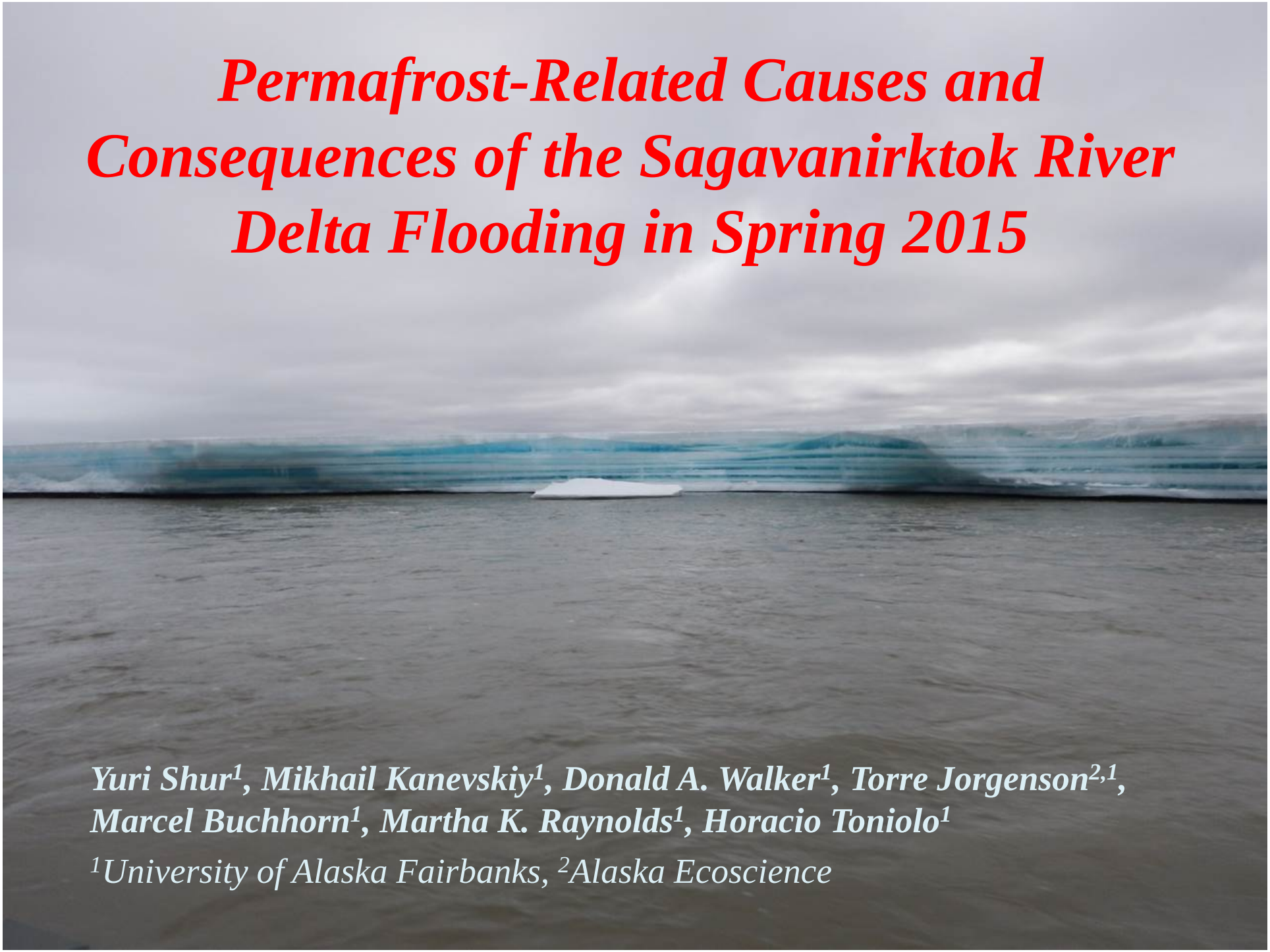
Permafrost-Related Causes and Consequences of the Sagavanirktok River Delta Flooding in Spring 2015



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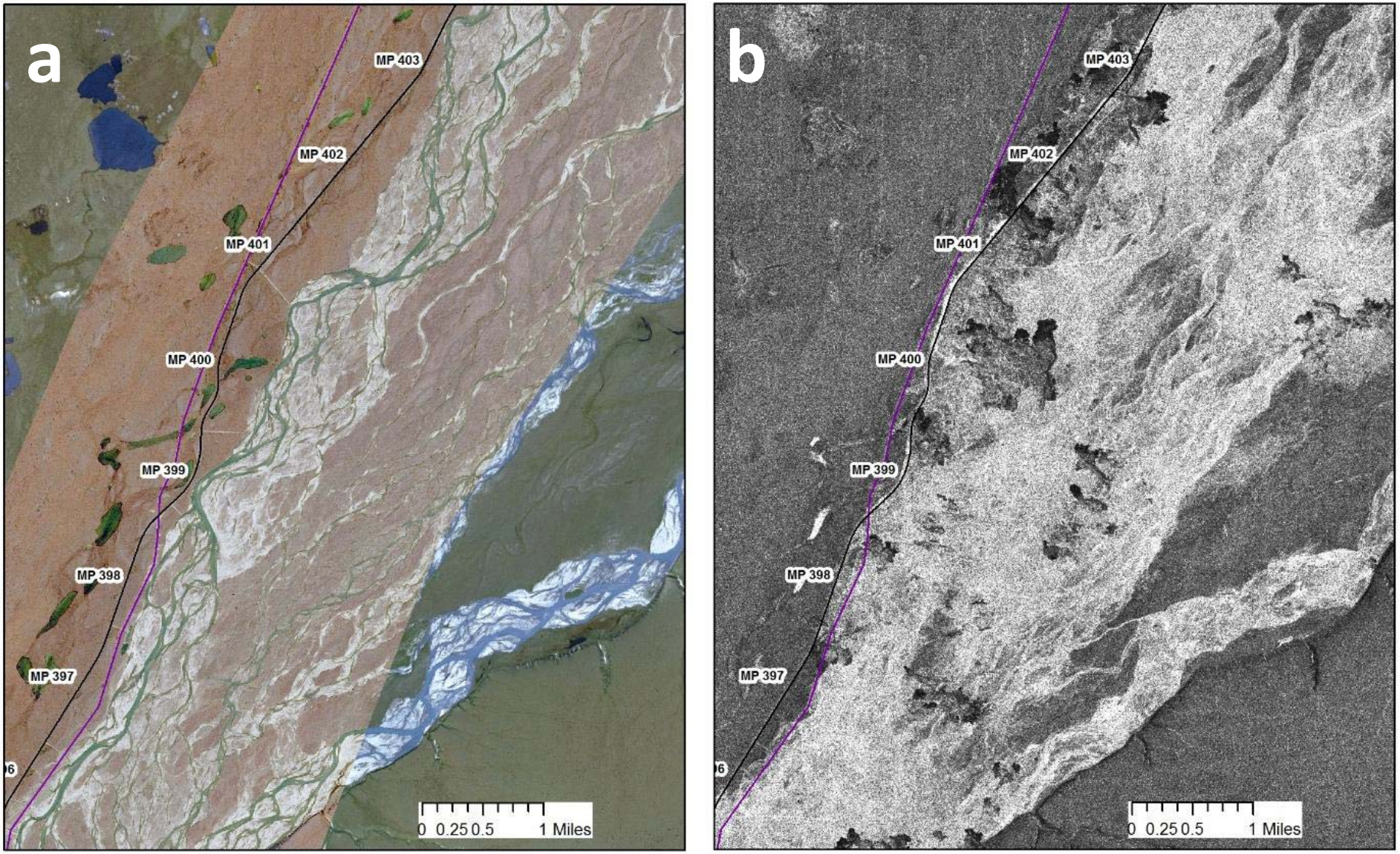
- In the first part of March 2015, a huge icing began to develop in the delta of the Sagavanirktok (Sag) River on the Beaufort Sea Coastal Plain of Alaska - an area with severe arctic climate and thick continuous permafrost.
- Icing (aufeis) is a mass of surface ice formed in winter by successive freezing of layers of water seeping from a river or a spring.
- River icings develop when winter flow in the river under ice is obstructed causing overflows. Icings occur in many cold regions but the permafrost region is the most susceptible to their formation.

