Internal Creep Dynamics of Frozen Debris Lobe-A, Brooks Range, Alaska (GC31H-1198)

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ABSTRACT

Frozen debris lobes (FDLs) are slow-moving landslides in permafrost, with 43 occurring within the Dalton Highway corridor in the Alaskan Brooks Range. FDL-A is the largest of the studied FDLs, and the closest to the infrastructure, located only 32.3m from the toe of the highway embankment as of October 2016. This FDL is currently moving 6.4 m/yr, and yearly measurements and analysis of historic imagery indicates that the rate is steadily increasing. Movement of FDL-A occurs mainly within a shear zone located near its base, with only 12% of the movement attributed to internal creep of the frozen, ice-poor sediment (i.e., ice content does not exceed pore volume of the soil). It is this smaller component of creep upon which we focus for this presentation. During a 2012 geotechnical investigation, we installed a MEMS-based in-place inclinometer (M-IPI) within a boring in FDL-A. Although the instrument sheared about one month after installation, the upper 20m continued to report displacement and temperature data until September 2015, when the device was severed at the surface. Analysis of strain rates produced from the M-IPI data indicates that FDL-A moves continuously throughout the year. Maximum strain occurs in the active layer during the summer months, with peak strain occurring during peak temperatures. Investigating strain from depths between 4m and 20m reveals that strain rates are fairly consistent with depth but vary seasonally. In fact, the depth-averaged strain demonstrates the same seasonal fluctuation as the surface temperature with a four-month lag. The three years of data indicate that the internal movement of FDL-A is closely tied to surface temperature.

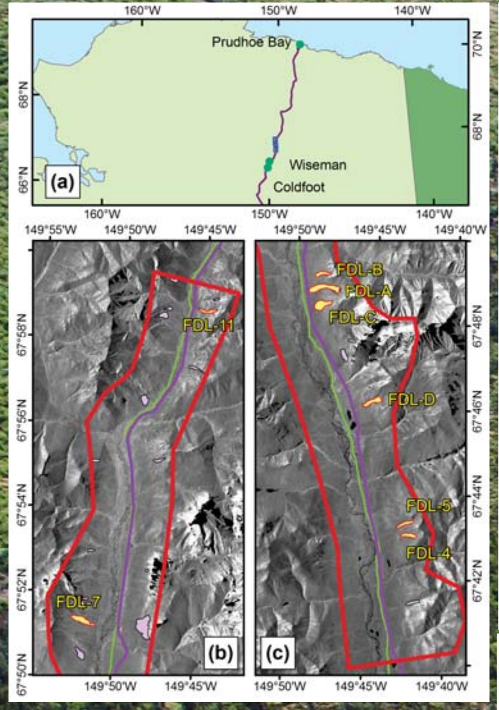
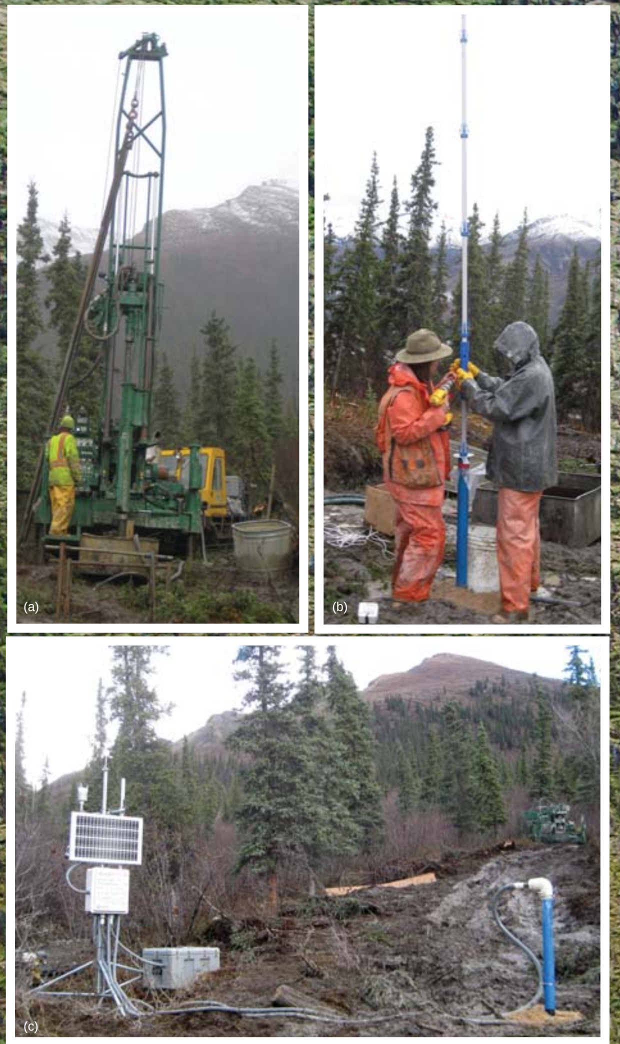


