



Monitoring and Analysis of Frozen Debris Lobes, Phase I



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<p>A slow-moving landslide (termed Frozen Debris Lobe-A (FDL-A)) is approaching the Dalton Highway near MP 219, at a distance of 195 ft from the northbound shoulder as of November 2012. Previous analysis of images from 1955 through 2008 indicated an average movement rate of 0.4 in. per day. To better understand the movement of FDL-A, including its soil properties, the direction and rate of movement, and the nature of the shear zone, we initiated a drilling/sampling and monitoring program in 2012. Based on the drilling results, FDL-A consists of silty sand with gravel, overlying white mica schist bedrock at a depth of 86.5 ft (where drilled). Measurements indicate that temperatures within FDL-A average 30°F, which is 2°F warmer than the surrounding permafrost. Water pressure exists within this feature, demonstrating a potentiometric surface 35 ft above the lobe surface. FDL-A demonstrated at least two modes of movement, with a shear zone between 66 ft and 74 ft below ground surface, and slow to moderate flow above this depth; combining these, FDL-A was moving at an average rate of 1.0 in. per day between September and November 2012. Recommendations for future work are included in our report.</p>				
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in ²	square inches	645.2	square millimeters	mm ²
ft ²	square feet	0.093	square meters	m ²
yd ²	square yard	0.836	square meters	m ²
ac	acres	0.405	hectares	ha
mi ²	square miles	2.59	square kilometers	km ²
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft ³	cubic feet	0.028	cubic meters	m ³
yd ³	cubic yards	0.765	cubic meters	m ³
NOTE: volumes greater than 1000 L shall be shown in m ³				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in ²	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm ²	square millimeters	0.0016	square inches	in ²
m ²	square meters	10.764	square feet	ft ²
m ²	square meters	1.195	square yards	yd ²
ha	hectares	2.47	acres	ac
km ²	square kilometers	0.386	square miles	mi ²
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m ³	cubic meters	35.314	cubic feet	ft ³
m ³	cubic meters	1.307	cubic yards	yd ³
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m ²	candela/m ²	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in ²

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

EXECUTIVE SUMMARY

A slow-moving landslide, recently termed a frozen debris lobe (FDL), is approaching the Dalton Highway near MP 219. One of several FDL's within the Dalton Highway corridor, FDL-A at MP 219 is the closest to the highway (approximately 195 ft at its closest point to the northbound shoulder of the highway surface at the time of this writing). Previous analysis of images from 1955 through 2008 indicated an average movement rate of 0.4 in. per day. To better understand the movement of FDL-A, including its soil properties, the direction and rate of movement, and the nature of the shear zone, we initiated a drilling/sampling and monitoring program in 2012.

We conducted a seismic survey in August 2012. The results indicated the presence of the permafrost table and cracks that penetrate from the lobe surface, resulting in areas of deeper thaw. Because of scheduling constraints and difficulty in maneuvering the drilling rig on the debris lobe surface, we did not have drilling data to verify the seismic results.

Together with a drill crew from the Alaska Department of Transportation and Public Facilities' (ADOT&PF) Northern Region Materials Section (NRMS), we conducted a drilling program during September 2012. We drilled a total of eight borings both on and off the lobe to 1) determine the soil profile and depth to bedrock typical of the greater area, 2) determine the thickness and stratigraphy of FDL-A, and 3) install instruments to measure temperature, water pressure, and slope movement. This feature, where drilled, is fairly homogeneous, mostly consisting of silty sand with gravel. It overlies white mica schist bedrock, intercepted at a depth of 86.5 ft below the ground surface (bgs) at one location. Temperature measurements indicate that the soil of FDL-A is 30°F at depth, which is 2°F warmer than the surrounding permafrost. We measured water pressure within the lobe that indicated a potentiometric surface 35 ft above the lobe surface. The water pressure at one boring was sufficient to enter into the sheared casing and flow up and out of the casing onto the ground surface. Additionally, we observed a significant volume of water flowing out from the lobe toe during the early winter. FDL-A demonstrated at least two modes of movement, with a shear zone between 66 ft and 74 ft bgs (where measured), and slow to moderate flow above the shear zone. Combining these modes of movement, FDL-A was moving at an average rate of 1.0 in. per day over the length of this research project, which is more than twice the historic rate determined from previous remote sensing analysis.

These initial results are encouraging, as they provide a first glimpse into FDL-A. As Phase II of this research, we recommend the following future work at FDL-A:

- Continue to measure surface markers using a differential global positioning system;
- Continue to maintain the automated data acquisition systems installed as part of Phase I, collecting temperature and slope movement data;
- Conduct a second drilling program on FDL-A;
- Conduct additional geophysical surveys across the surface of FDL-A, including the DC-Resistivity method;
- Conduct further laboratory testing of samples collected as part of Phase I, including strength testing of frozen samples;
- Model FDL-A in order to determine or confirm the shear surface geometry, to calculate the residual strength in the shear zone, and to identify possible mitigation strategies in order to protect the Dalton Highway.

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CHAPTER 1

BACKGROUND

Alaska's Dalton Highway crosses many miles of discontinuous and continuous permafrost. While engineers and maintenance crews routinely contend with permafrost-related issues, such as cuts through ice-rich permafrost and general embankment distress due to thaw settlement, they will need to face a new permafrost-related hazard in the southern Brooks Range. North of Coldfoot near Mile Post (MP) 219, an elongated lobe of frozen soil, rock, and debris is encroaching on the Dalton Highway (see Figure 1). Following a change in terminology, this feature is now termed a frozen debris lobe (FDL). Many FDLs are present within the Dalton Highway corridor; however, near MP 219, the critical FDL (referred to hereafter as FDL-A) is just outside of the highway right-of-way less than 200 ft from the Dalton Highway, and preliminary studies suggest that it is moving at an increasing rate.

Frozen debris lobes were identified previously (Hamilton 1978, 1979, 1981; Kreig and Reger 1982; Brown and Krieg 1983), but have never been studied in detail. Daanen "re-recognized" these features in 2006, and a preliminary study conducted from 2008 to 2010 by Daanen et al. (2012) suggested that the FDLs may move by a variety of mechanisms, such as permafrost creep, debris flows along the over-steepened toe, and basal sliding as evidenced by "bulldozed" vegetation near the toe (see Figure 2). Analysis of remotely sensed imagery indicated that FDL-A was moving at an average rate of 0.4 in. per day between 1955 and 2008 (Daanen et al. 2012; see the inset in Figure 1). Field measurements from 2010 indicated the toe of FDL-A was approximately 65-ft high and 560-ft wide. Assuming a cross-sectional shape based on digital elevation data, a unit weight appropriate for this material, and the historic rate of movement, approximately 1,200 ft³ of debris advances towards the highway every day. This equates to about 22,000 tons per year. For a sense of scale, imagine a 50-ton truck dumping 440 truck-loads per year on the highway (Daanen et al. 2012). Should this mass of moving material further encroach upon the Dalton Highway, it may impede the flow of essential goods and services to the oil and gas fields on the North Slope, resulting in severe economic loss.

Even before entering the right-of-way, FDL-A is affecting the Dalton Highway. As shown in Figure 3, runoff, debris flows, and possibly internal meltwater from FDL-A have deposited a large volume of sediment ahead of the lobe toe. This sediment has banked up against the highway embankment, completely burying one culvert inlet and partially burying another (see Figure 4). This represents a maintenance issue in itself, and may result in damage to the highway embankment during periods of high discharge through the existing culvert.

The complete analysis of any landslide in a non-permafrost location requires an understanding of its kinetics including knowledge of the soil properties, the direction and rate of movement, and the nature of the shear zone; without this information, it is impossible to select correct mitigation techniques. Since FDL-A is in a permafrost location, conventional slope stability analyses may be inadequate to determine the mechanism of movement and effectiveness of various mitigation techniques. While preliminary measurements provided a baseline estimate on movement rates and volume, they only were based on a few surface measurements and analysis from remotely-sensed images. To better understand movement of frozen debris lobes, we proposed to conduct a drilling/sampling and monitoring program.



Figure 1. Location of the study area within Alaska. The inset illustrates the termini position of FDL-A from 1955 (red line), 1979 (blue line), and 2008 (green line) from high-resolution aerial and satellite-based remotely sensed imagery. Two drainage channels in front of the lobe are not part of the moving body. (Inset modified from Daanen et al. 2012).



Figure 2. Indicators of frozen debris lobe (FDL) movement. (a) Trees are “bulldozed” and incorporated within the approaching FDL. (b) The toe of FDL-A rolled up the vegetative mat like a carpet. (c) The toe of nearby FDL-D (~3 mi. to the south of FDL-A), showing the approaching wall of debris. As the toe over-steepens, it is prone to debris flows during the summer months. (d) Trees growing on the surface of an FDL experience tension as the surface cracks and moves in multiple directions. The tree to the left has been split five-ways. (Photographs by M. Darrow)



Figure 3. The toe of FDL-A as seen to the east from the Dalton Highway in June 2011. The people in the foreground stand on recent sedimentation produced by FDL-A. (Photograph by M. Darrow)



Figure 4. Evidence of sedimentation from the outflow of FDL-A. (a) A culvert inlet nearly buried with recent deposition. (b) A second culvert inlet is already buried by the sediment (see right arrow). The location of the culvert in (a) is indicated with the arrow to the left in (b). (Photographs by M. Darrow)

RESEARCH OBJECTIVES

The overall goal of this research was to determine the movement mechanism of frozen debris lobes (FDLs). For this current phase of research (i.e., Phase I), the objectives were:

- To characterize the internal structure of a FDL through drilling and sampling;
- To monitor its movement to determine the nature of the shear zone and timing and rate of movement.

As the results from this phase of research provide only the first glimpse into the kinetics of FDLs, we anticipate that a future phase will include the determination of soil strength properties through laboratory testing, and the development of a slope stability model to identify the mechanism of movement and potential remediation methods.

CHAPTER 2

RESEARCH APPROACH

To achieve our overall research goal of determining the movement mechanism of FDL-A, we developed two major tasks, each of which was closely tied to the research objectives. These tasks are detailed in this chapter.

TASK 1: TO EXPLORE THE INTERNAL STRATIGRAPHY OF FDL-A THROUGH A DRILLING PROGRAM ACCOMPANIED BY A SEISMIC REFRACTION SURVEY

Seismic Refraction Surveys

To learn more about the internal structure of FDL-A, we used seismic refraction tomography. This method has long been used in permafrost regions (Hauck et al., 2007), which uses differences in the seismic wave velocity of various materials to identify the subsurface stratigraphy. We wanted to know if the seismic equipment was capable of detecting shear zones within the feature, as well as the bedrock surface.

We employed a SEISTRONIX RAS-24 v2.13 recording unit and twelve geophones at a 15-ft spacing. Each line was 165-ft long. We ran a total of six seismic lines, three lines perpendicular to the movement direction (i.e., L1, L2, L3), and three lines parallel to the movement direction (i.e., L4, L5, L6; see Figure 5 for seismic line locations). We positioned the seismic lines so that seven geophone locations were common between two immediately adjacent lines to ensure continuous data; a summary table of the seismic line configurations and geophone overlap is presented in Appendix A. We employed two shots per station, using a hammer hitting a metal plate, to produce higher quality data. We processed the data using RAYFRACT™ v2.74 tomography software. The original plan was to conduct the seismic survey after the drilling program, so that the various RAYFRACT models could be compared against the drill logs to check for accuracy in interpretation. Due to scheduling constraints, the seismic work was carried out in August 2012, with the drilling following in September. As will be discussed in the following section, we were unable to approach the toe of FDL-A while on its surface; thus, we do not have drilling data to verify the seismic results.

The resulting cross sections of seismic velocities are presented in Figure 6 through Figure 11. The velocities in the figures are presented in m/s as this is the software program output; however, in this discussion velocities are also presented in ft/s (in parentheses). The greatest depth that we achieved with our seismic lines was about 50 ft, which was insufficient to reach the bottom of FDL-A. Instead, our results indicate that the upper portion of FDL-A demonstrates high variability in seismic velocity. Hauck et al. (2007) indicated that velocities within the active layer range between 400 and 1,500 m/s (1,300 and 4,900 ft/s), with permafrost demonstrating a high contrast with velocities greater than 2,000 m/s (6,600 ft/s). Bush and Schwarz (1964), who conducted seismic refraction along the Nelson River in Manitoba, indicated that saturated sand and gravel, dense till, and compact clay all demonstrated velocities between 1,800 and 2,100 m/s (6,000 and 7,000 ft/s). Velocities increased as a function of the thickness of the frozen soil, ranging from 2,300 m/s (7,500 ft/s) for thin frozen layers to up to 4,300 m/s (14,000 ft/s) for thick frozen layers. Elsewhere on FDL-A, we intercepted the permafrost table between 6 and 8



Figure 5. Locations of field measurements on and near FDL-A. The base image, which was imported from Google Earth, was acquired in 2002. It does not accurately represent the location of FDL-A, which has advanced since its acquisition. Currently the toe of the lobe is at the location of the blue surface measurement points that intersect the text of “TH12-9000”. The placement of the seismic lines is represented by white lines adjacent to the geophone locations.

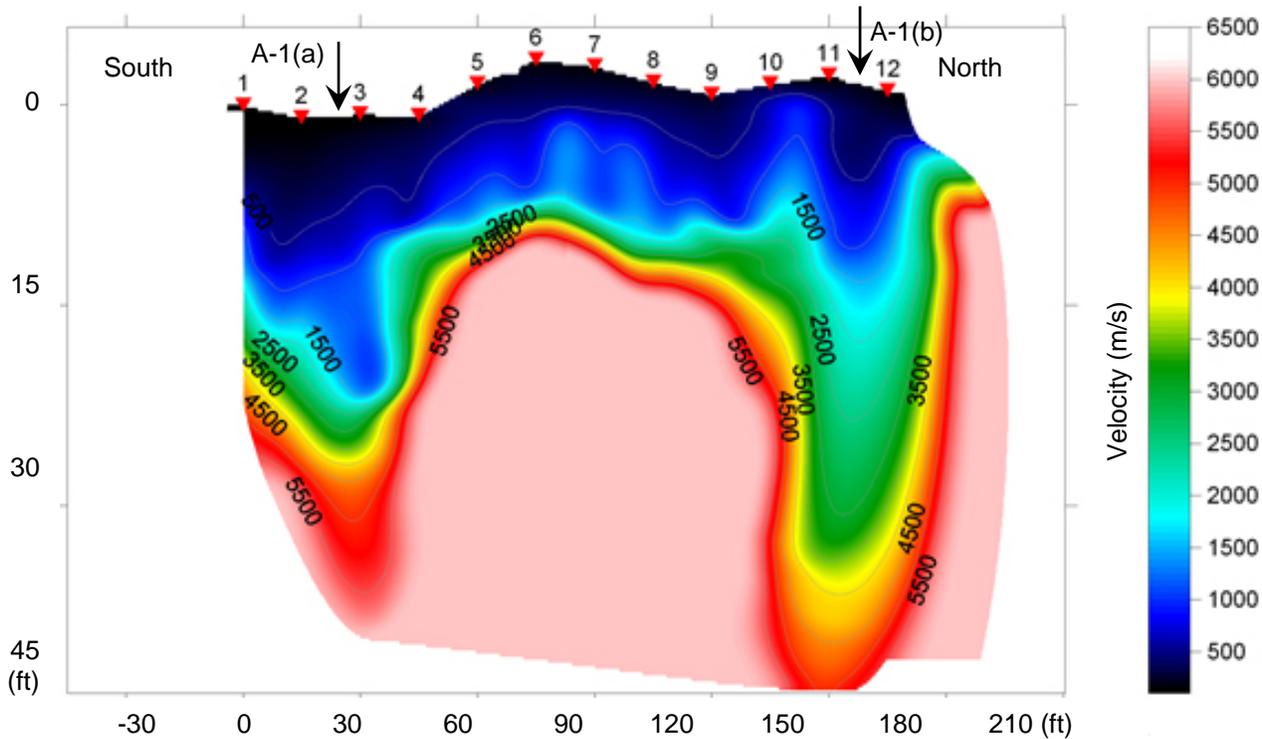


Figure 6. Seismic survey results for L1. Elevation and distance provided are relative to Shot 1 along this line. Velocity is provided in m/s from the seismic program. Arrows and identifiers correspond to those figures in Appendix A.