Photo: Alaska Department of Transportation and Public Facilities



Optical image (a) a narrow strip from SPOT6 shows river channel in 2014, with brown land and green water overlying optical Best Data Layer from Geographic Information Network of Alaska, compared with (b) TerraSAR-X image from April 8, 2015. Overflow appears as dark areas in SAR image (b); icing appears as white. Dalton Highway is black line with milepost labels (ADOT&PF shapefile), and Trans-Alaska Pipeline is purple line (AK DNR shapefile).

- **2015 Sag River icing developed in vicinity of Deadhorse and next to the Dalton Highway, the only road in northern Alaska that provides access to major Alaska oilfields and is parallel to the Trans-Alaska Oil Pipeline.**
- **The huge icing worked as an ice dam, which caused flooding of the highway and surrounding tundra and infrastructure.**
- **The overflow water raised to several meters above the normal winter level and flooded about 25 km of the Dalton Highway to a height of about one meter.**
- **This event led to the closure of the Dalton Highway from March 30 to April 2 and from April 5 to April 12.**

Photo: Alaska Department of Transportation and Public Facilities

- In mid-May, higher than usual air temperature in the upper watershed caused fast melting of snow and high floodwater, which was obstructed in the Delta by the extensive ice dam.
- The floodwater ran over the highway, washed out several stretches of it, and reached the Deadhorse Airport. The highway was closed again and reopened on June 5, after a 18-day-long closure.
- Media in Alaska, nationwide and even abroad covered the Dalton Highway flooding and some of them characterized it as “epic” and the flooding of biblical proportion.
- The Alaska governor Bill Walker twice (in April and May) issued Declarations of Disaster Emergency due to the unprecedented flooding.
- Cost of the highway repair: $46 M.

