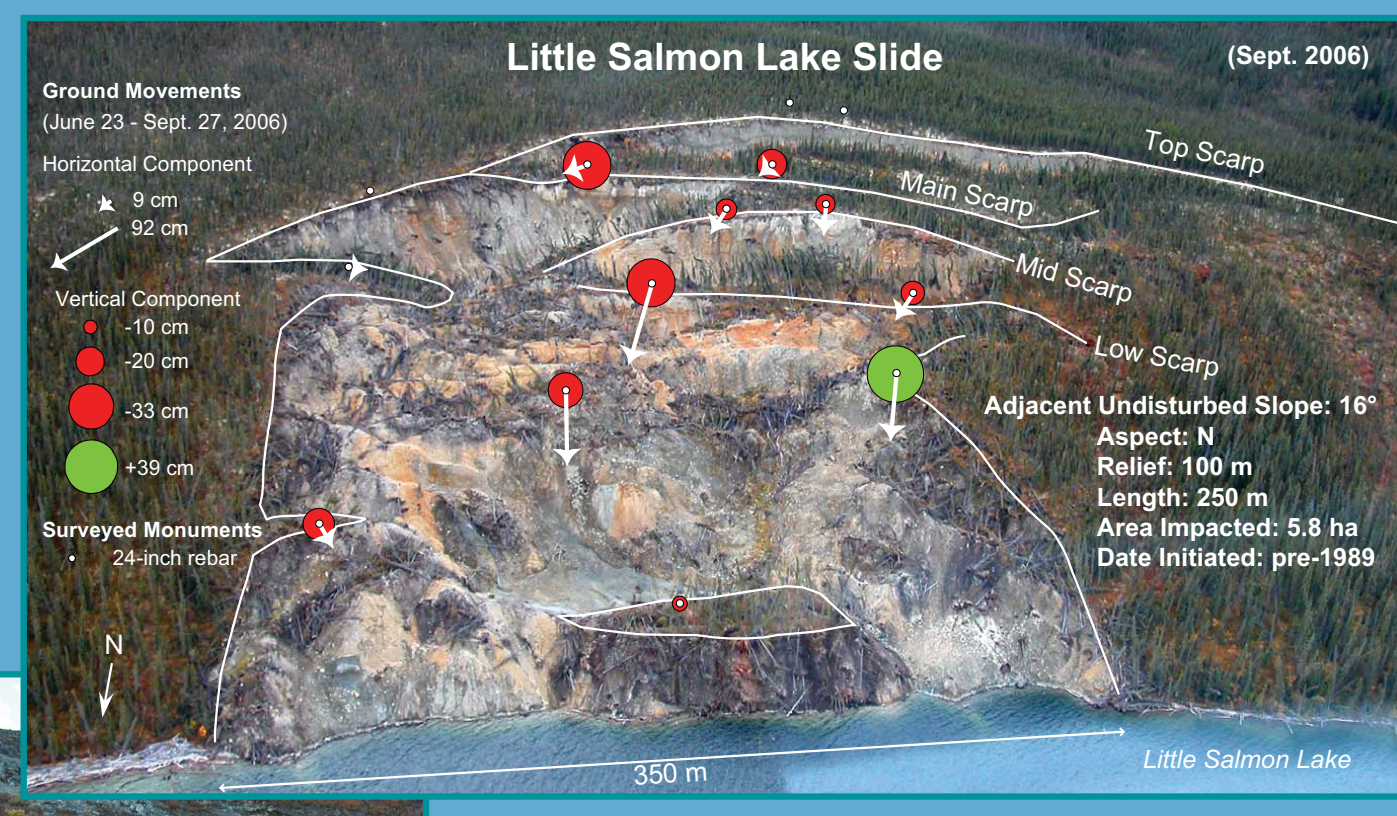

Little Salmon Lake Slide
(Sept. 2006)
Ground Movements
(June 23 - Sept. 27, 2006)
Horizontal Component
9 cm
92 cm
Vertical Component
-10 cm
-20 cm
-33 cm
+39 cm
Surveyed Monuments
24-inch rebar
Top Scarp
Main Scarp
Mid Scarp
Low Scarp
Adjacent Undisturbed Slope: 16°
Aspect: N
Relief: 100 m
Length: 250 m
Area Impacted: 5.8 ha
Date Initiated: pre-1989
N
350 m
Little Salmon Lake

***Figure 14**. At the Little Salmon Lake slide, permafrost creep and thaw of ice-rich material at the toe have caused a series of extensional ruptures (scarps) since 1989. Summer 2006 ground movements at the slide were surveyed using a Thales ProMark3 differential GPS (unit shown to left), which is reportedly accurate to 1 cm .*