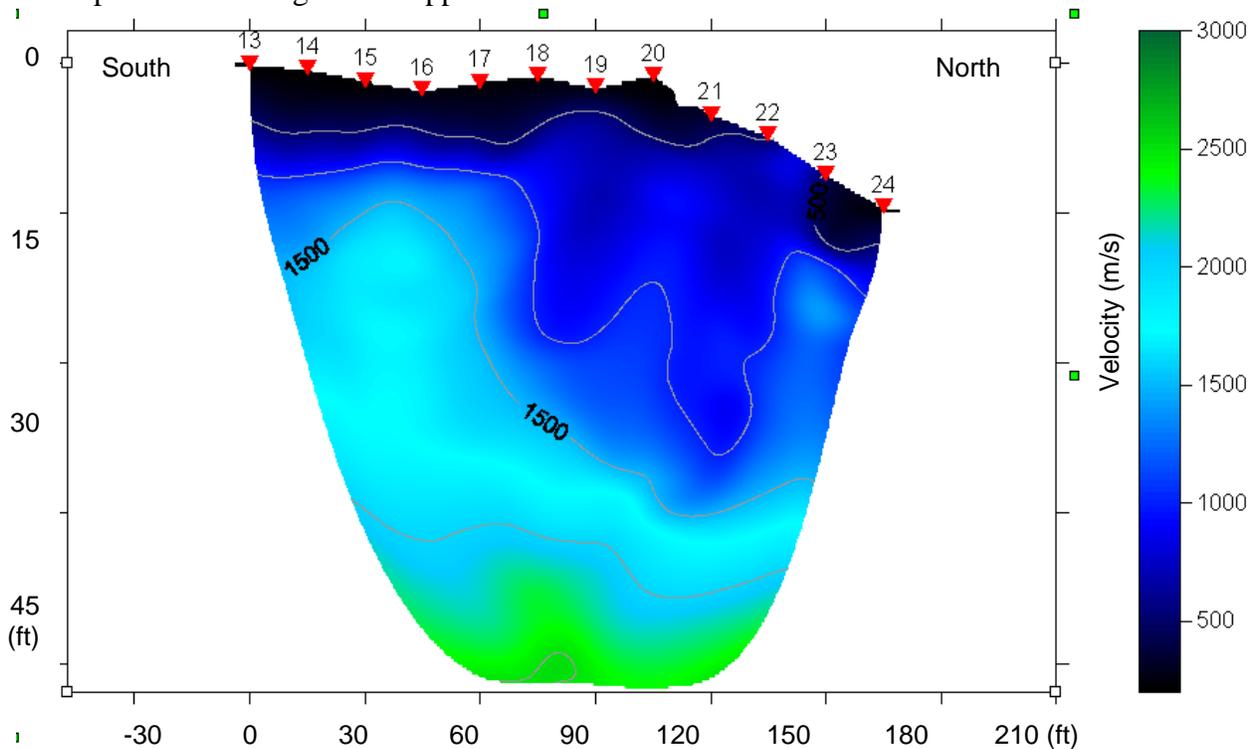


Figure 7. Seismic survey results for L2. Elevation and distance provided are relative to Shot 13 along this line. Velocity is provided in m/s from the seismic program.

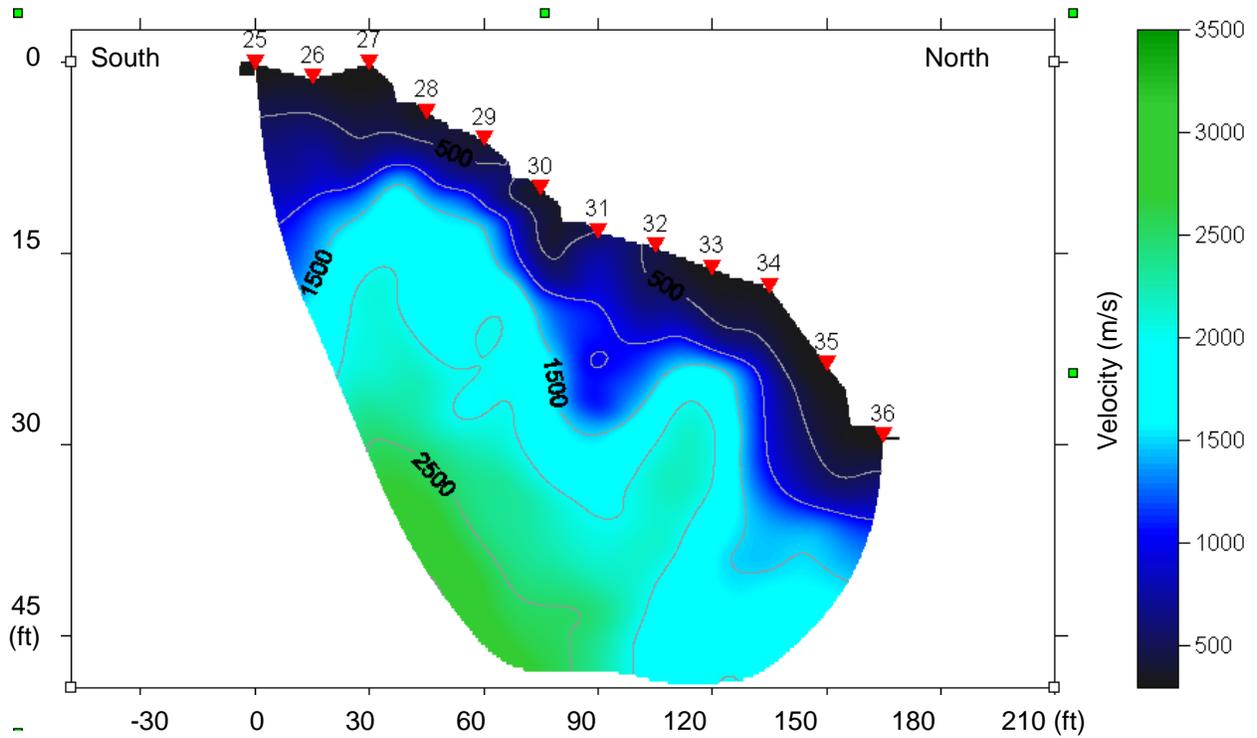


Figure 8. Seismic survey results for L3. Elevation and distance provided are relative to Shot 25 along this line. Velocity is provided in m/s from the seismic program.

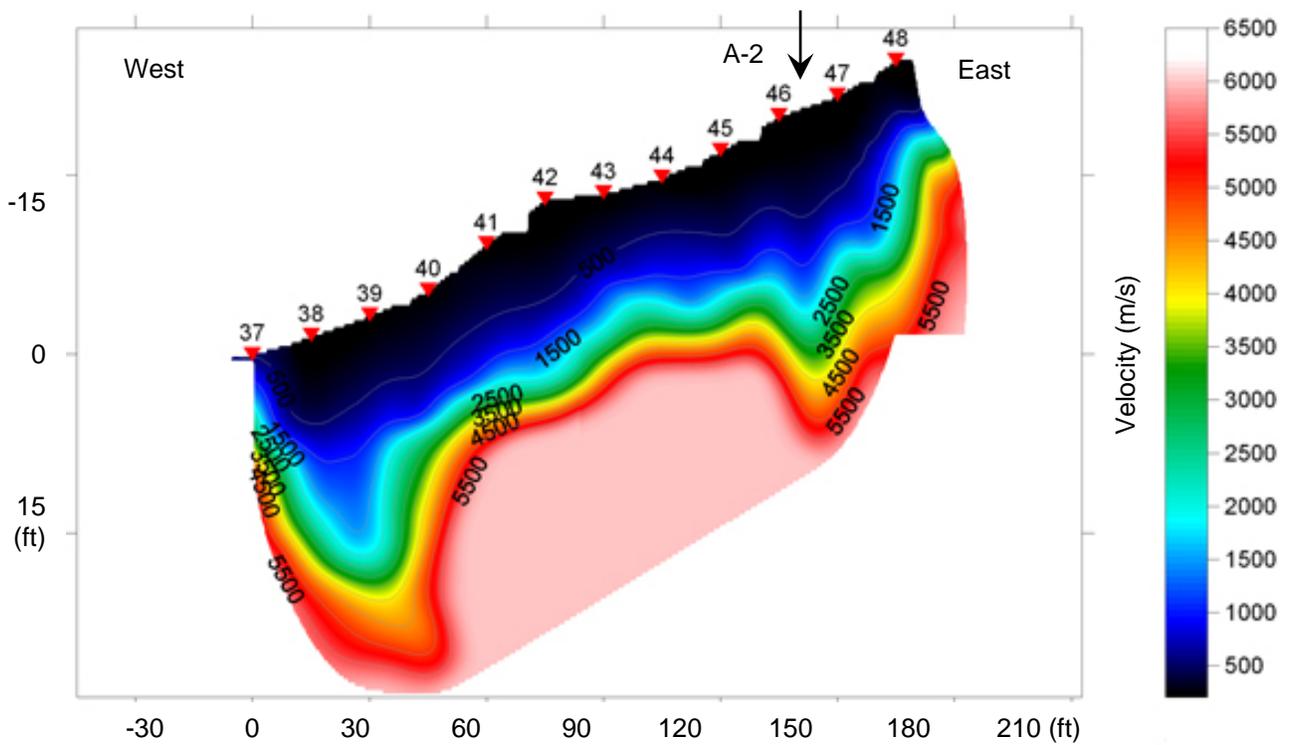


Figure 9. Seismic survey results for L4. Elevation and distance provided are relative to Shot 37 along this line. Velocity is provided in m/s from the seismic program. Arrow and identifier correspond to that figure in Appendix A.

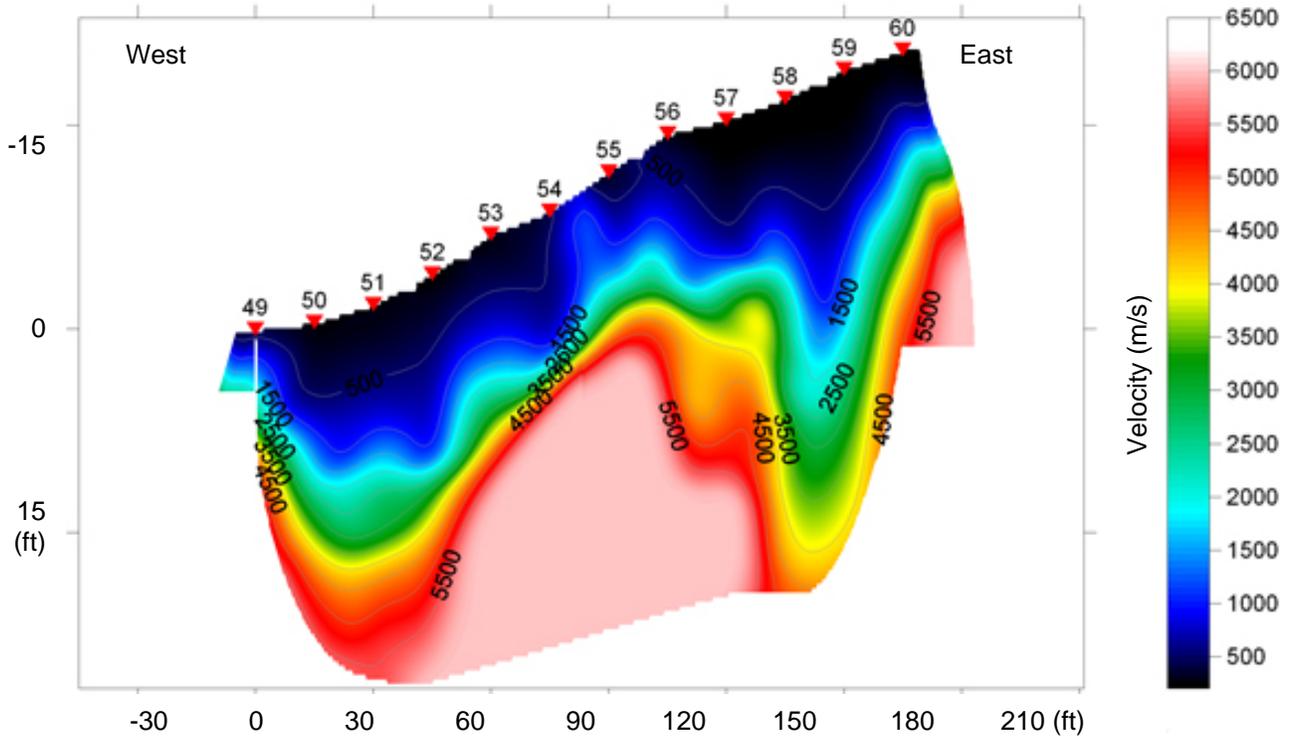


Figure 10. Seismic survey results for L5. Elevation and distance provided are relative to Shot 49 along this line. Velocity is provided in m/s from the seismic program.

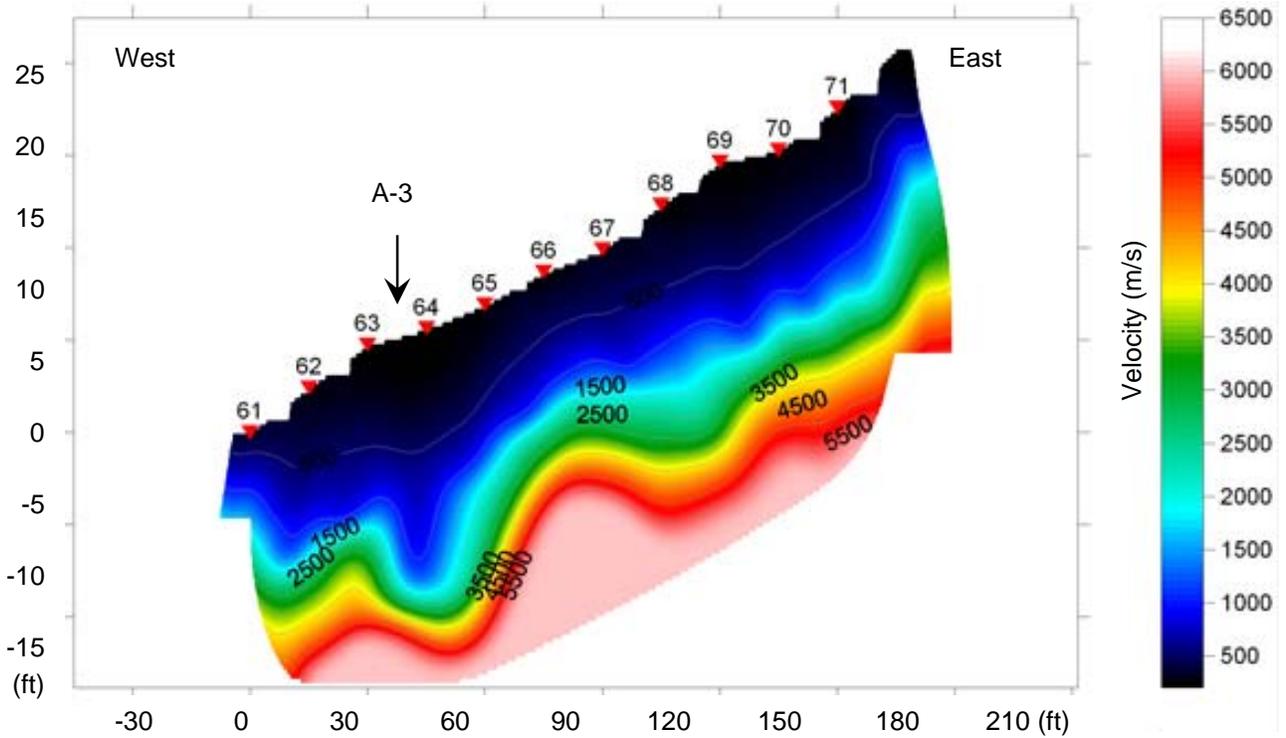


Figure 11. Seismic survey results for L6. Elevation and distance provided are relative to Shot 61 along this line. Velocity is provided in m/s from the seismic program. Arrow and identifier correspond to that figure in Appendix A.

ft bgs (below ground surface). In many parts of these profiles, this depth corresponds to the 1,500 m/s (4,900 ft/s) velocity. Additionally, the velocity for Line 1, and Lines 4 through 6 quickly increases with depth starting from 1,500 m/s (4,900 ft/s). Based on these characteristics, we interpret the 1,500 m/s (4,900 ft/s) contour to represent the permafrost table. The results for Lines 2 and 3 do not demonstrate the rapid increase in seismic velocity; additionally, the area of overlap between Lines 1 and 2 do not demonstrate the same range of velocities. We are uncertain if these results indicate that this portion of the lobe was thawed more deeply, or if the results are an artifact of how the data was collected and processed. Because of this uncertainty, we will limit the following discussion to Lines 1, and 4 through 6.