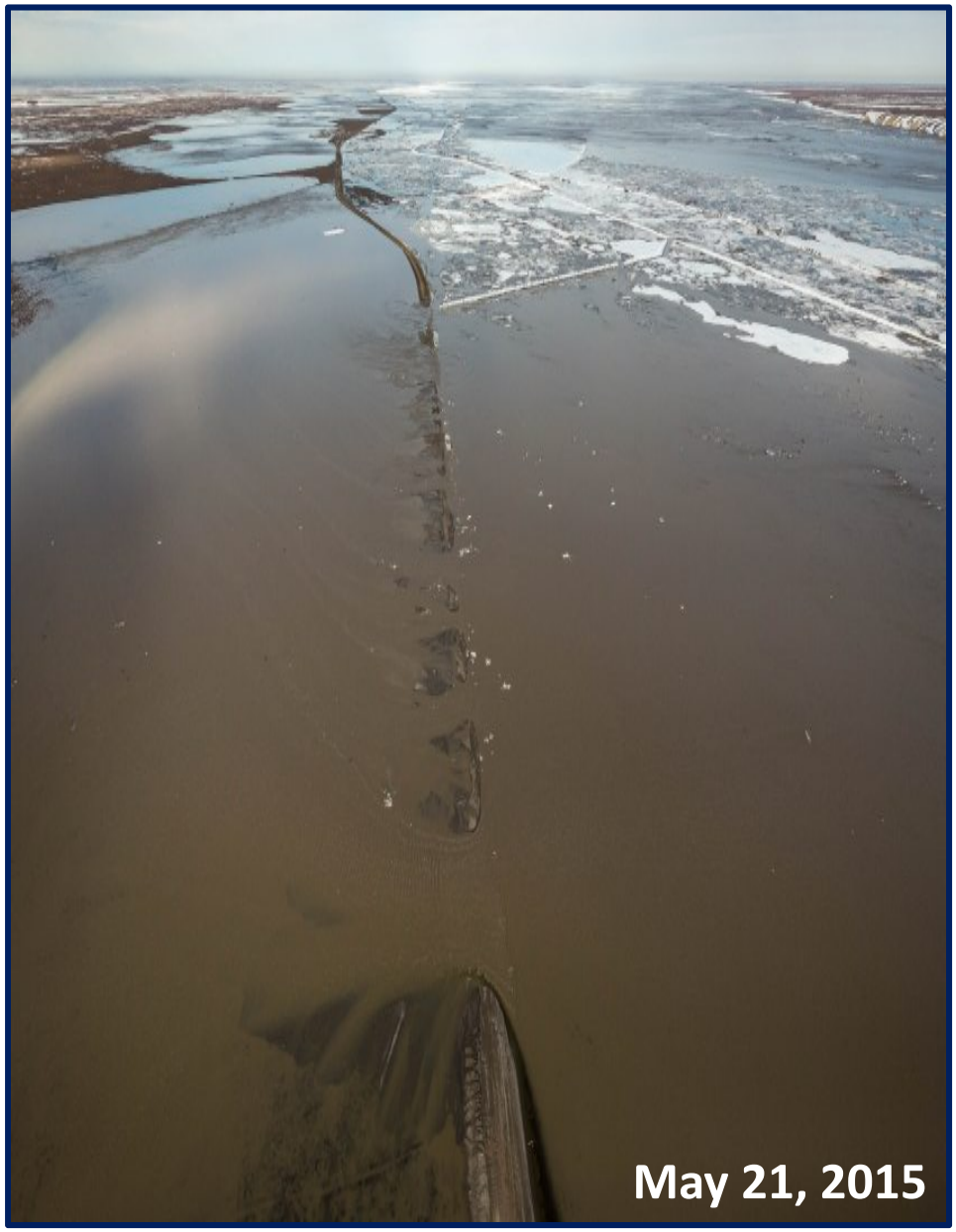


Photo: Alaska Department of Transportation and Public Facilities

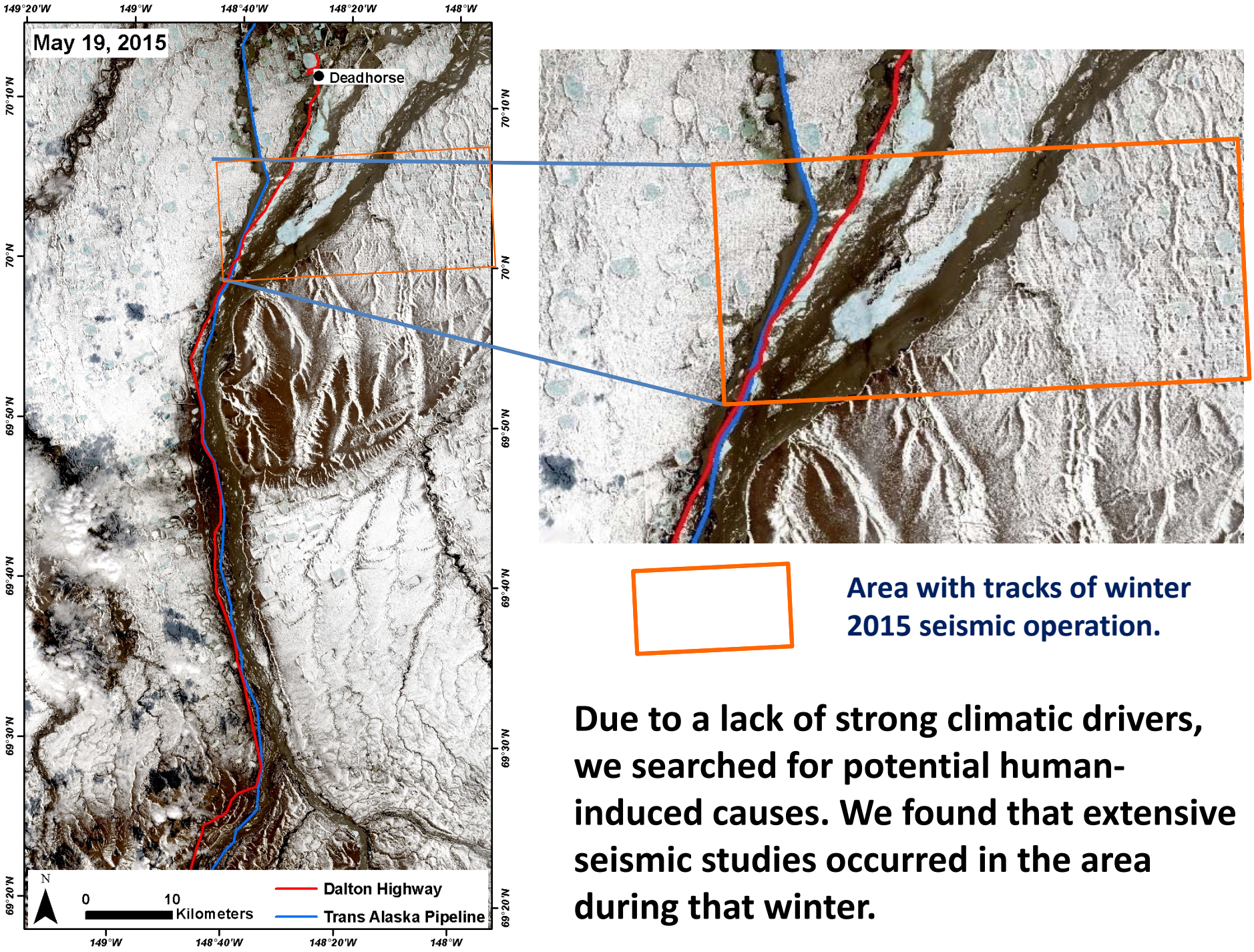

June 1, 2015

Flooding of the Dalton Highway and Deadhorse Airport.

Photos: Alaska Department of Transportation and Public Facilities

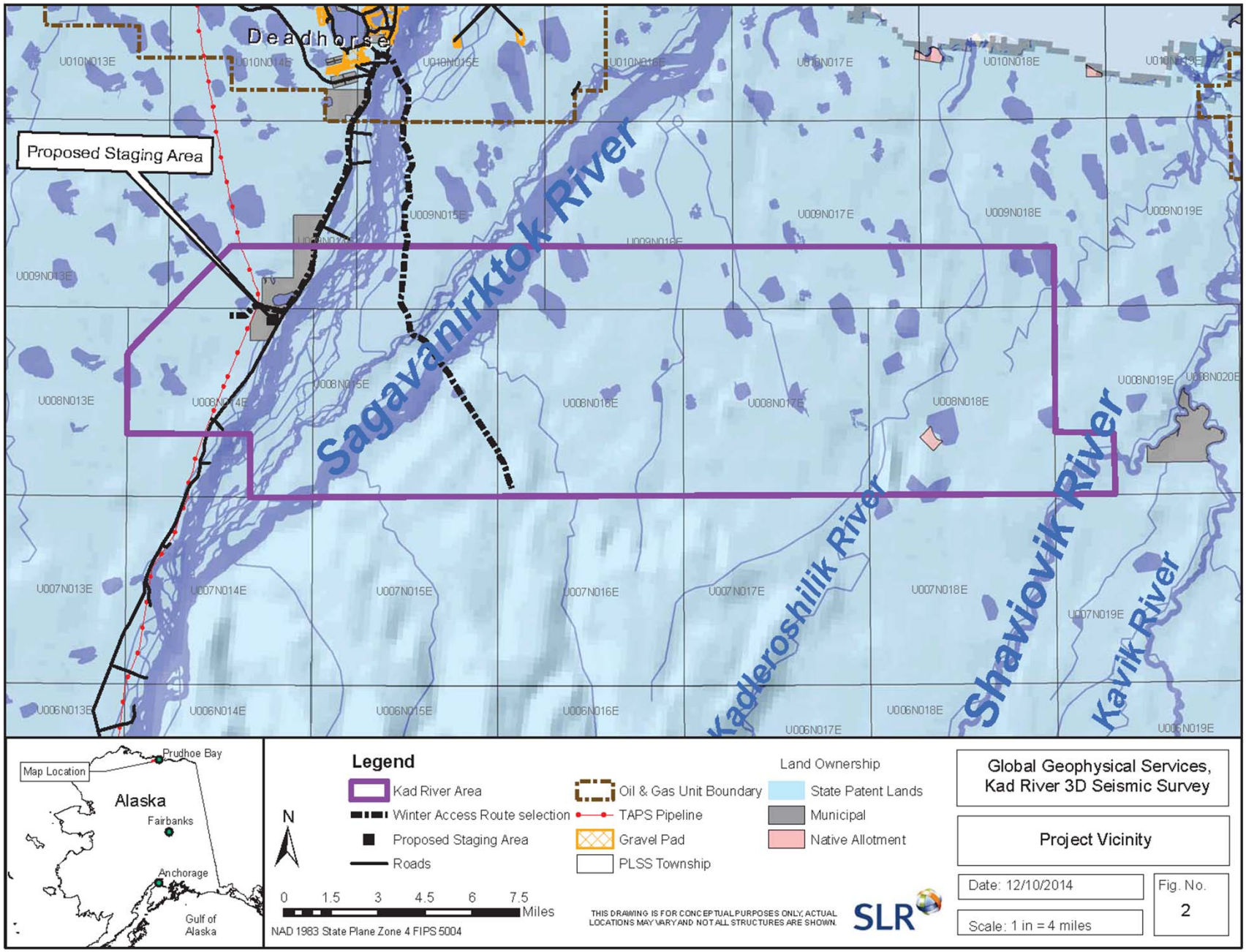
- Causes of the severe flooding of the Dalton Highway were widely attributed to high precipitations in the previous summer, cold winter, and to warm spring.
- Surprisingly, the causes of formation of the huge icing, which ultimately functioned as a large ice dam, were not discussed.
- From a permafrost science point of view, formation of the icing should be a starting point in any forensic study of the March to May 2015 severe and unusual flooding events on the Dalton Highway.
- Why was the under-ice flow obstructed, enhancing the overflow above the river ice? The main cause of icing formation is usually a deep freezing of the river and sediments beneath it. It can be natural or triggered by human activity. Under natural conditions, deep freezing may be caused by a severe winter and low snowfall.