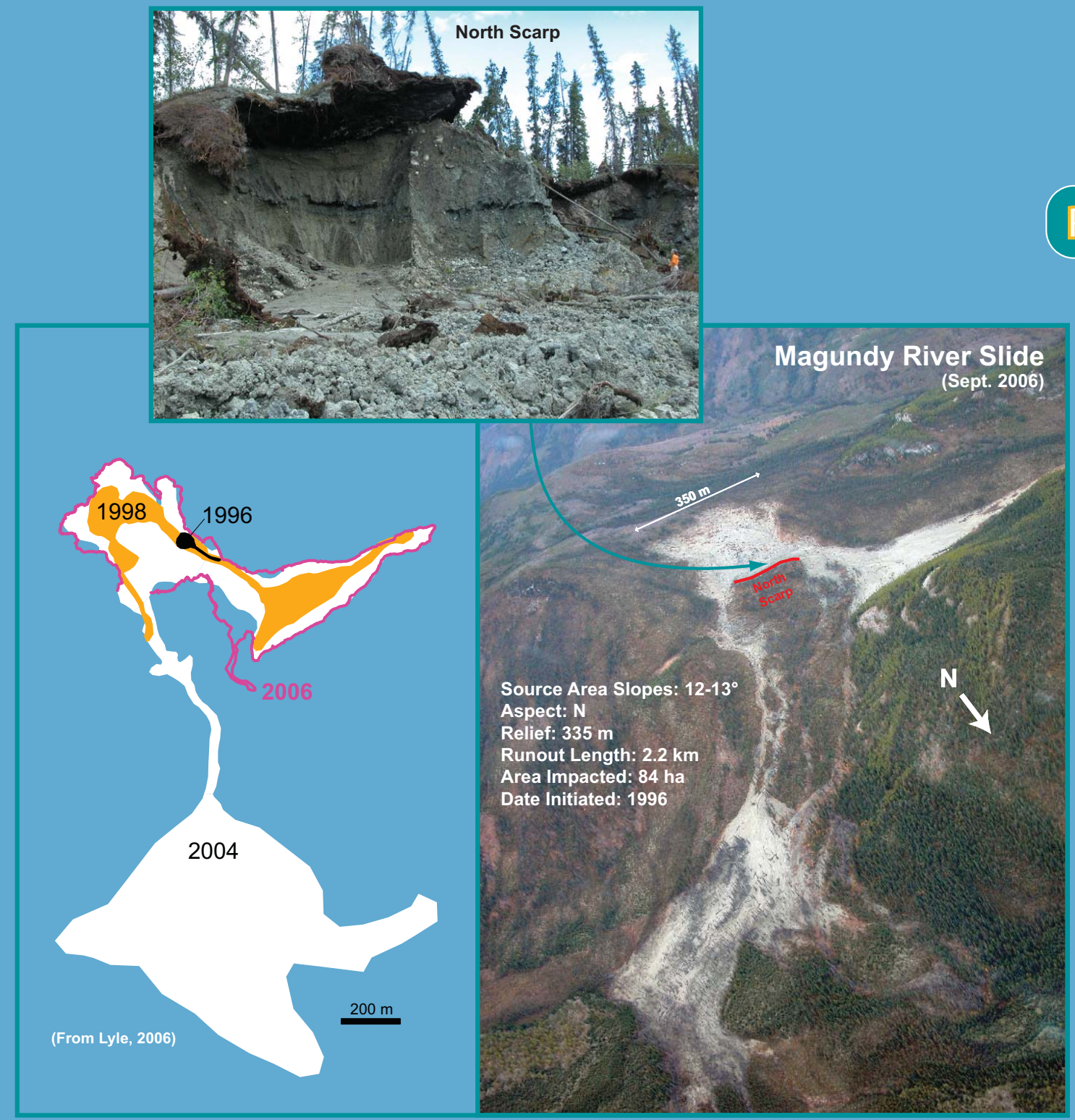

North Scarp
1998
1996
2006
2004
200 m
(From Lyle, 2006)
Magundy River Slide
(Sept. 2006)
350 m
North Scarp
N
Source Area Slopes: 12-13°
Aspect: N
Relief: 335 m
Runout Length: 2.2 km
Area Impacted: 84 ha
Date Initiated: 1996

***Figure 15**. The Magundy River slide has shown a rapid rate of growth since it was initatied as a small piping failure in 1996. Ice contents in the north scarp (inset at top) are as high as 50%. Retreat of this scarp averaged 30-40 m/year between 1998 and 2004, producing extensive debris flows that formed the large lower fan.*

Take Home Messages

- **Permafrost-related landslides can extend several km down slopes, can impact very large areas up to 200 ha and can remain active for decades.**
- **Infrastructure, recreational facilities and water quality have been significantly impacted by permafrost-related landslides in the recent past.**
- **Numerous active-layer detachments were triggered in the Dawson area after extensive forest fires in 2004.**
- **Permafrost-related landslides commonly occur on gentle to moderate slopes that are usually north facing, but can be south-facing.**
- **Basin characteristics several kilometers upslope of any proposed land-use should be evaluated for landslide and debris flow risk.**

Acknowledgements

Many thanks are owed to...

- Crystal Huscroft for wading through stacks of Pelly watershed air photos and collaborations at 10 Mile Creek.
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- Bernd Etzelmüller (University of Oslo, Norway) for performing resistivity surveys (10 Mile Ck and Kusawa Lake)
- Google Earth for making reconnaissance surveys a whole lot easier!

References

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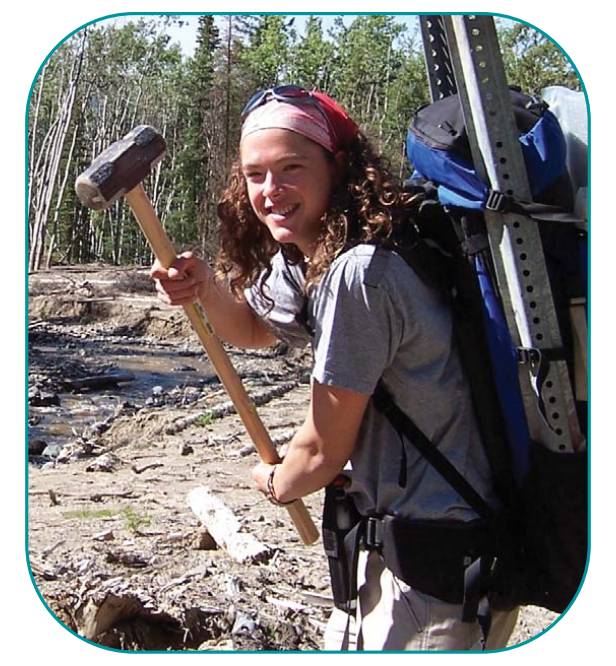

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