As mentioned above, the seismic velocity is far from uniform with depth. Instead, there are several areas where lower velocities are present dipping down into the subsurface. These low velocity areas seem to correlate with the location of cracks observed at the surface; photographs of examples of cracks documented along the seismic lines are included in Appendix A. As these cracks may function as conduits for liquid water, it follows that the water thaws the adjacent debris, which results in deep zones of lower seismic velocity.

Drilling Program

Together with a drill crew from the Alaska Department of Transportation and Public Facilities' (ADOT&PF) Northern Region Materials Section (NRMS), we conducted field investigations of FDL-A during two separate trips, September 17-23 and September 28-30, 2012. The goals of these investigations were 1) to determine the soil profile and depth to bedrock typical of the greater area, 2) to determine the thickness and stratigraphy of FDL-A, and 3) to install instruments to measure temperature, water pressure, and slope movement, as well as a meteorological station to record the local weather. All drilling was accomplished with a Central Mining Equipment (CME) 850X track-mounted drill, equipped with a 340-lb auto-hammer. We employed solid-stem and hollow-stem auger, and tricone and casing drilling methods (see Figures B-1 and B-2 for images of these drilling methods; additional photographs of the drilling program are included in Appendix B).

We drilled a total of eight borings (see Table 1 for a summary of the borings, Figure 12 for an aerial view of the drill rigs in position at FDL-A, and Figure 5 for boring locations). We located four borings to the west and south of FDL-A (i.e., TH12-9000 – TH12-9002, and TH12-9006) to determine depth to bedrock and to measure any general slope movement in the area. In these borings, we intercepted silty sand with gravel grading to sandy silt with gravel, overlying white mica schist bedrock (see Figure 13) averaging 12 ft bgs (see Appendix C for boring logs and Appendix D for laboratory test results). As the soil was not frozen in TH12-9000 (located between FDL-A and the highway), we drilled a second shallow boring in this area (TH12-9006) and installed a 1-in. PVC casing to facilitate later installation of temperature sensors (see Figure B-3). In contrast, the borings to the south of FDL-A intercepted frozen and ice-rich soil. These borings were located in an “undisturbed” area (see Figure B-4), and temperature sensors were installed to establish the typical temperature profile in the area. We installed slotted casing in TH12-9000 and TH12-9002 for manual measurements of slope movement (see Figure B-5).

Upon completion of these relatively shallow borings, we moved onto the lobe surface to drill through the FDL. Maneuvering the drill rig onto and around the FDL surface was not an easy task due to ubiquitous cracks, sharp changes in slope angle, and saturated soil at the surface.

Table 1. Summary of borings made during the September 2012 investigations. “HS” = hollow-stem auger, “SS” = solid-stem auger, “T/C” = tricone and casing, and “bgs” stands for below ground surface. The (()) symbols around the bedrock surface for TH12-9005 indicates the depth at which it was originally interpreted; however, measurements indicated that it was deeper than the total depth drilled at this location.

Test hole	Location	Drilling method	Total depth (ft bgs)	Permafrost table (ft bgs)	Bedrock surface (ft bgs)	General description	Instruments installed
TH12-9000	Between FDL-A and highway	HS	20.0	N/A	10.0	Silty sand w/ gravel over bedrock	Slotted casing for manual measurements
TH12-9001	S of FDL-A	SS	10.2	2.0	9.5	Ice-rich sandy silt and silty sand w/ gravel over bedrock	Temperature and matric potential sensors (satellite ADAS)
TH12-9002	S of FDL-A	HS	30.0	2.0	16.5	Ice-rich sandy silt w/ gravel over bedrock	Slotted casing for manual measurements, thermistor string
TH12-9003	On FDL-A	SS	10.0	8.0 (?)	N/A	Silty sand w/ gravel	Temperature and matric potential sensors
TH12-9004	On FDL-A	T/C	100.0	7.0 (?)	86.5	Silty sand w/ gravel over bedrock	Slotted casing w/ Geodaq probe, 2 piezometers, thermistor string (main ADAS)
(not logged; near TH12-9005)	On FDL-A	SS	10.0	---	---	---	Temperature and matric potential sensors (satellite ADAS)
TH12-9005	On FDL-A	HS	72.0	6.5	((66.0))	Silty sand w/ gravel ((over bedrock))	Slotted casing for manual measurements, thermistor string
TH12-9006	Between FDL-A and highway	SS	10.5	6.0	N/A	Sandy silt w/ gravel	1” PVC casing for later temperature sensor installation



Figure 12. Oblique aerial view of FDL-A during the September 2012 drilling program. This photograph was taken to the east, with the Dalton Highway in the foreground. The drilling support vehicles were located in a pull-out off of the highway (indicated by the lower yellow arrow) and the drill rig was positioned between the toe of the lobe and the highway at TH12-9000 (indicated by the upper yellow arrow). An old surficial drainage channel is indicated by the left red arrow. The surficial drainage shifted in recent years, and now flows off of the debris lobe to the south, as indicated by the right red arrow. (Photograph courtesy of F. Wuttig)



Figure 13. White mica schist bedrock as it appeared when sampled in a split spoon sampler (photograph shows about 1 ft of the sample). Notice the prominent foliation of the sample. (Photograph by M. Darrow)



Figure 14. Example of frozen silty gravel typical of FDL-A. For scale, this photograph spans a 2-ft long split spoon sample. (Photograph by M. Darrow)

Due to these difficulties, we were unable to locate borings near the toe of the lobe and along the previously positioned seismic lines. We drilled two shallow borings for installation of near-surface instrumentation, and two deeper borings intended to penetrate the FDL. In TH12-9004, the soil consisted of frozen silty sand with gravel and silty gravel with sand with small amounts of visible ice (see Figure 14) over white mica schist bedrock, which we verified at 86.5 ft bgs. We drilled this boring with tricone and casing, sampling with a split-spoon sampler every five to ten feet. We successfully installed slotted casing to 100 ft bgs, along with two piezometers and a thermistor string (see Figure B-6). Once backfilling with cement-bentonite grout was complete, we installed a MEMS in-place inclinometer (M-IPI), which is an automated device that measures slope movement (see Figures B-7 and B-8). Additionally at this location, we installed the main ADAS, complete with a meteorological station (see Figure B-9).

We drilled TH12-9005 with hollow-stem auger and without sampling, due to time constraints. In this boring, we intercepted similar silty sand with minor gravel to a depth of 66 ft bgs, where drill reaction suggested that we intercepted the bedrock surface. We installed slotted casing to a depth of 72 ft bgs and a thermistor string to 51.2 ft bgs, and backfilled with cement-bentonite grout (see Figure B-10). Additionally, we installed a second satellite ADAS at this location (see Figure B-11). A summary of all of the instruments installed and their specifications is provided in Appendix E.

TASK 2: TO MONITOR DEFORMATION, TEMPERATURE, AND PORE WATER PRESSURE WITHIN FDL-A

Following the drilling program, we returned to the site on October 13, October 27, November 10, and November 23, 2012 to collect manual measurements of the slotted casings and download data from all of the ADAS. On the October 27 trip, we drove 24 steel rods into the ground surface, attaching a yard stick and temperature recording device to each (see Figure 15). The location of each of these rods was measured immediately after installation, and again on November 10 and 23. We hope to continue making surface measurements in the spring of 2013. The deformation, temperature, and pore water pressure measurements are discussed in Chapter 3.



Figure 15. Measuring movement of the FDL-A surface. (a) Repeated measurements were made throughout the fall using a differential global positioning system (D-GPS) unit. (b) We installed steel rods, with yard sticks (spray-painted pink for high visibility) and (c) temperature recording devices attached (indicated with yellow arrow). (Photographs by M. Darrow)

CHAPTER 3

FINDINGS

TEMPERATURE MEASUREMENTS

Because of the variety of drilling methods used during the field investigation, we analyzed the temperature data to determine the time necessary to achieve thermal equilibrium after drilling. TH12-9004 was drilled with tricone and casing, and the drilling fluid was heated and circulated through the casing to ease its extraction; TH12-9005 was drilled with hollow-stem auger. Each of these borings was backfilled with cement-bentonite grout having a temperature of approximately 54°F during backfilling. After drilling, the equilibrating process required approximately 40 days for TH12-9004 and 25 days for TH12-9005. In contrast, the thermistors in TH12-9002, which was backfilled with tamped sand, reached thermal equilibrium throughout the boring approximately 15 days after drilling. These trends are visible in Figure 16, which is a plot of temperatures from all three cased boreholes at the same vertical scale.

During the drilling program, the permafrost table was intercepted at approximately 2 ft bgs in the “undisturbed” area and between 6.5 ft and 8 ft bgs on FDL-A. Given the time of year, these depths can be interpreted as the active layer depths typical for the general area and the FDL, respectively. Averaging the sensors at depths in pseudo-equilibrium indicates that the permafrost temperature in the “undisturbed” area is 28°F, whereas the temperatures at depth within FDL-A average 30°F.

Figure 17 through Figure 19 are temperature profiles for each of the cased borings from installation to November 23. Each plot combines the temperature measurements made with the variety of sensors at each location. Most of the measured temperatures fit the trend that developed with depth during the equilibrating process. One exception to this is the temperature measured at 85 ft bgs in TH12-9004 (see Figure 19). The temperature recorded by the vibrating wire piezometer at 85.5 ft bgs (i.e., “P2”) also is plotted in Figure 19. As the P2 temperature fits the expected trend, the likely explanation for the higher temperature is that it represents a malfunctioning thermistor. Unfortunately, all thermistors below 60 ft bgs failed on October 11, 2012. On October 26, the P2 unit also failed. Another exception to the stable temperature trend is illustrated with data collected on November 23 (see Figure 19). Starting on November 9, the remaining thermistors at depth began reporting a steady increase in temperature resulting in above-freezing values, as indicated by the somewhat erratic temperature profile from November 23; yet the vibrating wire piezometer located at 53.5 ft bgs (i.e., “P1”) measured 29.7°F, matching the previous temperature trend. Figure 20 is a plot of temperatures obtained using the M-IPI device installed within the casing in TH12-9004. The sensors in the M-IPI are not calibrated, but previous research indicated that they report temperatures $\pm 0.4^\circ\text{F}$ (Darrow, 2012). To reduce some of the temperature variability to illustrate data trends better, nearest pairs of readings were averaged together; these average values are plotted in Figure 20. The device stopped reporting accurate temperatures below 65.5 ft bgs on October 24; however, the data above this depth are sufficient to indicate below freezing temperatures. Thus, the thermistors below 15 ft bgs began to malfunction on November 9, likely the result of glycol entering the cable and affecting the measured resistance. The glycol could reach the thermistors because of the earlier shearing of the cable.

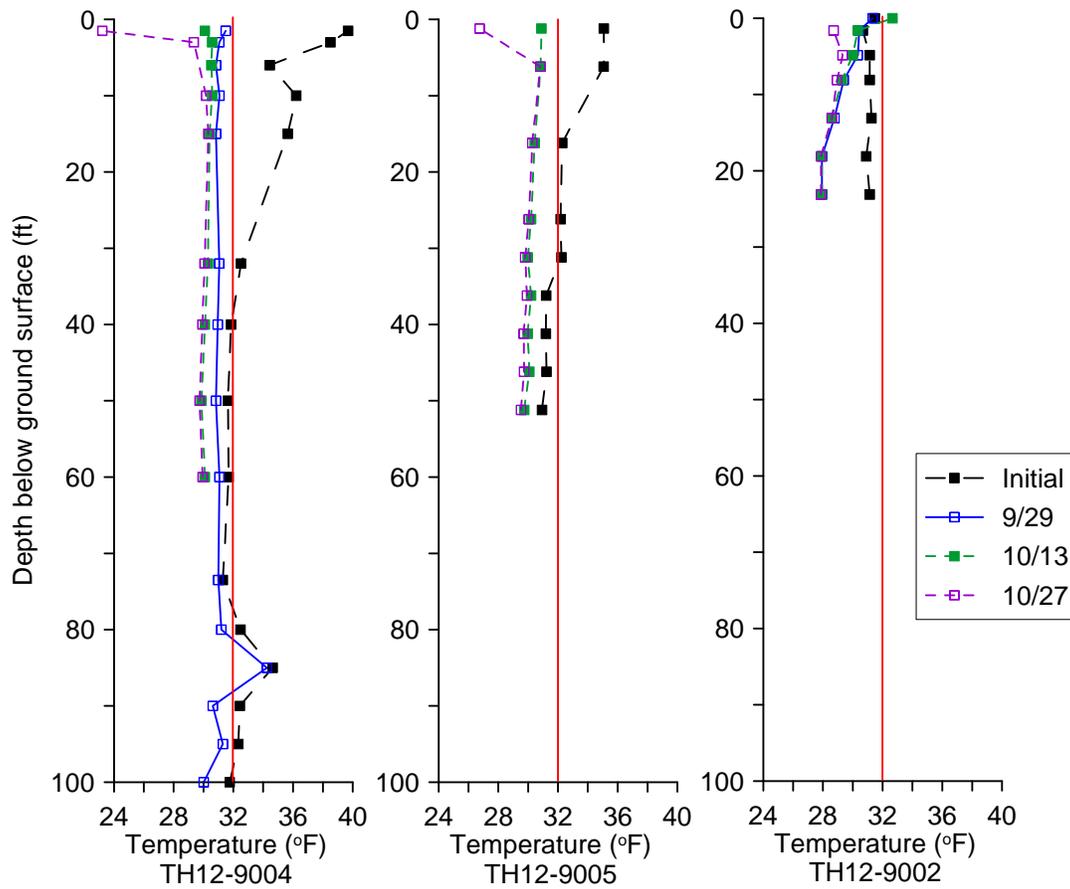


Figure 16. Temperature profiles for borings located on FDL-A (i.e., TH12-9004 and TH12-9005) and in the “undisturbed” area (i.e., TH12-9002), illustrating time for thermal equilibrium after drilling. The phase-change temperature is indicated by the vertical red line. The “initial” readings are September 19, 2012 for TH12-9002, September 22, 2012 for TH12-9004, and September 30, 2012 for TH12-9005.