- **Comparison of temperatures for the cold period prior overflow and icing formation during the winter of 2014-2015 and for the similar period of the previous winter did not show any significant difference.**
- **Snowfall in the winter of 2014-2015 was 86.3 cm (October to March), which is practically two times greater than in the previous winter. It means that freezing in the winter of 2014-2015 should be smaller than in the previous winter and weather conditions could not cause the icing formation.**



Due to a lack of strong climatic drivers, we searched for potential human-induced causes. We found that extensive seismic studies occurred in the area during that winter.

Area of seismic survey



Source: MLUPNS 14-007, Geophysical Exploration Permit, Kad River 3D Seismic Survey Permit Approval

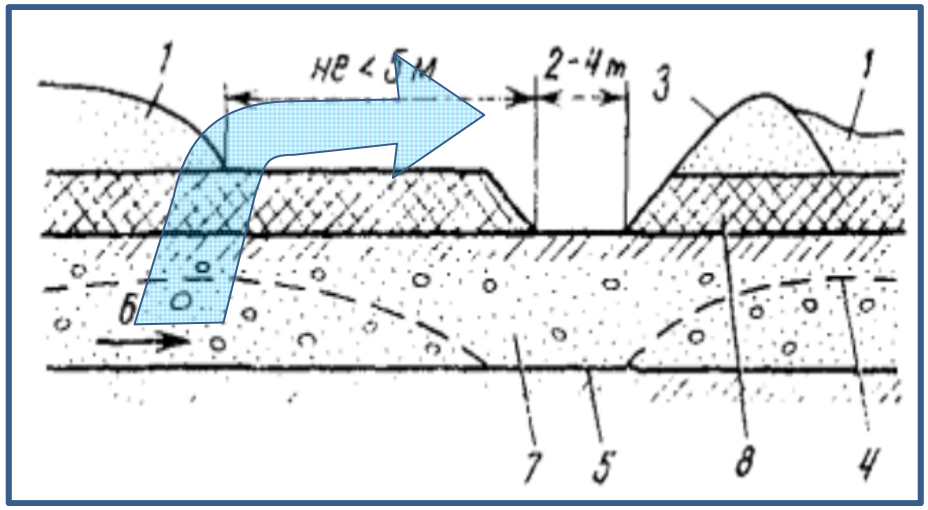
- **The staging place was established at the west side of the river and seismic work was performed east of river with some assigned river crossings.**
- **Such activity over deltas of northern rivers is one of well-known causes of icing formations. In Russia, with its numerous arctic rivers, scientists and engineers know that deltas are very susceptible to icing formation associated with winter roads.**

Provisions of Russian Standard VSN 137-89. *"Design, construction and maintenance of winter roads in Siberia and North-East of the USSR."*

- **3.12. As a rule, it is necessary to avoid sites where icings occur or their potential occurrence can be predicted as a result of construction and use of winter roads.**
- **Such sites include north facing slops with a shallow permafrost table and suprapermafrost ground water; sites with springs of underground water; wet slopes; and deltas with braded channels of shallow depth.**
- **3.13. Development of icings occurs mainly at crossings of any streams in mountains, at parts of rivers with bars, rapids, islands, alluvial fans, braided gravel channels, in deltas and their tributaries.**

Induced Icing

- Some other sources specify that even a single crossing by a tractor can lead to icing formation. Other guidance also advise that river should be crossed at sites where the channels are straight and it is necessary to avoid crossings in areas with riffles, sand bars, islands, and especially in deltas.
- Numerous crossings of the delta packed snow and acted as well-known frost belts (an engineering term).
- A frost belt forces deep freezing at specific site and artificially creates an obstruction to flow of water and forces it to the surface in a sufficient distance from a structure, which should be protected.
  - Winter roads over the Sag River Delta worked as frost belts and we consider them as the main cause of the formation of the gigantic icing and “biblical” scale flooding.



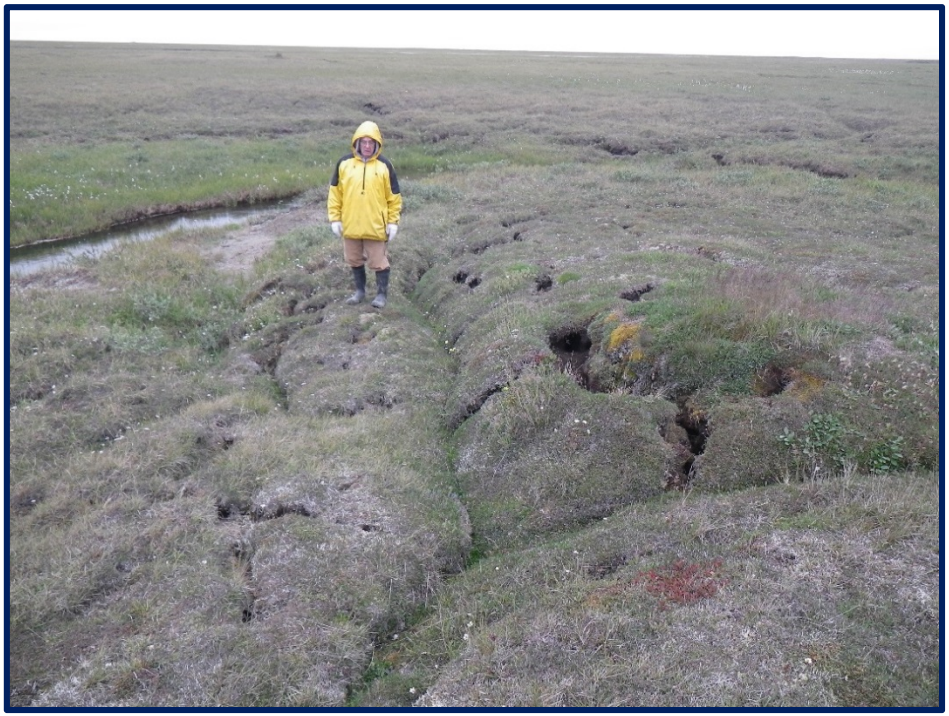
Frost belt.