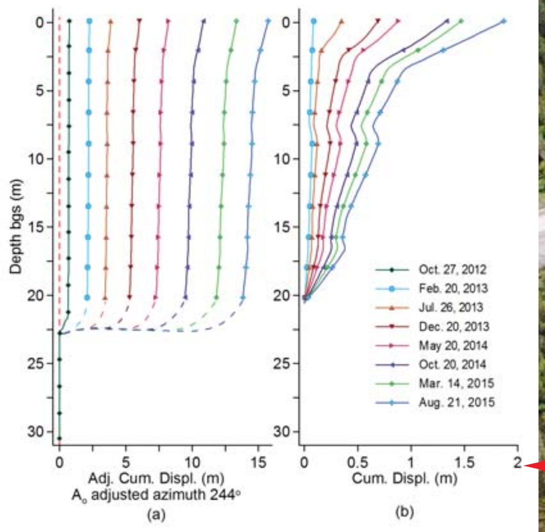
Figure 1. Location of the project area (a) relative to major communities along the Dalton Highway, northern Alaska. The blue rectangles in (a) indicate the location of maps (b) and (c), which illustrate the northern and southern portions of the area of interest (AOI), respectively. The AOI is indicated by the red polygon, the Dalton Highway is in purple, the Trans Alaska Pipeline System (TAPS) is in green, the investigated FDLs are in yellow, and other FDLs within the AOI are in lavender.



SUBSURFACE INVESTIGATION (September 2012)

- Silty sand with gravel (SM) to 26.4m bgs; overlying chloritic schist bedrock (location of borehole indicated by red circle on FDL-A)
- Installed:
  - Thermistors
  - Vibrating wire piezometers
  - MEMS-based in-place inclinometer (M-IPI)
  - Weather station
  - Automated data acquisition system (ADAS)
- M-IPI characteristics:
  - 8-ft long flexible modules
  - MEMS-based accelerometer sensors, measure tilt
  - Accelerometer and temperature sensors located every 0.3m
  - Connected by underwater electrical connectors; stiffened by coupler assembly
  - 3 to 4 centralizers guide M-IPI into slotted casing

Figure 2. 2012 subsurface investigation. (a) CME 850X track-mounted drill rig; (b) installing the M-IPI; (c) completed installation.



M-IPI DATA

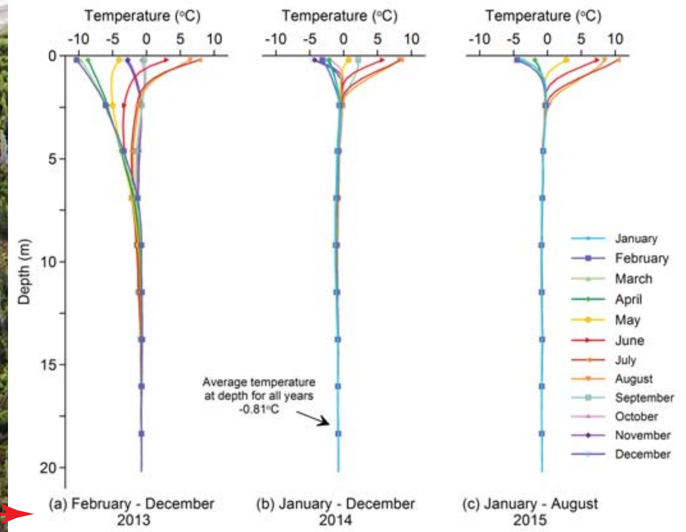
- Indicated a shear zone 20.1 to 22.6m bgs
- Sheared off at 20.2m on October 31, 2012
- Upper portion continued to report data until September 6, 2015 when the ADAS was damaged and the casing and M-IPI were severed at the surface (we suspect sabatoge via moose...)
- Upper portion moved 15.7m downslope from original installation location
- Surviving M-IPI indicated internal creep component
- No-snow conditions until December in 2012 caused cooler subsurface temperatures in 2013
- Subsurface temperatures warmed in 2014 and 2015
- Average temperature at depth is -0.81°C

SURFACE MEASUREMENTS

- Surface marker pins installed October 2012
- Measured multiple times a year with a DGPS unit
- Indicate variable seasonal movement

Figure 3. Cumulative displacement for the M-IPI: (a) total cumulative displacement, adjusted to account for movement in shear zone; (b) cumulative displacement of only the upper 20.2m.

Figure 4. Temperature profiles from TH12-9004 for (a) 2013, (b) 2014, and (c) 2015.