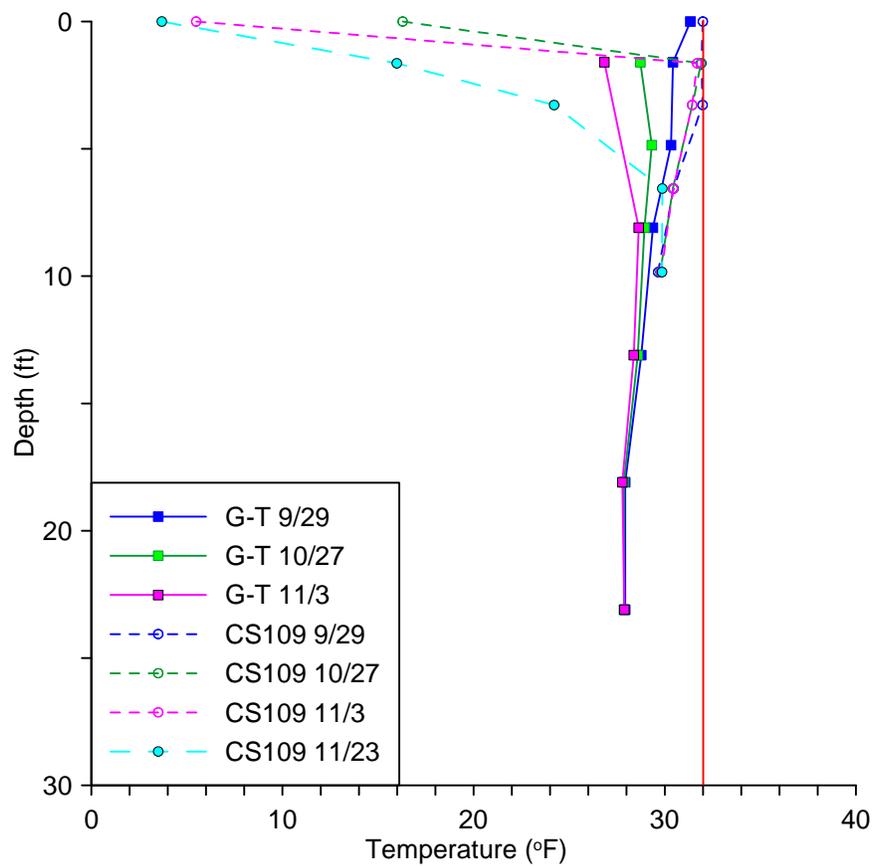


Figure 17. Combined temperature readings for the TH12-9002 area. “G-T” measurements are from the thermistor string within the boring, and “CS109” measurements are from sensors installed in TH12-9001 about 20 ft away. The phase-change temperature is indicated by the vertical red line.

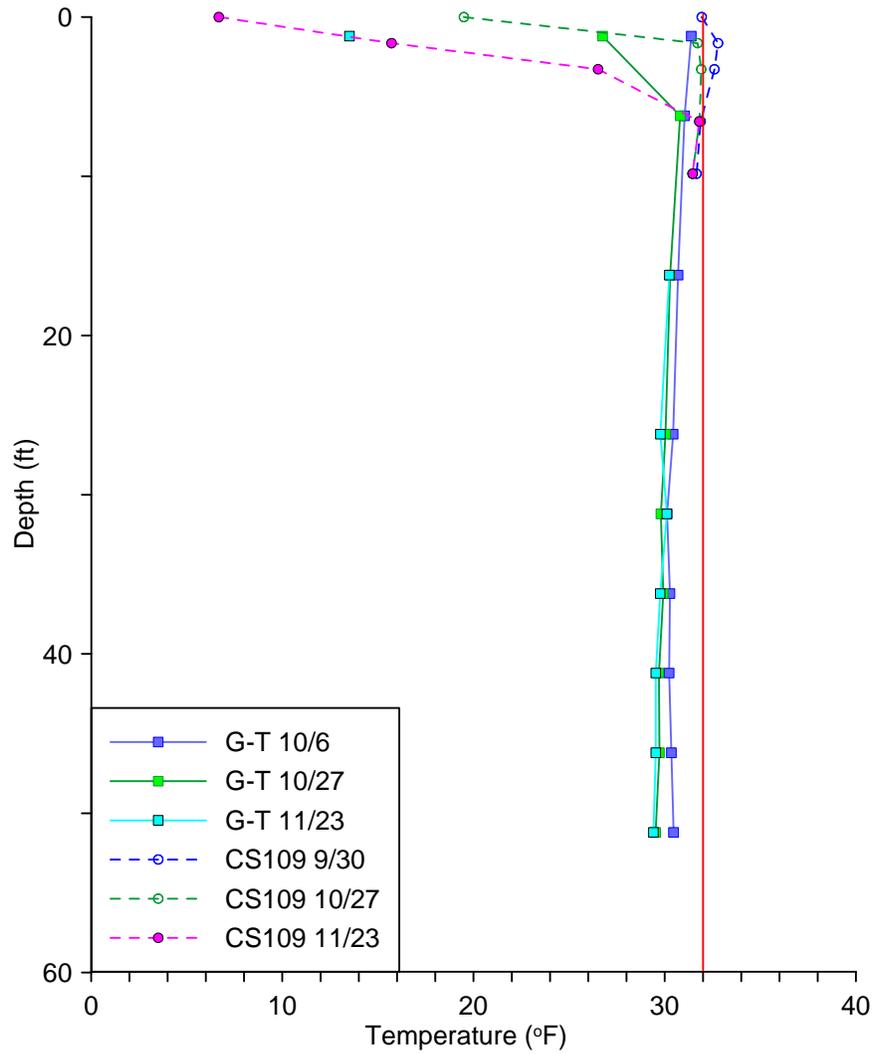


Figure 18. Combined temperature readings for the TH12-9005 area. “G-T” measurements are from the thermistor string within the boring, and “CS109” measurements are from sensors installed in a boring made about 50 ft away. The phase-change temperature is indicated by the vertical red line.

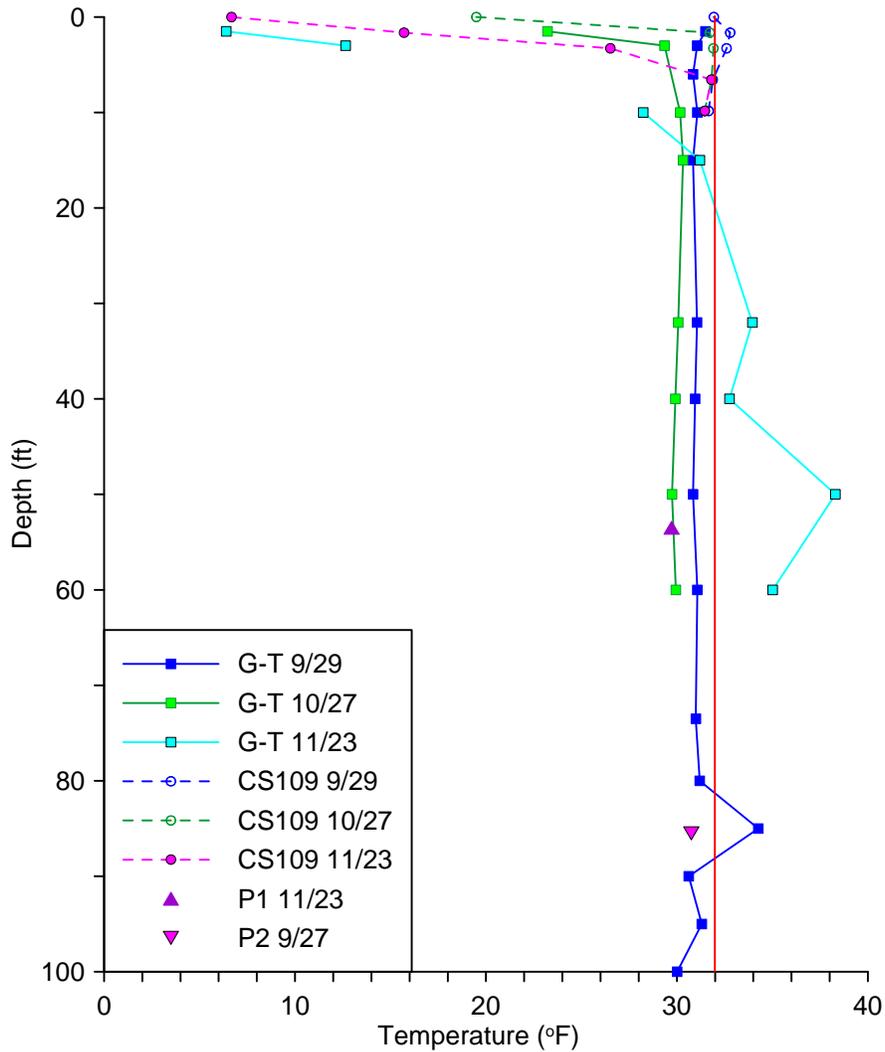


Figure 19. Combined temperature readings for the TH12-9004 area. “G-T” measurements are from the thermistor string within the boring, “P1” and “P2” are readings from the vibrating wire piezometers installed at 53.5 and 85.5 ft bgs, respectively, and “CS109” measurements are from sensors installed in a boring made about 15 ft away. The phase-change temperature is indicated by the vertical red line.

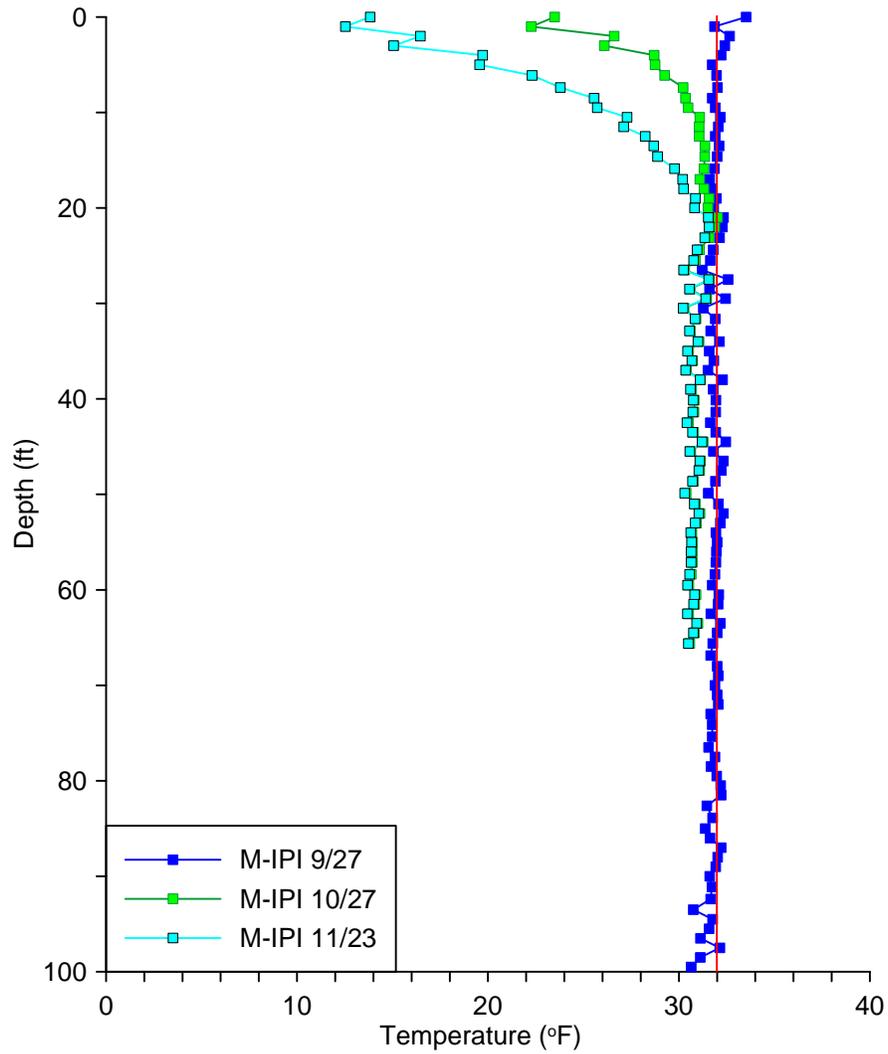


Figure 20. Temperature readings from the M-IPI device installed within TH12-9004. Nearest pairs of readings were averaged to reduce the scatter. The phase-change temperature is indicated by the vertical red line.

SLOPE MOVEMENT

Measurements of TH12-9000 and TH12-9002 indicate that there is no appreciable slope movement between FDL-A and the highway or to the south of the lobe where drilled (see Figure 21). Figure 22 contains plots of cumulative displacement from the M-IPI device installed in TH12-9004, and the manual inclinometer readings of TH12-9005. We corrected the data for TH12-9004 using vector summation (Cornforth 2005) to determine the direction and magnitude of maximum movement. We also corrected for the cumulative change in depth of the sensors, as horizontal movement along the shear zone pulled the M-IPI device further down into the casing. These adjusted readings (shown in Figure 22a) indicate movement within a well-developed shear zone between 66 ft and 74 ft bgs. When drilling this interval, the drilling fluid changed from gray to a dark brown at 70 ft and 76 ft bgs, indicating zones rich in organic material. Wood pieces were flushed up in the drilling fluid/cuttings from 74 to 84 ft bgs. We collected some of these wood pieces, which were well-preserved within the frozen debris. We sent one of the larger pieces of wood to Beta Analytic Inc. for ^{14}C dating. The calibrated results indicate that the wood was 1,330 years old. Based on its location below the current shear zone and above the bedrock surface, this wood is the remnant of a tree that either was growing on the slope and was covered by the debris lobe, or was buried and incorporated within the debris lobe and carried some distance downslope.

The plots of cumulative displacement in Figure 22a demonstrate fairly consistent movement over the measurement period, with a total of 31.2 in. of movement at the surface in about 31 days, or approximately 1.0 in. of movement per day. Early in the morning of October 24, the M-IPI began to record “retrogressive” movement upslope between 67 and 70 ft bgs. Considering the earlier failure of the thermistor string and the subsequent failure of the piezometer, we suspected that a few of the M-IPI sensors were damaged in the shear zone. The manufacturer of the device agreed, indicating that the sensors “probably deformed or rotated within the housing” (J. Lemke, pers. comm., Nov. 2012). Despite the damaged sensors, the entire M-IPI continued to record data, acquiring reasonable measurements of cumulative displacement below the depth of 70.5 ft. The sensor original at 69.5 ft bgs recorded the largest amount of shear (i.e., 30.4 in.) within this zone before failing. Then on October 31, the M-IPI sensors below 66 ft bgs ceased reporting data. Movement of FDL-A has continued, however, as indicated by the sensors above 66 ft bgs.

At first glance, it appears that only about 2 in. of movement occurred overall in TH12-9005 (see Figure 22b). Instead, these readings indicate that this boring is too shallow; when drilling, we did not penetrate through the shear zone and into the underlying bedrock as was suggested by drill reaction. Ideally, a slotted casing is installed 10 to 20 ft beyond the depth of movement (Cornforth 2005, Dunncliff 1993) so that systematic errors can be identified and corrected based on the zone of stable readings below the shear surface. This zone of stable readings is missing in Figure 22b; however, if the movement below 67 ft in TH12-9004 is factored out, the cumulative displacement appears to be about 3 in. (see Figure 22c), or about the same order of magnitude as seen in TH12-9005. Thus, since the casing in TH12-9005 does not penetrate the shear zone, it is only recording the deformation within the sliding mass. Although minor in comparison to the amount of movement within the shear zone, the upper portion of the lobe also is deforming, as indicated by the progressive “leaning” of the casing. This suggests that there is both internal shear and slow to moderate flow occurring within FDL-A.