Technical manual on design, construction, and maintenance of roads on streams with icings, 1989 Highway Administration of Russian Federation

- **In May 2015, flooding overflowed the Dalton Highway and surrounding tundra. Running water was channelized by temporal culverts installed during the emergency response and by the troughs of high-centered polygons.**
- **Water ran into open thermal cracks and reached the gravel layer creating underground flow pathways through gravel toward the river. Running through the gravel, water eroded ice wedges and extremely ice-rich floodplain deposits from below and from the sides, which caused significant settlement of the polygonal surface.**
- **The organic-rich active layer strengthened by roots of grasses and shrubs was the most resistant to thermal erosion because . This thin resistant layer created the low residual polygonal ground that transformed from high-centered ice-wedge polygons.**

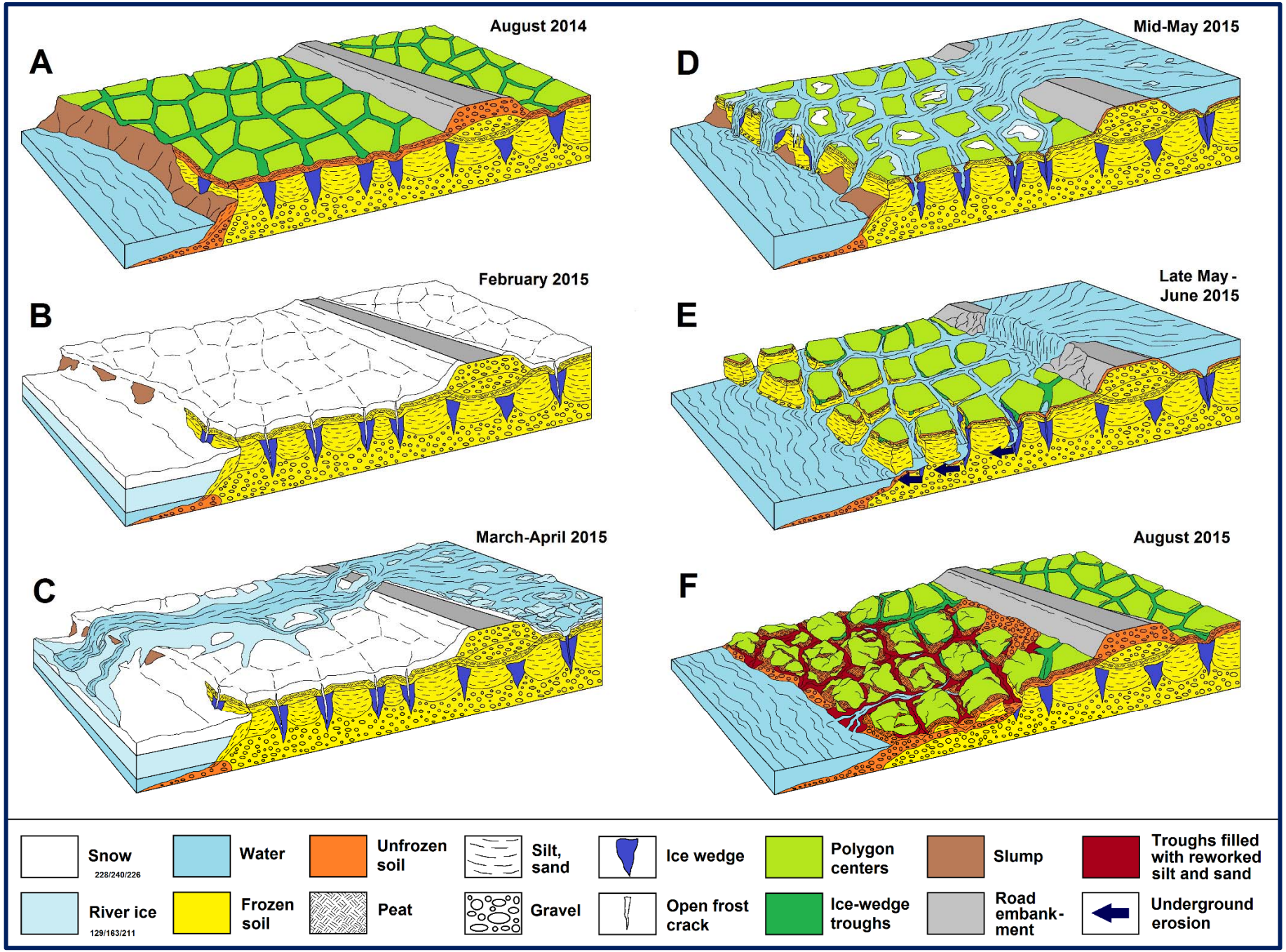
Photos: Alaska Department of Transportation and Public Facilities