STRAIN DATA

- Cyclical strain pattern is present for all depths
- Temperature at depth does not demonstrate cyclical pattern
  - Temperature indicates slight warming
  - Less than 0.1ºC change at depth
- Cyclical strain pattern matches surface temperature pattern with a four-month offset
  - Temperature peaks in late June; strain peaks in late October

Figure 5. Graphical representation of TH12-9004, indicating frozen zones, depths of noted water pressure and wood fragments, and the shear zone (a). Graphs of strain and temperature at five depths are presented as (b) - (f).

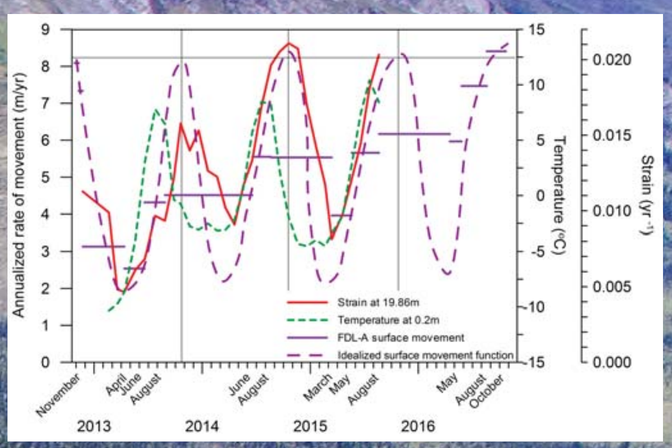


Figure 6. Comparison of seasonal surface movement rates, near-surface soil temperature, and strain rate at depth. Graph also includes an idealized surface movement function developed from surface movement and M-IPI data, and seasonal rates determined from InSAR analysis.

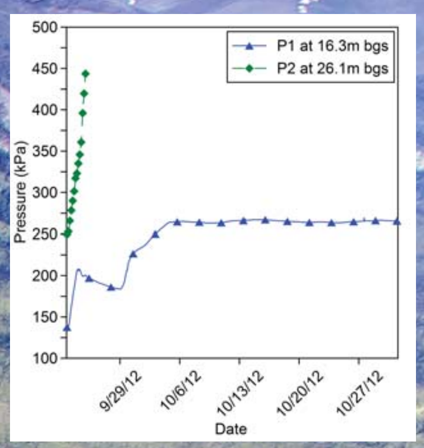


Figure 7. Water pressure measured by two vibrating-wire piezometers. The piezometer at 26.1m failed within three days of installation, after the measured pressure exceeded the over-range capacity of the device.

DISCUSSION

- Surface measurements from October 2012 and 2016 demonstrated the fastest rates measured.
- We developed an idealized surface movement function (Figure 6), with maximum values in late October based on DGPS measurement dates and magnitudes, and minimum values in February based on M-IPI data and InSAR analysis (not presented here).
- The cyclical strain pattern matches the idealized surface movement function.
- Snow melt and summer rainfall infiltrate FDL-A through tension cracks. Several transverse cracks span the entire width of FDL-A near its upper retrogressive thaw slump (indicated by a red arrow on FDL-A); we suspect these cracks penetrate to the main shear zone. During the 2012 subsurface investigation, we observed evidence of water pressure at several depths (Figure 5a), and subsequently measured high water pressure above and below the shear zone (Figure 7). Although the lower piezometer failed within days of its installation, data from the upper piezometer indicated little change in water pressure. Thus, although the high pore water pressure lowers the effective stress in the shear zone and enables FDL-A to move, it does not contribute to the sinusoidal pattern demonstrated in the strain data.
- We hypothesize that the seasonal pattern in FDL-A's surface movement and strain rates is directly related to the active layer depth. Surface measurements indicate that FDL-A has formed levees along its flanks. The lobe moves along a basal shear zone, but its movement also requires shearing along each levee. When the active layer is completely frozen, this increases the shear strength along each levee and reduces the overall movement rate. When the active layer is completely thawed (approximately 2 to 2.5-m deep, depending on the year), the shear strength along the levees is reduced and the lobe movement reaches a maximum.

32.3m (October 2016)

DALTON HIGHWAY

TRANS ALASKA PIPELINE SYSTEM (TAPS)

SUGGESTED FUTURE WORK

- Conduct an additional subsurface investigation to collect samples for soil strength measurements; and water presssure, temperature, and displacement data.
- Conduct a geophysical survey to map shear zone distribution.
- Install additional surface measurement markers on the levees of FDL-A to determine their movement rates.
- Continue to collect soil temperature data to understand annual and seasonal variability.
- Build a numerical model to simulate FDL temperatures, hydrology, and movement.

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Background photograph courtesy of T. Paris