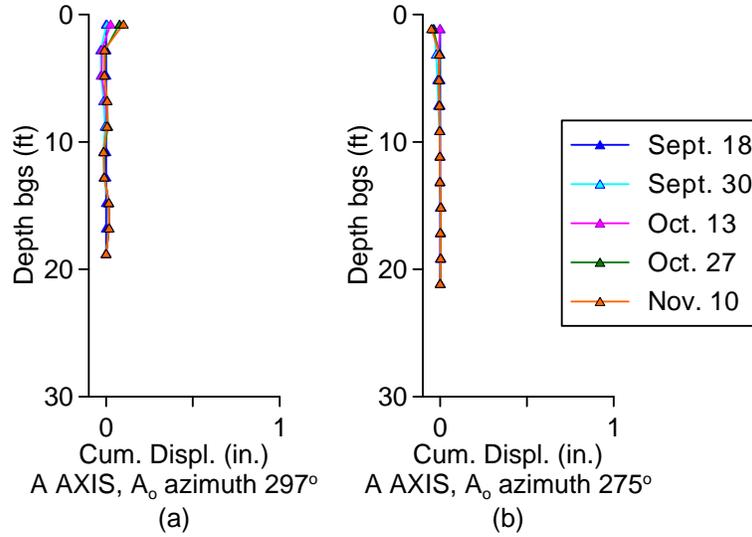


Figure 21. Cumulative displacement measurements for (a) TH12-9000 and (b) TH12-9002.

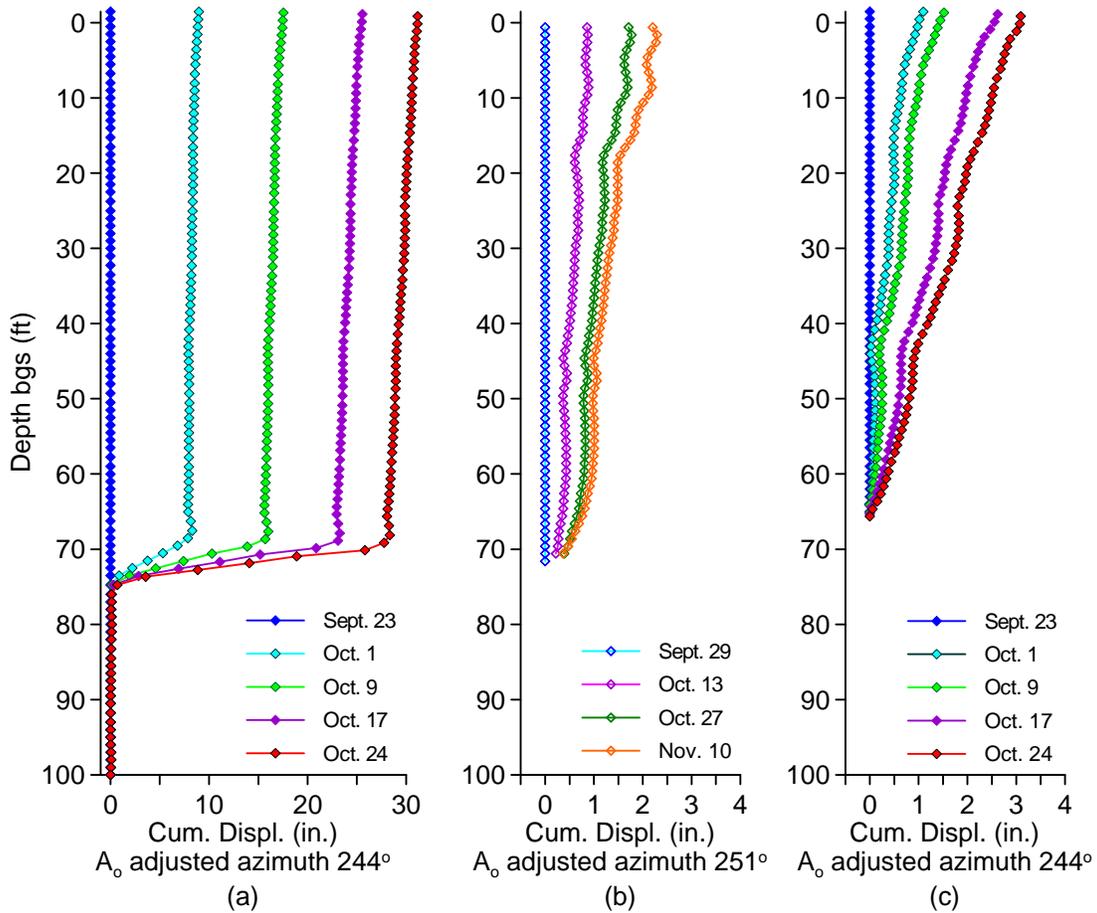


Figure 22. Cumulative displacement measurements for (a) TH12-9004 and (b) TH12-9005. The data in (a) was adjusted to show only movement from above the shear zone at 67.5 ft bgs; the adjusted data is shown in (c).

Figure 23 illustrates changes in the rate of movement measured at two different depths within TH12-9004. These rates were calculated from the surface sensor and the sensor originally at 69.5 ft bgs, which experienced the most displacement before the M-IPI device completely sheared. We continued to calculate the rate at this depth until the readings became unreliable on October 30. Calculations of the surface rate of movement were possible until the device indicated retrogressive motion on October 24. The combined movement of shear and slow to moderate flow is apparent as the movement rate at the surface was higher than the rate at 69.5 ft bgs throughout the measurement period. The data in Figure 23 also indicate that FDL-A was slowing down during this time. Movement at the shear zone was more consistent, averaging just over 0.8 in. per day. Movement at the surface was highest in late September, at approximately 1.2 in. per day; by the end of the measurement period, it slowed to nearly the same rate as the shear zone. This indicates that the internal flow was stopping over the measurement period, perhaps due to the dropping temperature within the surficial portion of the lobe.

On subsequent trips to FDL-A, we continued to observe signs of ongoing movement on its surface. The late fall of 2012 was unusual as there was no appreciable snowfall (several residents in nearby Wiseman and Coldfoot comments on this unusual lack of precipitation). This allowed us to observe cracks in the ground surface that would otherwise have been covered with snow (see Figure 24 for examples).

WATER PRESSURE

Figure 25 contains the water pressure readings for the two piezometers installed in TH12-9004. Both piezometers demonstrated a steep rise in pressure immediately after installation. The rise in P2 continued for 56 hours, at which point the piezometer began reporting erroneous values. The rise in P1 continued for 28 hours, gradually dropped, then rose again to record a nearly constant pressure of 88.5 ft of water. We suspect that the initial rise in pressure in both P1 and P2 was due to a combination of equilibrating to the *in situ* water pressures and the swelling of the cement-bentonite grout. Each piezometer is rated to an operating pressure of 117 ft of water (350 kPa) with an over-range of two times the full scale. Despite the large over-range, it appears that the high pressure of 155 ft of water was sufficient to damage the lower piezometer, P2. Beginning in early October 2012, the upper piezometer at 53.5 ft bgs consistently read water pressure indicating a potentiometric surface 35 ft above the ground surface. Initially, we suspected that this was due to an incorrect laboratory calibration; however, subsequent trips made to the site indicated that this reading may be accurate.

To ensure that the slotted casings remained free of ice for future readings, we filled each casing with propylene glycol. On October 27, we observed that the fluid level in TH12-9004 had dropped about 3 ft, confirming that the casing had sheared and some fluid had leaked out. On November 10, we observed that the fluid level had risen to fill the casing and was dripping out from the top. The high fluid level was again apparent on November 23, as indicated by drips running down the outside of the casing and accumulating on the M-IPI safety line (see Figure 26a). These fluid pressure observations suggest that groundwater has entered the casing through cracks within the shear zone, and is under enough pressure so as to flow up and out of the casing at the surface. We observed additional phenomena that indicated groundwater flow at FDL-A. Along the northern portion of the toe, water flowed out of the slope and into the forested area beyond (see Figure 26b). This ice-covered area was considerable in area and represented a significant volumetric discharge from FDL-A as the surface froze in early winter.

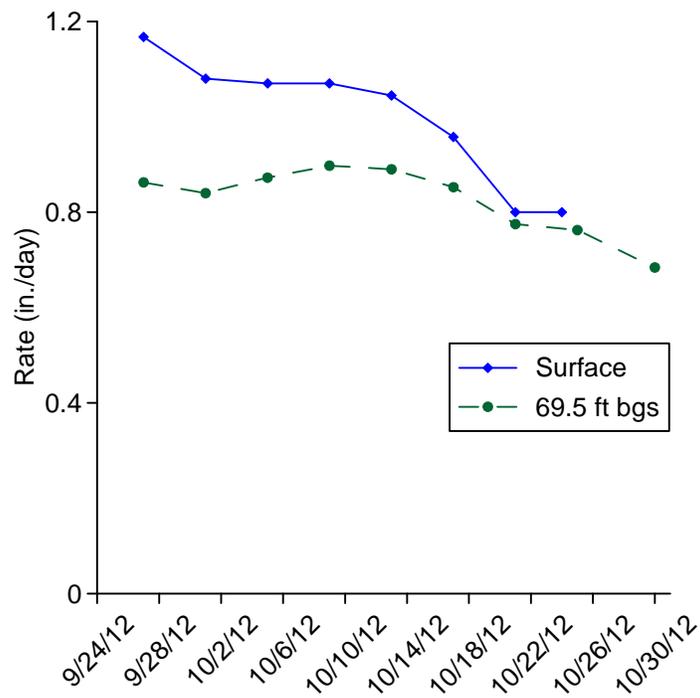


Figure 23. Changes in the movement rate of FDL-A measured within TH12-9004. Rates are plotted for M-IPI sensors at the surface and at 69.5 ft bgs.

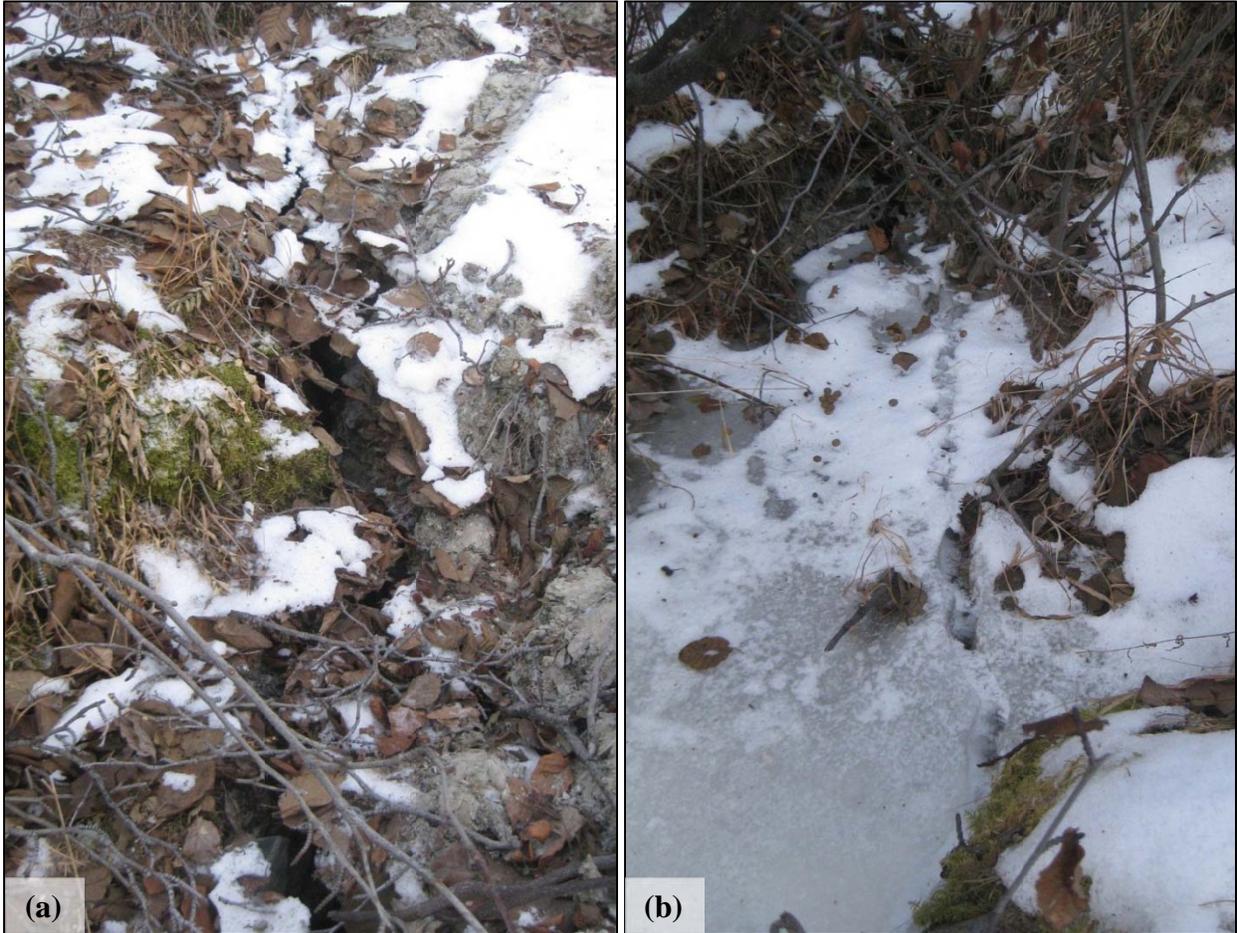


Figure 24. Evidence of on-going movement in the early winter of 2012. (a) A crack separates the leaf litter and snowfall of late September. (b) Water that ponded on the surface in late September and subsequently froze is penetrated by a crack that continued beyond the extent of this photograph. (Photographs by M. Darrow)

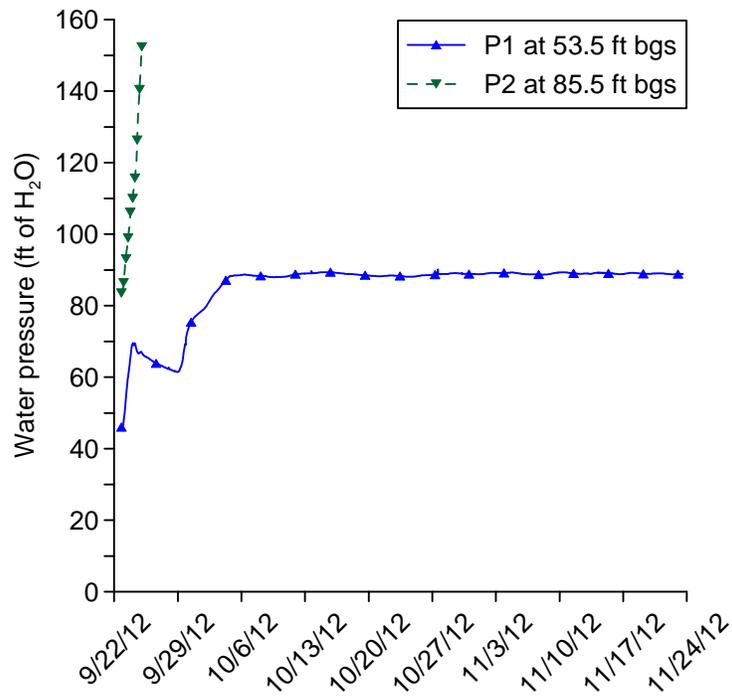


Figure 25. Water pressure measurements from TH12-9004. The vibrating wire piezometer at 85.5 ft bgs failed on September 25, 2012.