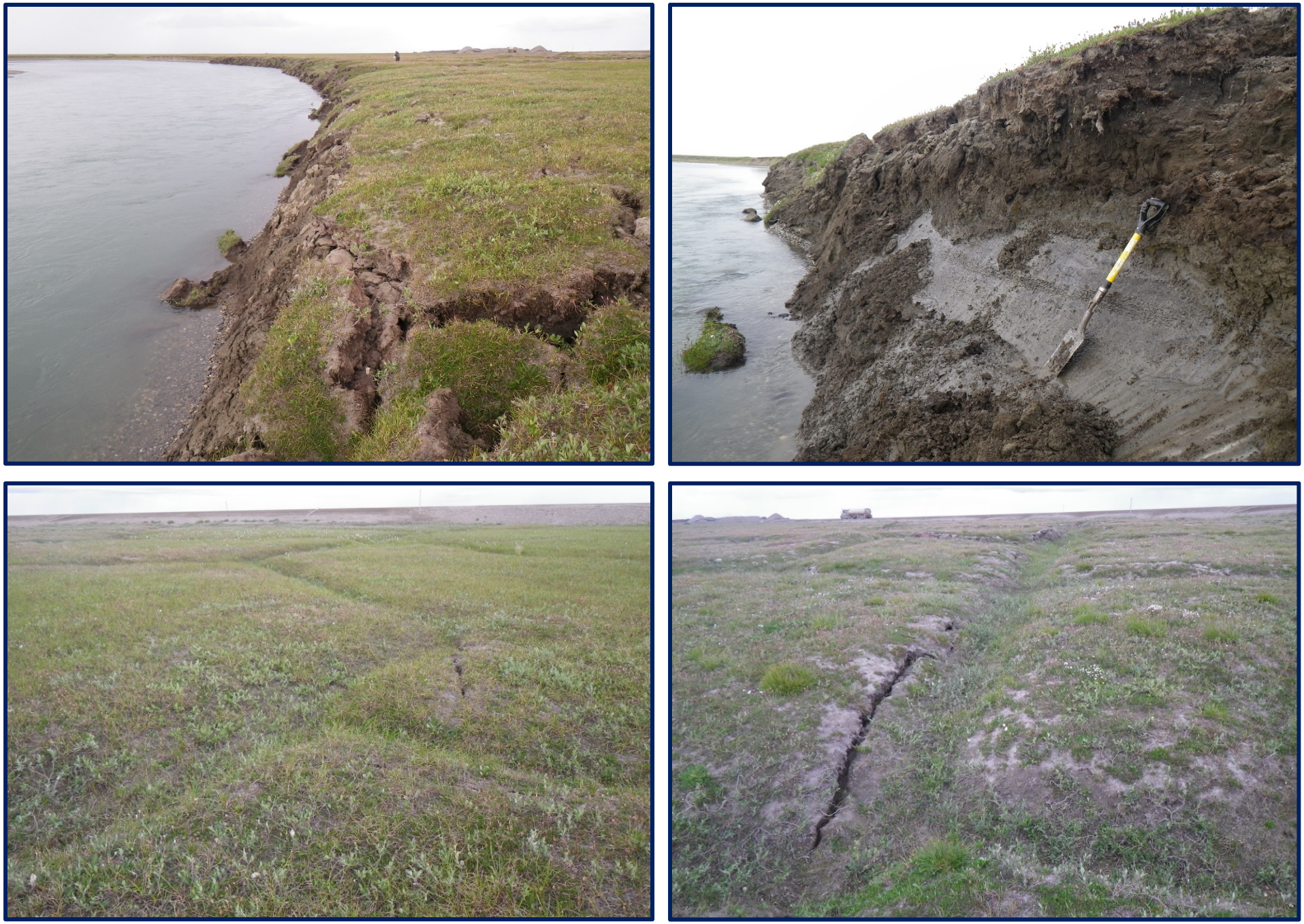
- During our field work in the vicinity of Deadhorse in previous years, we observed areas of polygonal ground with a thin (< 1 m) layer of peat and fine-grained soil over the river gravel. It was similar to the polygonal surface of the adjacent flood plain, but lower in elevation in about 2-3 m and without ice wedges.
- The observed features were located next to a stream created by water flow through two big culverts installed under the Dalton Highway. Severe flooding of 2015 and its impact on surrounding tundra revealed the process leading to formation of such features. The process of underground thermal erosion was described by Fortier and co-authors (2007) and Shur and co-authors (2012).



August 2014

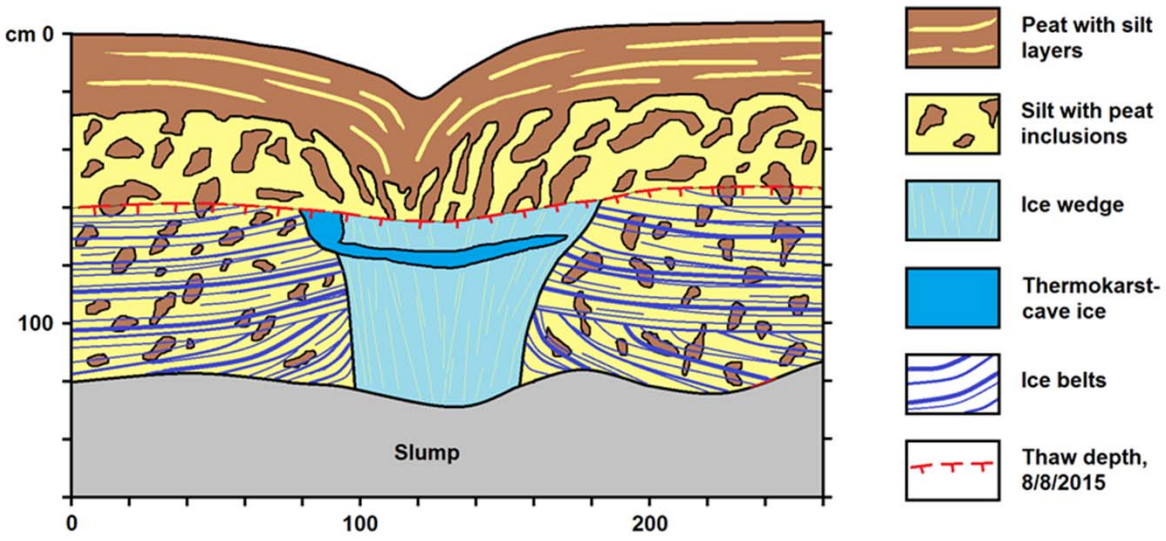
Conceptual model: Degradation of the upper permafrost caused by flooding

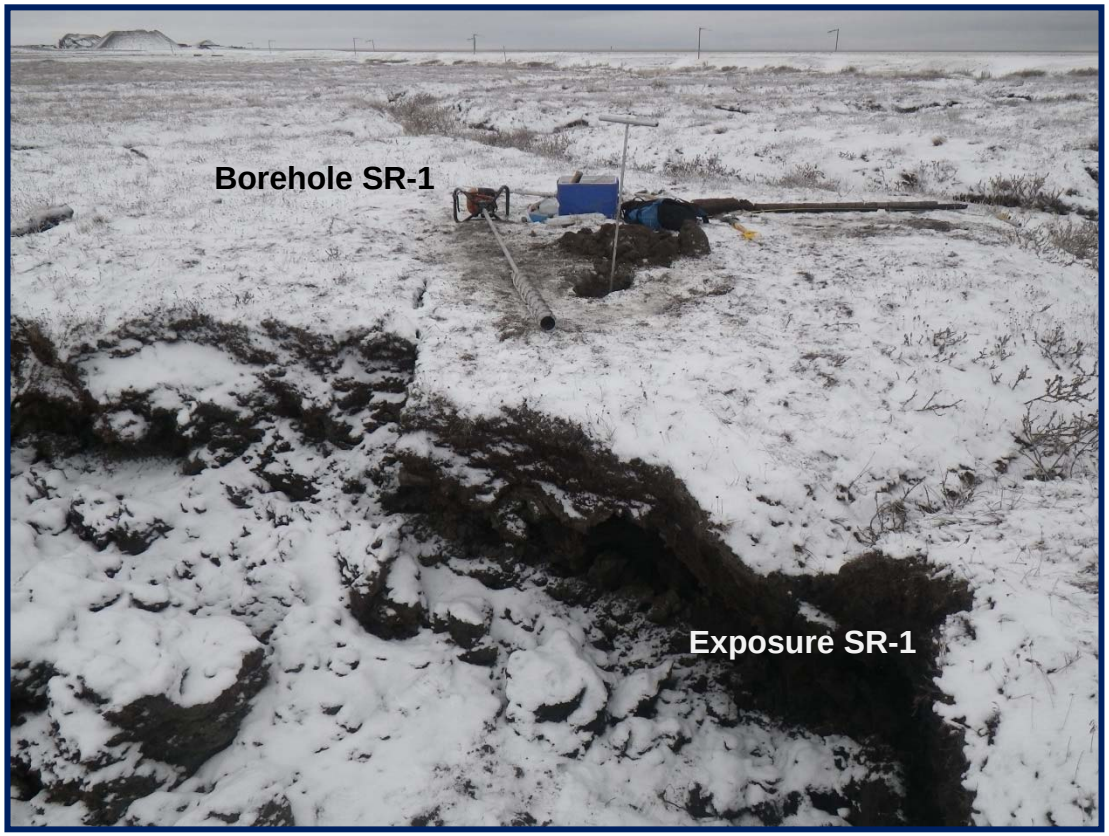




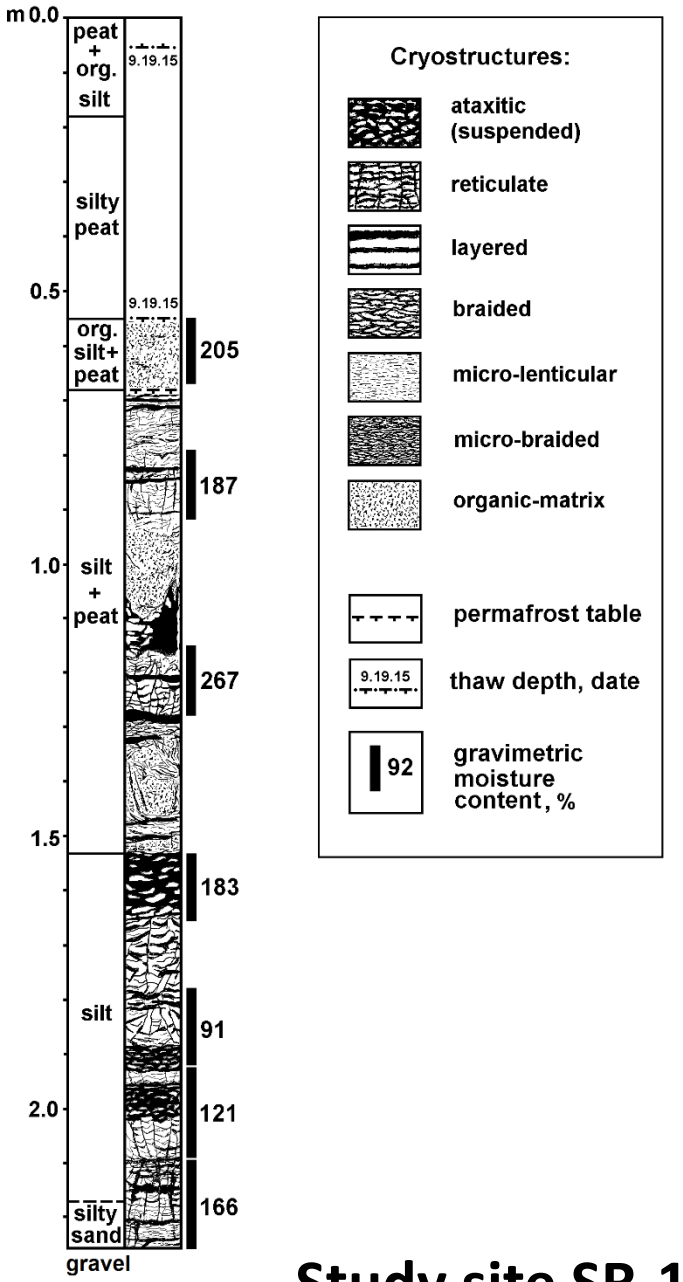
Study site SR-1, August 2012 (prior to the flooding)