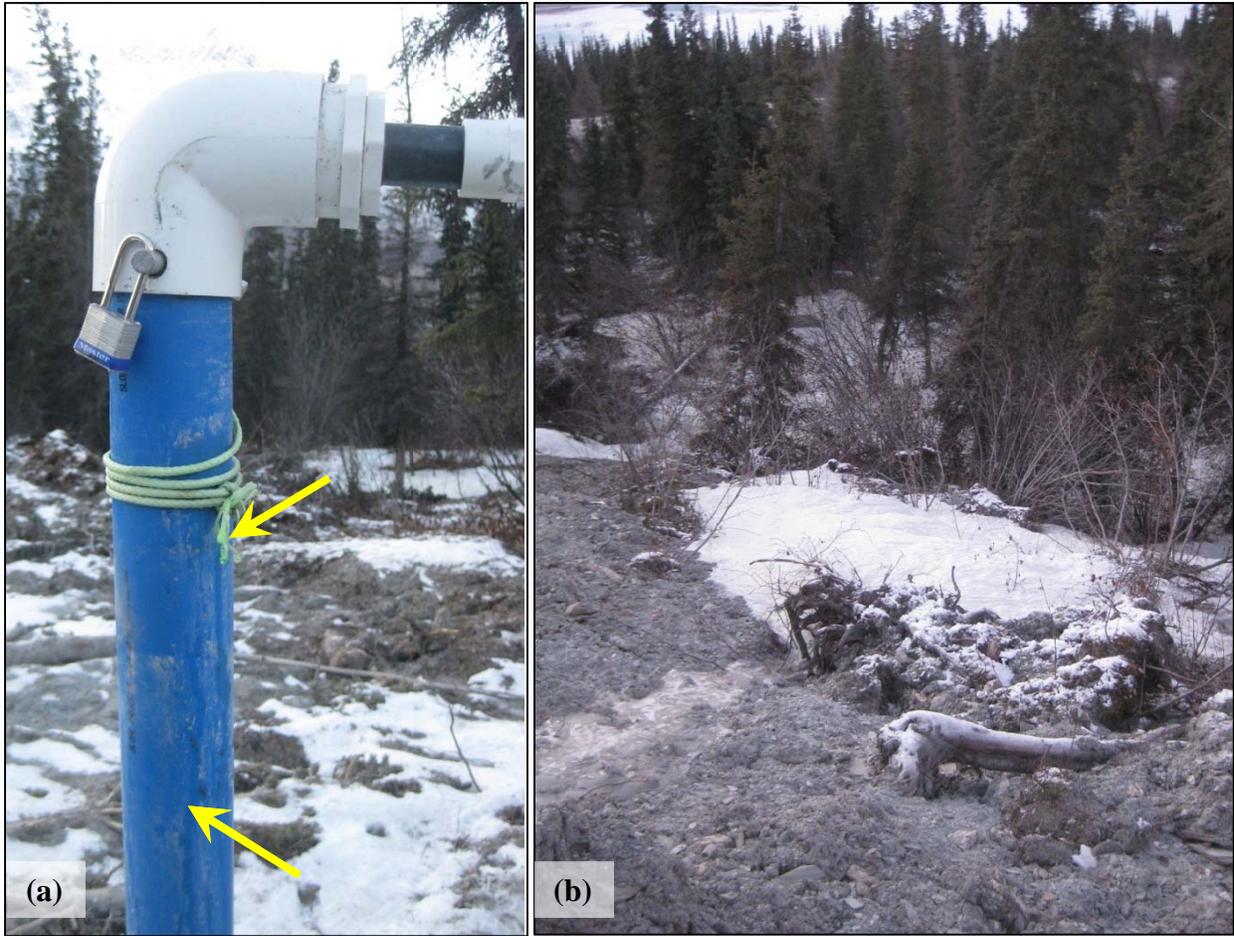


Figure 26. Evidence of groundwater flow at FDL-A. (a) Propylene glycol overflowing the top of the slotted casing in TH12-9004 drips from the M-IPI safety line and runs down the outside of the casing (indicated by arrows). (b) Ice formed along the toe of FDL-A; the Dalton Highway is visible near the top of the photograph. (Photographs by M. Darrow)

DISCUSSION OF TH12-9004 FINDINGS

TH12-9004 was the most successful boring of the 2012 drilling program, as it intercepted both the shear zone and the bedrock surface, and the instrumentation installed within yielded much of our data. Figure 27 is a schematic summary of the major features of the subsurface and the drilling events. It also graphically summarizes the locations of thermistor beads and vibrating wire piezometers. The loss of drilling fluid and the presence of water pressure during drilling suggests a network of subsurface cracks through which water may flow. Indeed, the fact that water has entered into the sheared casing supports this idea.

SURFACE MOVEMENT MEASUREMENTS

The results of our surface movement measurements are presented in Figure 28. Total movement measured from October 27 to November 23 for each point is provided in ft in the figure (points that could not be measured on either of those days are shown, but no measurements are provided). Based on the measurements made of the slotted casing in TH12-9002, we assume that the southernmost measurement point off of the lobe is not moving. In Figure 28, this point is indicated with a circle, and the text “+/-0.14”. As there is apparent movement of 0.14 ft between the measurement dates, we use this value as the minimum error of the other measurements. Additionally, in some low topographic areas and areas with thick vegetation, readings necessitated holding the DGPS at a greater height. This was especially true on November 23, when cold temperatures caused low battery power in the base station unit. This contributes to additional error. For example, the northernmost point off of the lobe most likely is not moving; however our measurements indicate 0.8 ft of movement. Considering these issues, we are treating the data presented in Figure 28 as preliminary; additional measurements must be made to reduce the error.

Despite its preliminary nature, the amount of movement indicated in Figure 28 is sufficient to make initial observations of the overall movement of FDL-A. These initial readings indicate between 1.0 and 1.9 ft of movement at the toe, increasing in magnitude upslope to a maximum of 3.2 ft of movement in 28 days. These values equate to rates of 0.4 to 0.8 in. per day at the toe and 1.4 in. per day upslope. The arrows indicate that while movement is in the downslope direction to the west, there is some variation in the direction of overall movement for this set of measurements. Again, since this is preliminary data, we will need to make additional measurements before we can verify or dismiss these variations in movement direction.

DENDROGEOMORPHOLOGY

Positioning the drill rig on the surface of FDL-A required cutting a few spruce trees. We collected slabs from the stumps of these trees, along with their geographic location on FDL-A, and will use these for a dendrogeomorphologic analysis. Dendrogeomorphology is a technique used to date slope movement in areas with few historical records (Carrara et al. 2007; Carrara and O’Neill 2003; Fantucci and Sorriso-Valvo 1999; Guida et al. 2008; Tamulonis and Kappel 2009). As a tree grows, it records information on its orientation and health via its rings. When growing vertically, the tree produces concentric rings. Should the tree shift from a vertical orientation, it corrects for this by producing more growth on its leaning side. Ground movement within FDL-A has caused disruption of the lobe surface. Most trees demonstrate a split or curved trunk, and ground movement has caused the roots of some trees to be pulled in various directions.

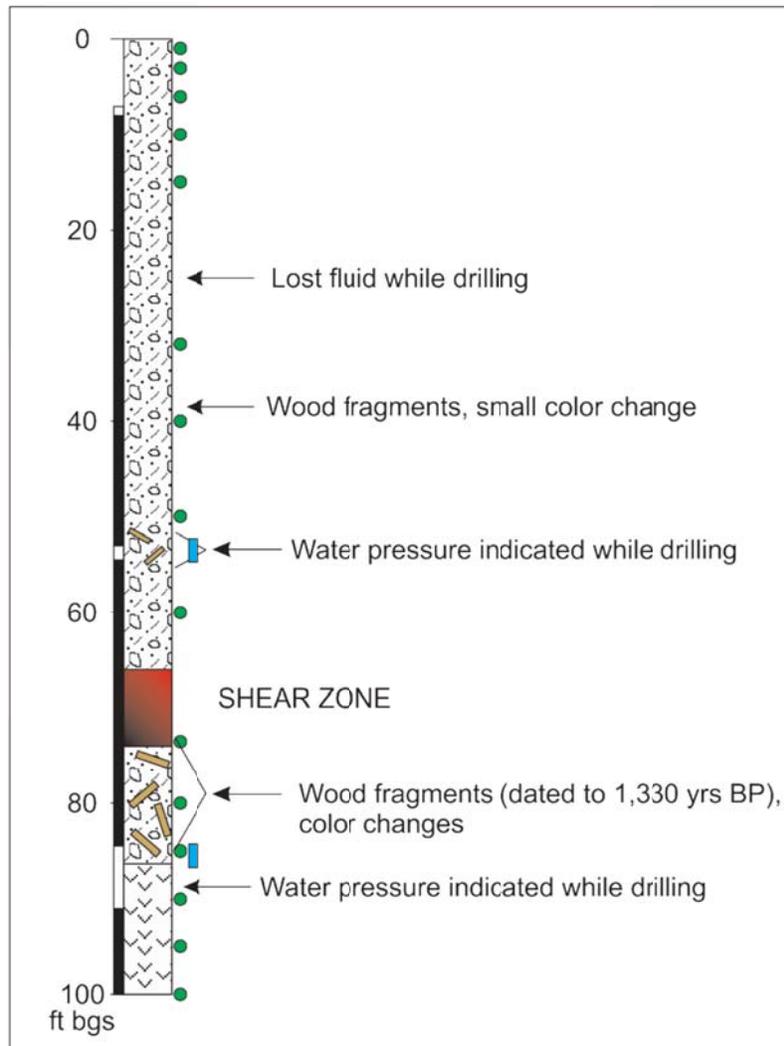


Figure 27. Schematic of TH12-9004, showing locations of major features and events during drilling and borehole instrumentation. Thermistor beads are represented by green circles at depths of 1.5, 3, 6, 10, 15, 32, 40, 50, 60, 73.5, 80, 85, 90, 95, and 100 ft bgs. Vibrating wire piezometers are represented by blue rectangles at 53.5 and 85.5 ft bgs. Wood fragments are indicated by brown rectangles, and the bedrock surface is at 86.5 ft bgs. The shear zone is between 66 and 74 ft bgs. Frozen ground is represented by the black bar along the left of the boring schematic; white portions of the bar represent questionably frozen areas.



Figure 28. Summary of surface movement measurements. All points were measured using a differential global positioning system (DGPS). The length of all arrows is the same; they indicate direction of movement only, not velocity. Total movement for each point is provided in feet near the head of each arrow. The circle around the southernmost point indicates the use of this point for error calculations, which we estimate at ± 0.14 ft.

Figure 29 illustrates a particular tree ring pattern associated with one such tree that grew on the shifting surface of FDL-A for 248 years. The pattern reveals that the tree started its life growing vertically for about 23 years, after which time the ground shifted. Eighty-two years went by with very dense growth rings, possibly due to damage in the root system, but without a shift in the tree's growth direction. The next 27 years indicate that the tree grew in a different direction. The tree shifted again after another 28 years, followed by 48 years of continuous rotation, like a corkscrew. The last 40 years of growth on the tree shows a relatively stable period. More detailed growth information can be obtained by comparing the width of the rings to healthy trees in the area; stress caused from ripping roots would reduce the tree's growth, resulting in thinner rings. As part of future studies, we will develop a dataset of tree ring width and correlate it to movement of FDL-A.



Figure 29. Tree slab from the FDL-A surface, showing tree ring deformation as a result of changing tree orientation. The photograph contains annotations indicating the age of particular rings when change in the tree's orientation occurred. (Photograph by R. Daanen)

CHAPTER 4

CONCLUSIONS, RECOMMENDATIONS, AND SUGGESTED RESEARCH

We successfully drilled and collected samples of FDL-A during the 2012 field investigations. This feature, where drilled, is fairly homogeneous, mostly consisting of silty sand with gravel. It overlies white mica schist bedrock, the surface of which was verified in one boring at 86.5 ft bgs. We obtained the first set of *in situ* slope movement and deep temperature measurements within this feature. Temperature measurements indicate that the temperature of the FDL is 2°F warmer than the surrounding permafrost. FDL-A demonstrates at least two modes of movement, with a shear zone between 66 ft and 74 ft bgs (where measured), and slow to moderate flow above the shear zone. Combining these modes of movement, FDL-A was moving at an average rate of 1.0 in. per day over the length of this research project, which is more than twice the historic rate determined from previous remote sensing analysis.

These initial results are encouraging, as they provided us with the first view into FDL-A. The results also help us to identify important remaining questions to understand its movement better, which is critical in establishing a mitigation plan. The following is an outline of suggested future work at FDL-A.

- Continue to measure the surface markers using a differential global positioning system (DGPS) device. We installed these pins in October 2012 since we did not penetrate the shear zone in TH12-9005. Continued measurements will help to locate where the shear zone intercepted in TH12-9004 intersects the surface. These measurements also will indicate whether FDL-A is moving only in the downhill direction or if it is also spreading laterally. Additionally, measuring snow depth and soil surface temperatures at these markers may provide insight into how the lobe's microclimate affects its movement.
- Continue to maintain the ADAS sites, collecting temperature and slope movement data from TH12-9004, as well as weather data collected at the main ADAS. These data may provide correlations between slope movement and local weather at the feature.
- Although costly, a wealth of information was gained from the borings into FDL-A. The 2012 field crew also learned the best methods to use for successful penetration of the debris lobe, retrieval of samples, and installation of casings and instruments. We recommend a follow-up drilling program on FDL-A. Five additional borings (three forming a cross section near the toe of the lobe, one near TH12-9004 but on the northern portion of the lobe, and one farther uphill to form a longitudinal profile; all borings completed with slotted casing and selectively-placed piezometers) would provide a more comprehensive understanding of the lobe soils, the position of the shear zone throughout the lobe, variation in movement rate across the lobe, and the distribution of water pressure.
- Conduct geophysical surveys across FDL-A. Geophysical methods are inexpensive compared to drilling programs, and cover greater cross-sectional area than borings; however, the results must be ground-truthed with drilling data. The seismic method produced reasonable results, but the length of our geophone lines prohibited reaching the bottom of FDL-A. We recommend conducting another seismic survey with longer lines

in order to penetrate the bedrock surface. Future surveys should be conducted in the vicinity of TH12-9004 and TH12-9005 in order to ground-truth the results. Alternatively or in addition to the seismic work, we recommend using other methods, such as 1) electrical resistivity (capacitively-coupled resistivity like OhmMapper, or electrical resistivity tomography), and 2) induced polarization tomography. These methods have the best potential to reach the bottom of the lobe and may be able to identify areas of liquid water. Used together, they may be able to delineate unfrozen areas within the lobe.

- Conduct further laboratory testing of the samples collected during the drilling program, including strength testing of the frozen samples. This could be completed using creep tests, from which strength parameters such as apparent cohesion and the internal friction angle would be determined.
- Finally, we recommend modeling FDL-A. A “traditional” quantitative analysis of this landslide using a limit equilibrium approach (either deterministic or probabilistic) could be conducted using a refined input geometry from the additional field work recommended above; however, we suspect that a more sophisticated approach that incorporates the movement’s dependence on temperature may be required. Modeling is necessary to determine or confirm the geometry of the shear surface, to examine the effects of pore water pressure, to determine the probability of failure within the range of material properties, to calculate the residual strength in the shear zone, and to identify possible mitigation strategies in order to protect the Dalton Highway.