Exposure SR-1, August 8, 2015

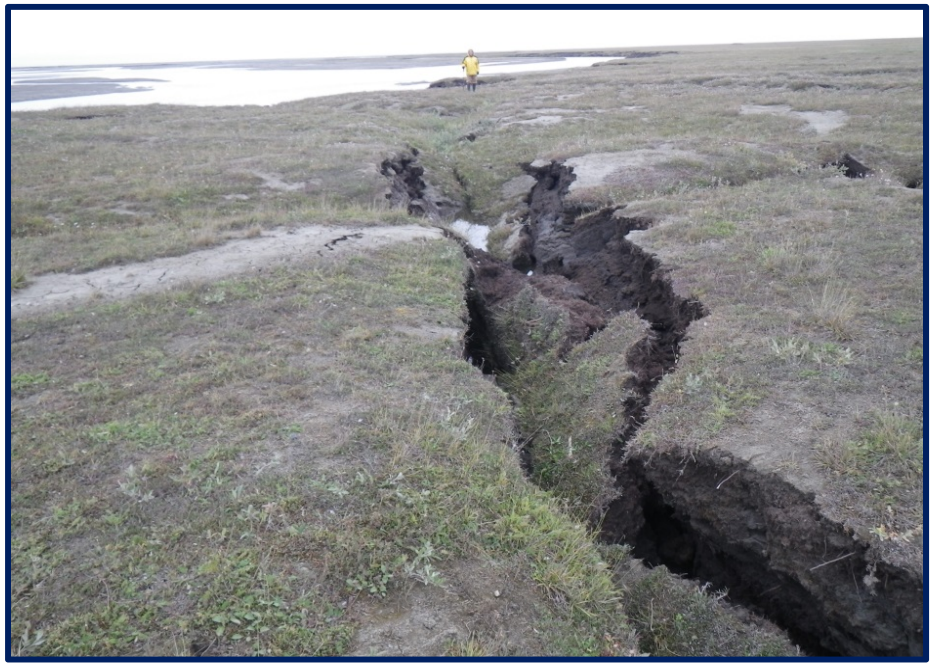




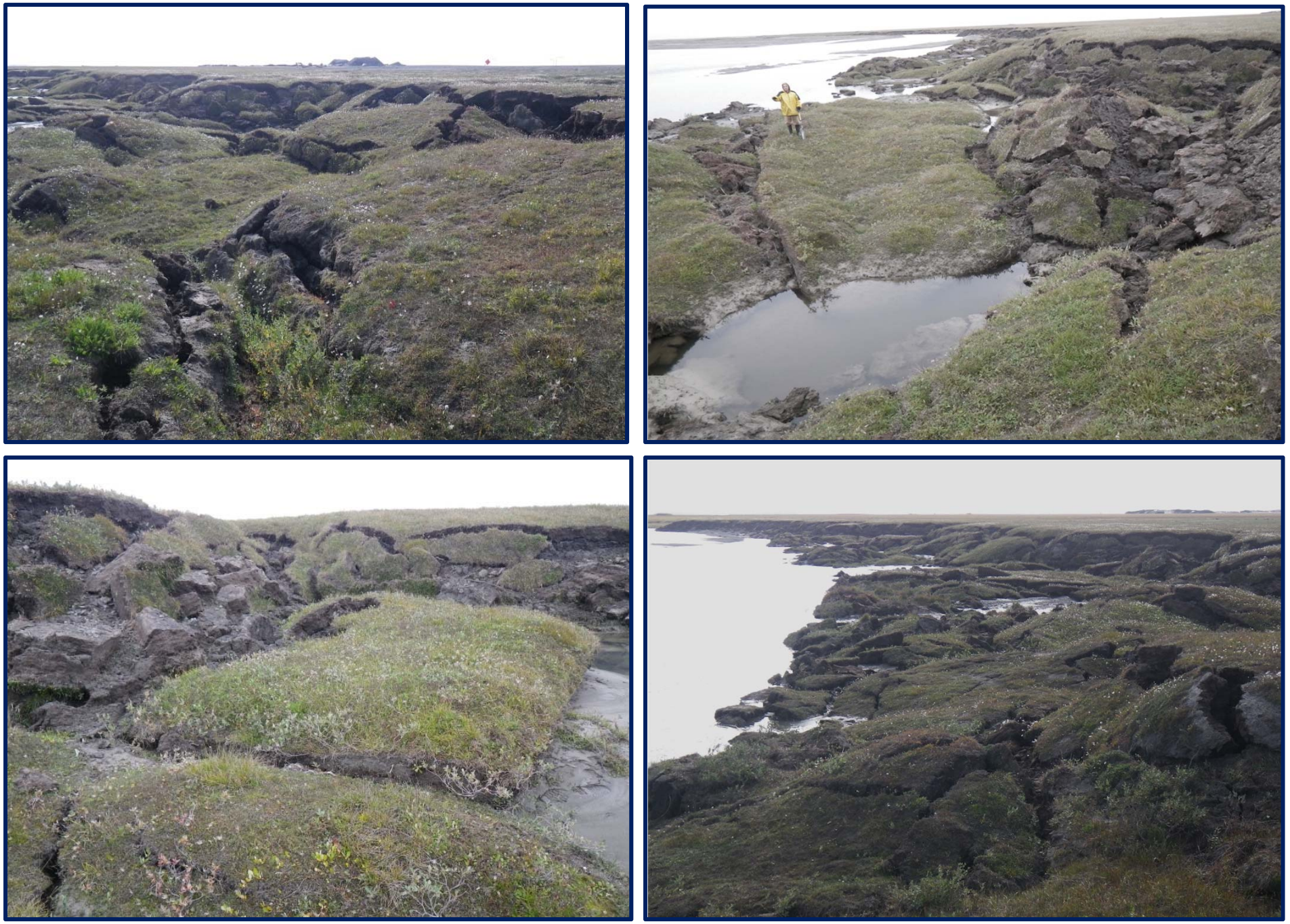
Borehole SR-1, September 19, 2015



Study site SR-1

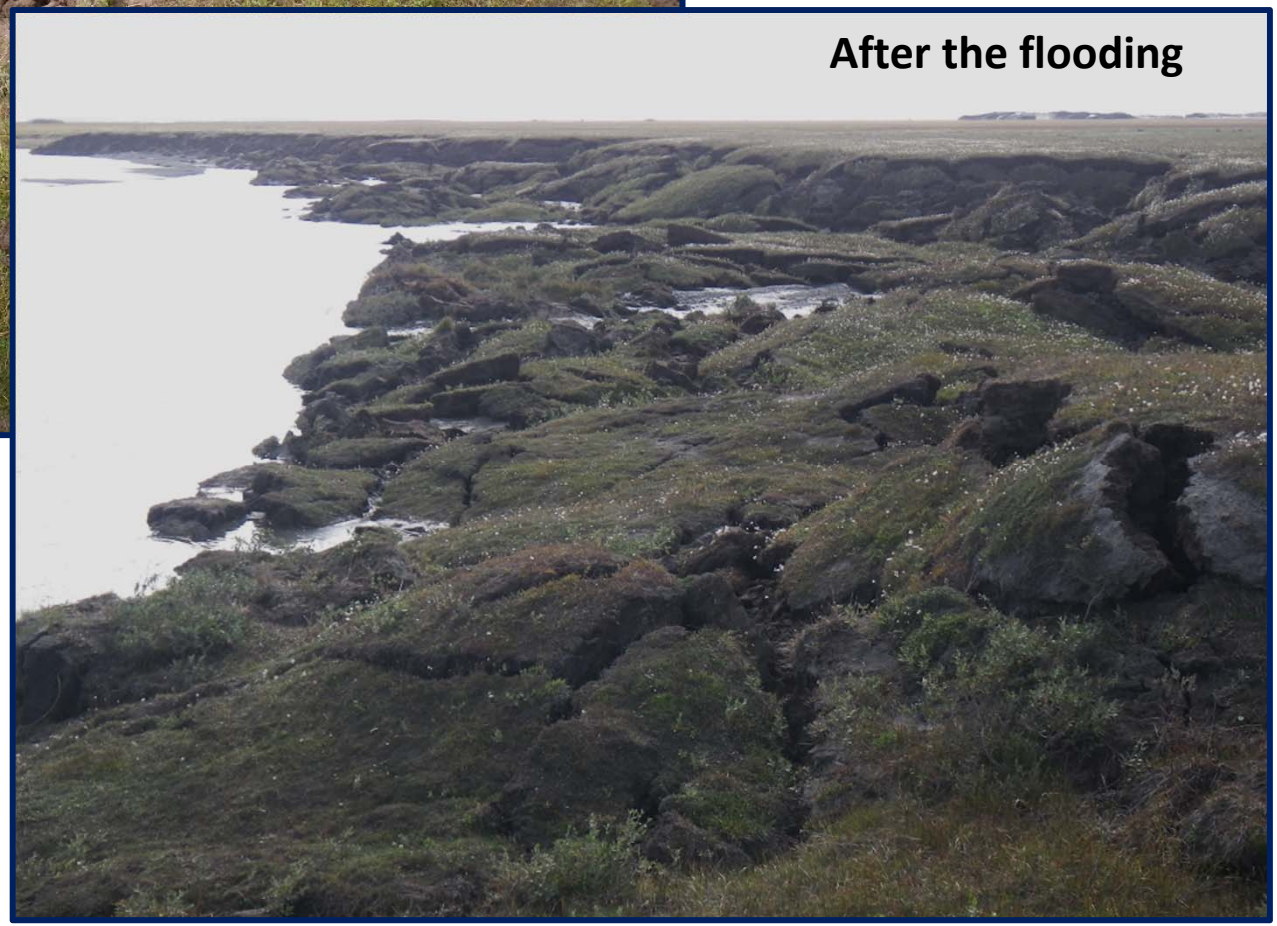


Site SR-1, August 2015, after the flooding. Troughs concentrate flow and water creates funnels



Site SR-1 after the flooding and underground erosion, August 2015.

Study site SR-1



Conclusions

- **Formation of the gigantic icing and following “epic” flooding of the Sag River Delta, Alaska in spring 2015 were most likely caused by human activity.**

- **A vast area of high-centered polygons was degraded by flooding water reaching the gravel layer through open cracks and melting ground ice and thawing ice-rich flood-plain deposit from below.**

Work in the area of flooding was supported by the US National Science Foundation grant ArcSEES # 1263854.

Many thanks to Alaska Department of Transportation and Public Facilities for photographs taken during flooding

References:

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