CHAPTER 5

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APPENDIX A: 2012 SEISMIC LINE CONFIGURATION SUMMARY AND SURFACE CRACKS

Table A-1. Summary of seismic line configurations and geophone overlap. The shot numbers are listed below each line; adjacent position indicates where lines overlap.

North-south lines			East-west lines		
Line 1	Line 2	Line 3	Line 4	Line 5	Line 6
1			37		
2			38		
3			39		
4			40		
5			41		
6	13		42	49	
7	14		43	50	
8	15		44	51	
9	16		45	52	
10	17		46	53	
11	18	25	47	54	61
12	19	26	48	55	62
	20	27		56	63
	21	28		57	64
	22	29		58	65
	23	30		59	66
	24	31		60	67
		32			68
		33			69
		34			70
		35			71
		36			72



Figure A-1. Cracks (indicated by dashed yellow lines) along seismic Line 1 on FDL-A. (a) Crack between Shots 2 and 3; photograph was taken towards the south, facing the left-flank of FDL-A (photograph by M. Darrow); (b) crack between Shots 11 and 12; photograph was taken towards the south. (Photograph by J. Simpson)



Figure A-2. Crack (indicated by the dashed yellow line) along seismic Line 4 between Shots 46 and 47. This photograph was taken towards the east, facing uphill on FDL-A. (Photograph by M. Darrow)



Figure A-3. Cracks (indicated by the dashed yellow lines) along seismic Line 6 between Shots 63 and 64. This photograph was taken towards the west, facing downhill on FDL-A. (Photograph by M. Darrow)

APPENDIX B: PHOTOGRAPHS OF THE SEPTEMBER 2012 DRILLING PROGRAM



Figure B-1. Typical rig set-up for hollow-stem auger, with the CME 850X track-mounted drill. Photograph taken while drilling TH12-9000. (Photograph by M. Darrow)



Figure B-2. Typical rig set-up for tricone and casing. Photograph taken while drilling TH12-9004. (Photograph by M. Darrow)



Figure B-3. Completed casing installations for TH12-9006 in the foreground and TH12-9000 in the background to the right. This photograph is taken to the south; the Dalton Highway is to the right of the photograph, and the toe of FDL-A is to the left. (Photograph by M. Darrow)



Figure B-4. Location of TH12-9002. View is to the southwest, with the Dalton Highway visible in the middle-right of the figure. (Photograph courtesy of M. Carew)



Figure B-5. Final set-up of the “undisturbed” satellite ADAS. This photograph was taken to the north; the Dalton Highway is located to the left of this photograph, and FDL-A is beyond the trees that are just visible in the fog. The ADAS and slotted casing were covered with tree branches to reduce their visibility from the highway. (Photograph by M. Darrow)



Figure B-6. Configuration of the piezometer and thermistor bead at the bottom and outside of the casing installed in TH12-9004. (Photograph by M. Darrow)



Figure B-7. Installing the MEMS-based in-place inclinometer (M-IPI) within the slotted casing in TH12-9004. (Photograph by J. Simpson)



Figure B-8. Completed casing and instrument installation in TH12-9004. (Photograph by M. Darrow)



Figure B-9. Completed “main” ADAS location and casing installation of TH12-9004. (Photograph by M. Darrow)



Figure B-10. Completed casing installation for TH12-9005. (Photograph by M. Darrow)



Figure B-11. Completed “lower” satellite ADAS installation. TH12-9005 is located beyond the brush behind the ADAS in the photograph. (Photograph by M. Darrow)

APPENDIX C: BORING LOGS FROM THE SEPTEMBER 2012 DRILLING PROGRAM

Drilling Method		Depth in (Feet)	Casing Blows / ft	Sample Data				Frozen	Graphic Log	Ground Water Data		GENERAL COMMENTS: Location determined with handheld Garmin etrex GPS, UTM zone 6, currently 61.5 ft on a bearing of 63deg from the lobe front
				Method	Number	Blow Count	Sample Interval			N-Value	While Drilling	
FINAL TEST HOLE LOG												
STATE OF ALASKA DOT/IF Northern Region Materials Geology Section			ALASKA UNIVERSITY TRANSPORTATION CENTER University of Alaska Fairbanks - INE			Project <u>Frozen Debris Lobe-A, Dalton Highway MP219</u>			Test Hole Number <u>TH12-9000</u>			
						Field Geologist <u>M. DARROW</u>			Equipment Type <u>CME 850</u>			Total Depth <u>20 Feet</u>
Field Crew <u>J. CLINE, P. LANIGAN, K. MAXWELL, R. DAANEN, J. SIMPSON</u>			Weather <u>Rain, snow, wind</u>			Dates Drilled <u>9/17/2012 - 9/17/2012</u>			UTM <u>N7524488, E381121</u>			
TH Finalized By <u>M. DARROW</u>			Vegetation <u>spruce, light moss, alder</u>			Latitude, Longitude			Elevation			
SUBSURFACE MATERIAL												
0 ORG MAT 0												
1 Tn Silty SAND 1												
2 w/ Gravel 2												
3 w/ Cobbles 3												
4 moist, wet at 4.5 4												
5 SAMPLE 12-2500 (1.0-6.0): SM, 36.1% -200, LL NV, PI NP 5												
6 30% recov. 6												
7 SAMPLE 12-2501 (6.2-6.5): NM 7.6% 7												
8 Bn Well-graded SAND 8												
9 w/ Silt & Gravel 9												
10 white mica schist colluvium 10												
11 100% recov. 11												
12 Gy BEDROCK, soft(white mica schist) 12												
13 SAMPLE 12-2502 (11.0-11.5): NM 8.6% 13												
14 SAMPLE 12-2503 (11.5-14.5): 14												
15 Sample collected but not tested 15												
16 16												
17 17												
18 SAMPLE 12-2504 (18.0-18.5): NM 2.2% 18												
19 100% recov. on 6 in. 19												
20 BOH 20												
Drilling Notes: Installed SI casing to 20.0; used 8 50-lb bags of sand to tamp for backfill (2.5 ft/bag tamped sand)												
NR AKDOT TEST HOLE LOG - USCS FDL-A, DALTON219.GPJ, NR_AKDOT_PRECON_USCS.06_28_07.GDT, 12/5/12												

Note: Unless otherwise noted, all samples are taken with 1-3/8-in. ID Standard Penetration Sampler driven with 140 lb. hammer with 30-in. drop. CME Auto Hammer Cathead Rope Method



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FINAL TEST HOLE LOG

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Project Frozen Debris Lobe-A, Dalton Highway MP219 Test Hole Number TH12-9001
 Field Geologist M. DARROW Total Depth 10.2 feet
 Field Crew S. PARKER, R. DAANEN, J. SIMPSON Equipment Type CME 850 Dates Drilled 9/18/2012 - 9/18/2012
 Weather light snow, no wind UTM N7524313, E381160
 TH Finalized By M. DARROW Vegetation alder, cotton grass, willow, some spruce, moss Elevation _____

Drilling Method	Depth in (Feet)	Casing Blows / ft	Sample Data				Frozen	Graphic Log	Ground Water Data		GENERAL COMMENTS: Location determined with handheld Garmin etrex GPS, UTM zone 6	
			Method	Number	Blow Count	Sample Interval			N-Value	While Drilling		After Drilling
S-S Auger	0										SUBSURFACE MATERIAL	
	1										ORG MAT	
	2										Tn Sandy SILT w/ Gravel	
	3										wet, s/ Org, w/ vis. ice SAMPLE 12-2505 (2.5-3.0): NM 122.2%	
	4											
	5											
	6											Bn Silty SAND w/ Gravel
	7											wet when thawed, layers of gravel @ 6.5
	8											
	9											
	10										BOH Gy BEDROCK, soft(white mica schist) SAMPLE 12-2506 (10.0-10.2): NM 23.7%	

Drilling Notes: Installed 3/4" PVC w/ CS109s and matric pot1 sensors (@ 1.6, 3.3, 6.6, 9.8 ft bgs); backfilled w/ cuttings

NR AKDOT TEST HOLE LOG - USCS FDL-A, DALTON 219, GPJ NR, AKDOT, PRECON, USCS 05, 28, 07, GDT, 12/5/12

Note: Unless otherwise noted, all samples are taken with 1-3/8-in. ID Standard Penetration Sampler driven with 140 lb. hammer with 30-in. drop. CME Auto Hammer Cathead Rope Method



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Northern Region Materials
Geology Section

FINAL TEST HOLE LOG

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Project Frozen Debris Lobe-A, Dalton Highway MP219 Test Hole Number TH12-9002
 Field Geologist M. DARROW Total Depth 30 feet
 Field Crew S. PARKER, R. DAANEN, J. SIMPSON Equipment Type CME 850 Dates Drilled 9/18/2012 - 9/18/2012
 Weather light snow, no wind UTM N7524307, E381161
 TH Finalized By M. DARROW Vegetation alder, cotton grass, willow, some spruce, moss Elevation _____

Drilling Method	Depth in (Feet)	Casing Blows / ft	Sample Data				Frozen	Graphic Log	Ground Water Data		GENERAL COMMENTS: Location determined with handheld Garmin etrex GPS, UTM zone 6
			Method	Number	Blow Count	Sample Interval			N-Value	While Drilling	
	0										SUBSURFACE MATERIAL
	0										ORG MAT
	1										Tn Sandy SILT
	2										w/ Gravel
	3										wet, w/ vis. ice (Vx)
	4										
	5										
	6		SS	12-2507	6						100% recov., 50% vis. ice
	7				12						SAMPLE 12-2507 (6.0-6.5): NM 33.2%
	8				11						Vol. WC 39%
	9				12						
	10										
	11										
	12		SS	12-2508	13						100% recov., 50% vis. ice
	13				16						SAMPLE 12-2508 (11.5-12.0): NM 20.2%
	14				23						Vol. WC 38%
	15				23						
	16										
	17		SS	12-2509	18						100% recov.
	18				56						SAMPLE 12-2509 (16.0-16.5): NM 11.9%
	19				100+						Vol. WC 22%
	20										Gy BEDROCK, soft (white mica schist)
	21										dry to moist, w/ hard and soft layers
	22										
	23										
	24										
	25										
	26										
	27										
	28										
	29										
	30										ROCK

NR AKDOT TEST HOLE LOG - USCS FDL-A, DALTON 219, GPJ NR, AKDOT, PRECON, USCS 05, 28, 07, 60T, 12/6/12

Note: Unless otherwise noted, all samples are taken with 1-3/8-in. ID Standard Penetration Sampler driven with 140 lb. hammer with 30-in. drop. CME Auto Hammer Cathead Rope Method



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Geology Section

FINAL TEST HOLE LOG

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Project Frozen Debris Lobe-A, Dalton Highway MP219 Test Hole Number TH12-9003
 Field Geologist M. DARROW Total Depth 10 feet
 Field Crew J. CLINE, P. LANIGAN, K. MAXWELL, S. PARKER, R. DAANEN, J. SIMPSON Equipment Type CME 850 Dates Drilled 9/19/2012 - 9/19/2012
 Weather ~35degF, light rain UTM N7524579, E381419
 TH Finalized By M. DARROW Vegetation wh. spruce, tea, alder, moss, lichen Elevation _____

Drilling Method	Depth in (Feet)	Casing Blows / ft	Sample Data				Frozen	Graphic Log	Ground Water Data		GENERAL COMMENTS: Location determined with handheld Garmin etrex GPS, UTM zone 6
			Method	Number	Blow Count	Sample Interval			N-Value	While Drilling	
S-S Auger	0										SUBSURFACE MATERIAL ORG MAT w/ roots, moss Gy Silty SAND w/ Gravel moist, moist to wet @ 3.0, mica silt, cold ROCK
	1										
	2										
	3										
	4										
	5										
	6										
	7										
	8										
	9										
10											

Drilling Notes: Installed 3/4" PVC w/ CS109s and matric pot1 sensors (@ 1.6, 3.3, 6.6, 9.8 ft bgs); backfilled w/ cuttings

NR AKDOT TEST HOLE LOG - USCS FDL-A, DALTON 219, GPJ NR, AKDOT, PRECON USCS 05_28_07.GDT 12/5/12

Note: Unless otherwise noted, all samples are taken with 1-3/8-in. ID Standard Penetration Sampler driven with 140 lb. hammer with 30-in. drop. CME Auto Hammer Cathead Rope Method



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FINAL TEST HOLE LOG

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Test Hole Number TH12-9004

NR AKDOT TEST HOLE LOG - USCS FDLA, DALTON 219 GPJ NR AKDOT PRECON USCS_06_28_07.GDT 12/6/12

Drilling Method	Depth in (Feet)	Casing Blows / ft	Method	Number	Blow Count	Sample Interval	N-Value	Frozen	Graphic Log	
	35	42	SS	12-2514	32					SUBSURFACE MATERIAL
	36	62			37					SAMPLE 12-2514 (34.5-36.5); SS Liner (to be tested); 50% recov, bent liner
	37	164			73					
	38	240								
	39	308								
	40	54	SS	12-2515	16					SAMPLE 12-2515 (39.5-41.5); SS Liner (to be tested); 125% recov (cuttings on btm), bent liner
	41	82			29					
	42	244			52					
	43	319			66					
	44	368								
	45	66	SS	12-2516	19					SAMPLE 12-2516 (44.5-46.5); SS Liner (to be tested); 100% recov., only drove 18", lg schist clast in shoe
	46	157			30					
	47	202			100					
	48	326								
	49	440								
	50	86	SS	12-2517	18					100% recov., only drove 18", clear ice coatings & random veins
	51	135			38					SAMPLE 12-2517 (50.5-51.0); NM 20.7%
	52	245			31					
	53	320								
	54	432								
	55	58	SS	12-2518	41					Gy Silty GRAVEL w/ Sand w/ Boulders w/ organics, chunks of wood, lg cobble/boulder 65.2-66.2
	56	50			43					
	57	58			62					
	58	57			100+					100% recov., peat frags, chunks of wood
	59	65								SAMPLE 12-2518 (56.0-56.5); NM 16.0%
	60	120			13					100% recov.
	61	192			19					
	62	273			35					
	63	288			39					
	64	340								
	65	83								
	66	85								
	67	101								Bn-Gy Silty SAND w/ Gravel w/ organics; pre-drilled 54.2-59.5, 64.5-92.0; drilling fluid turned dk Bn @ 76.5, wood chunks in cuttings 74.0-84.5; Gn-Gy 79.5-86.5
	68	87								
	69	81								
	70	60	SS SS	12-2520	12					SAMPLE 12-2520 (69.5-71.5); SM, 26.6% -200, LL NV, PI NP
	71	57		12-2519	15					100% recov., chunks of wood, clear ice veins
	72	59			24					SAMPLE 12-2519 (71.0-71.5); NM 15.8%
	73	61			30					Vol. WC 33%
	74	66								
	75									



FINAL TEST HOLE LOG



NR AKDOT TEST HOLE LOG - USCS FD-LA DALTON 218.GPJ NR AKDOT PRECON USCS.D6.28.07.GDT 12/6/12

Drilling Method	Depth in (Feet)	Casing Blows / ft	Method	Number	Blow Count	Sample Interval	N-Value	Frozen	Graphic Log		
Tri-cone & Casing	62										
	76										
	77	114									
	78	104									
	79	94									
	80	29		SS SS 12-2521 12-2522	10						
	81	26	23								
	82	26	18								
	83	19									
	84	17									
	85	16									
	86	22									
	87										
	88										
	89										
	90					100+					
	91										
	92										
	93										
	94										
	95										
	96										
	97										
	98										
	99										
	100										

SUBSURFACE MATERIAL

SAMPLE 12-2521 (79.5-81.5):
SS Liner (to be tested); 100% recov., bent liner, clear ice

SAMPLE 12-2522 (81.0-81.5): NM 18.2%
Vol. WC 33%

Gy BEDROCK, soft (white mica schist)
water pressure in rod @ 89.0

SAMPLE HABS (89.5-91.5): NM 6.3%
100% recov.

ROH

Drilling Notes: Heated drilling fluid to ~54 degF to break casing free; installed SI casing to 100.0, w/ thermistor string & 2 piezometers; backfilled with cement-bentonite grout, lost grout @ 25.0; installed Geodaq 9/22/12



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Northern Region Materials
Geology Section

FINAL TEST HOLE LOG

Sheet 1 of 2

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Project: Frozen Debris Lobe-A, Dalton Highway MP219 Test Hole Number: TH12-9005
 Field Geologist: M. DARROW Total Depth: 72 feet
 Field Crew: S. PARKER, P. LANGAN, K. MAXWELL, J. SIMPSON, K. DAANEN Equipment Type: CME 850 Dates Drilled: 9/28/2012 - 9/29/2012
 TH Finalized By: M. DARROW Weather: ~35degF, light rain UTM: N7524546, E381344
 Vegetation: wh. spruce, tea, alder, moss, lichen Latitude, Longitude: _____
 Elevation: _____

Drilling Method	Depth in (Feet)	Casing Blows / ft	Sample Data				Frozen	Graphic Log	Ground Water Data		GENERAL COMMENTS:
			Method	Number	Blow Count	Sample Interval			N-Value	While Drilling	
	0										SUBSURFACE MATERIAL Location determined with handheld Garmin etrex GPS, UTM zone 6, K. Maxwell logged 0-47.0 on 9/28/12; Subsequent SI readings indicate no BX at BOH
	1										
	2										
	3										
	4										
	5										
	6										
	7										
	8										
	10										
	11										
	12										
	13										
	14										
	15										
	16										
	17										
	18										
	19										
	20										
	21										
	22										
	23										
	24										
	25										
	26										
	27										
	28										
	29										
	30										
	31										
	32										
	33										
	34										
	35										

NR AKDOT TEST HOLE LOG - USCS 06 28 07 60T 12/6/12

Note: Unless otherwise noted, all samples are taken with 1-3/8-in. ID Standard Penetration Sampler driven with 140 lb. hammer with 30-in. drop. CME Auto Hammer Cathead Rope Method



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FINAL TEST HOLE LOG

Sheet 2 of 2

ALASKA UNIVERSITY TRANSPORTATION CENTER
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Test Hole Number TH12-9005

Drilling Method	Depth in (Feet)	Casing Blows / ft	Method	Number	Blow Count	Sample Interval	N-Value	Frozen	Graphic Log
H-S Auger	35								
	36								
	37								
	38								
	39								
	40								
	41								
	42								
	43								
	44								
	45								
	46								
	47								
	48								
	49								
	50								
	51								
	52								
	53								
	54								
	55								
	56								
	57								
	58								
	59								
	60								
	61								
	62								
	63								
	64								
	65								
	66								
	67								
	68								
	69								
70									
71									
72									

NR AKDOT TEST HOLE LOG - USCS, FDL-A, DALTON 219, GPJ, NR, AKDOT, PRECON, USCS, 06, 28, 07, GDT, 12/6/12

Drilling Notes: HS auger "dog-legged" @ 25.0 when reinstalled on Day 2; installed SI casing to 72.0, HS bit was lost down-hole; installed 1" tremie pipe with thermistor string to 52.0; backfilled with cement-bentonite grout through tremie



STATE OF ALASKA DOT/PF
Northern Region Materials
Geology Section

FINAL TEST HOLE LOG

ALASKA UNIVERSITY TRANSPORTATION CENTER
University of Alaska Fairbanks - INE



Project Frozen Debris Lobe-A, Dalton Highway MP219 Test Hole Number TH12-9006
 Field Geologist M. DARROW Total Depth 10.5 feet
 Field Crew S. PARKER, P. LANIGAN, K. MAXWELL Equipment Type CME 850 Dates Drilled 9/30/2012 - 9/30/2012
 Weather ~30degF, light snow UTM N7524502, E381129
 TH Finalized By M. DARROW Vegetation wh. spruce, alder, moss Latitude, Longitude
 Elevation

Drilling Method	Depth in (Feet)	Casing Blows / ft	Sample Data					Frozen	Graphic Log	Ground Water Data		GENERAL COMMENTS: Location determined with handheld Garmin etrex GPS, UTM zone 6
			Method	Number	Blow Count	Sample Interval	N-Value			While Drilling	After Drilling	
S-S Auger	0											SUBSURFACE MATERIAL ORG MAT Gy-Bn Sandy SILT w/ Gravel w/ Cobbles moist, varying to Bn-Gy, wet below 3.0; cuttings 35.2degF @ 4.0, 31.7degF @ 7.0 B.O.H.
	1											
	2											
	3											
	4											
	5											
	6											
	7											
	8											
	9											
	10											

Drilling Notes: Installed 1" PVC to 10.0 for later thermistor installation;
backfilled w/ cuttings

NR AK007 TEST HOLE LOG - USCS FDL-A, DALTON 219.GPJ NR AYDOT PRECON USCS 06_28_07.GDT 12/5/12

Note: Unless otherwise noted, all samples are taken with 1-3/8-in. ID Standard Penetration Sampler driven with 140 lb. hammer with 30-in. drop. CME Auto Hammer Cathead Rope Method

APPENDIX D: LABORATORY TESTING RESULTS

(Prepared for STATE OF ALASKA DOT&PF - NORTHERN REGION)
LABORATORY TESTING REPORT

PROJECT NAME: Frozen Debris Lobe A
LOCATION: Dalton Highway
SAMPLED BY: M. Darrow

TEST HOLE NO.	TH12-9000	TH12-9000	TH12-9000	TH12-9000	TH12-9001	TH12-9001	TH12-9002
DEPTH (feet)	1.0-6.5	6.2-6.5	11.0-11.5	18.0-18.5	2.5-3.0	10.0-10.2	6.0-6.5
STATION (LOCATION)	N7524488	N7524488	N7524488	N7524488	N7524313	N7524313	N7524307
OFFSET (feet)	E381121	E381121	E381121	E381121	E381160	E381160	E381161
LAB NO.	12-2500	12-2501	12-2502	12-2504	12-2505	12-2506	12-2507
DATE SAMPLED	17-Sep-12	17-Sep-12	17-Sep-12	17-Sep-12	18-Sep-12	18-Sep-12	18-Sep-12
% Passing							
3"							
2"							
1.0"	100.0						
Gravel 0.75"	98.4						
0.5"	95.0						
0.375"	90.2						
#4	74.7						
#8	63.0						
Sand #40	47.2						
#50	44.5						
#100	39.9						
Silt/Clay #200	36.1						
0.02	28.0						
Hydro 0.005	17.0						
0.002	12.0						
0.001	0.0						
LIQUID LIMIT	NV						
PLASTIC INDEX	NP						
USCS CLASSIFICATION	SM						
SOIL DESCRIPTION	SiSa w/Gr	SiSa w/Gr	(Bx-soft)	(Bx-soft)	(SaSi w/Gr)	(Bx-soft)	(SaSi w/Gr)
NATURAL MOISTURE		7.6	8.6	2.2	122.2	23.7	33.2
ORGANICS							
SP.GR. (FINE)	2.82						
SP.GR. (COARSE)							
MAX DRY DENSITY							
OPTIMUM MOISTURE							
L.A. ABRASION							
DEGRADATION FACTOR							
SODIUM SULF. (CRSE)							
SODIUM SULF. (FINE)							
REMARKS:							

(Soil descriptions shown in parantheses are based on field determinations.)

(Prepared for STATE OF ALASKA DOT&PF - NORTHERN REGION)
LABORATORY TESTING REPORT

PROJECT NAME: Frozen Debris Lobe A
 LOCATION: Dalton Highway
 SAMPLED BY: M. Darrow

TEST HOLE NO.	TH12-9002	TH12-9002	TH12-9004	TH12-9004	TH12-9004	TH12-9004	TH12-9004
DEPTH (feet)	11.5-12.0	16.0-16.5	21.0-21.2	31.0-31.5	50.5-51.0	56.0-56.5	71.0-71.5
STATION (LOCATION)	N7524307	N7524307	N7524572	N7524572	N7524572	N7524572	N7524572
OFFSET (feet)	E381161	E381161	E381423	E381423	E381423	E381423	E381423
LAB NO.	12-2508	12-2509	12-2512	12-2513	12-2517	12-2518	12-2519
DATE SAMPLED	18-Sep-12	18-Sep-12	19-Sep-12	19-Sep-12	20-Sep-12	20-Sep-12	21-Sep-12
% Passing							
3"							
2"							
1.0"							
Gravel 0.75"							
0.5"							
0.375"							
#4							
Sand #8							
#40							
#50							
#100							
Silt/Clay #200							
0.02							
Hydro 0.005							
0.002							
0.001							
LIQUID LIMIT							
PLASTIC INDEX							
USCS CLASSIFICATION							
SOIL DESCRIPTION	(SaSi w/Gr)	(SaSi w/Gr)	(SiSa w/Gr)	(SiSa w/Gr)	(SiSa w/Gr)	(SiGr w/Sa)	SaSi w/Gr
NATURAL MOISTURE	20.2	11.9	13.7	16.4	20.7	16.0	33.2
ORGANICS							
SP.GR. (FINE)							
SP.GR. (COARSE)							
MAX DRY DENSITY							
OPTIMUM MOISTURE							
L.A. ABRASION							
DEGRADATION FACTOR							
SODIUM SULF. (CRSE)							
SODIUM SULF. (FINE)							
REMARKS:							
(Soil descriptions shown in parantheses are based on field determinations.)							

(Prepared for STATE OF ALASKA DOT&PF - NORTHERN REGION)
LABORATORY TESTING REPORT

PROJECT NAME: Frozen Debris Lobe A
LOCATION: Dalton Highway
SAMPLED BY: M. Darrow

TEST HOLE NO.	TH12-9004	TH12-9004	TH12-9004	TH12-9005	TH12-9005	TH12-9005	
DEPTH (feet)	69.5-71.5	81.0-81.5	89.5-91.5	0.0-10.0	10.0-20.0	27.0-32.5	
STATION (LOCATION)	N7524572	N7524572	N7524572	N7524546	N7524546	N7524546	
OFFSET (feet)	E381423	E381423	E381423	E381344	E381344	E381344	
LAB NO.	12-2520	12-2522	HABS	12-2523	12-2524	12-2525	
DATE SAMPLED	21-Sep-12	21-Sep-12	21-Sep-12	28-Sep-12	28-Sep-12	28-Sep-12	
% Passing							
3"							
2"							
1.0"	100.0			100.0			
Gravel 0.75"	95.5			99.0	100.0	100.0	
0.5"	91.3			98.0	97.6	97.6	
0.375"	87.1			95.9	95.7	94.5	
#4	76.0			83.6	85.1	86.0	
Sand #8	64.5			68.0	70.5	71.2	
#40	39.0			44.2	49.8	50.2	
#50	35.3			39.5	45.4	45.0	
#100	30.4			33.5	38.0	39.5	
Silt/Clay #200	26.6			28.9	34.3	35.3	
Hydro 0.02	18.0			22.0	25.5	31.0	
0.005	9.0			13.0	11.0	12.5	
0.002	5.0			7.0	7.0	7.5	
0.001	0.0			0.0	0.0	0.0	
LIQUID LIMIT	NV			NV	NV	NV	
PLASTIC INDEX	NP			NP	NP	NP	
USCS CLASSIFICATION	SM			SM	SM	SM	
SOIL DESCRIPTION	SaSi w/Gr	(SaSi w/Gr)	(Bx-soft)	SiSa w/Gr	SiSa	SiSa	
NATURAL MOISTURE		18.2	6.3	28.0	40.0	24.6	
ORGANICS							
SP.GR. (FINE)	2.76			2.80	2.96	3.00	
SP.GR. (COARSE)							
MAX DRY DENSITY							
OPTIMUM MOISTURE							
L.A. ABRASION							
DEGRADATION FACTOR							
SODIUM SULF. (CRSE)							
SODIUM SULF. (FINE)							
REMARKS:							
(Soil descriptions shown in parantheses are based on field determinations.)							

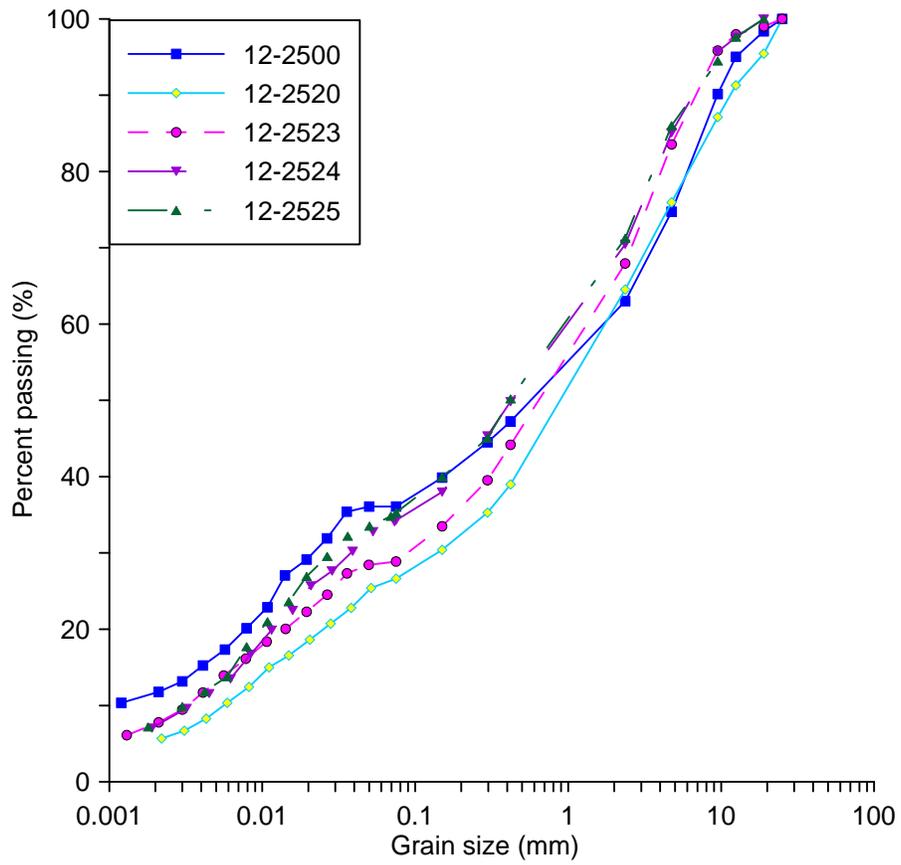


Figure D-1. Grain size distributions for the five samples tested from FDL-A.

Table D-1. Summary of instruments installed at FDL-A in 2012. Items listed below the double-line divider are part of the ADAS installations. Specifications for the temperature, water pressure, and matric potential sensors are given in units provided by the manufacturer. Quantities are provided in parentheses.

Parameter measured	Instrument model	Specifications
Temperature	Geokon Model 3800 thermistor string (3 strings)	Standard temperature range: -50 to 150°C Accuracy of thermistor beads: ±0.5°C
Temperature	Campbell Scientific (CS) CS109-L82 (15 sensors)	Temperature range: -50 to 70 °C Tolerance: ±0.2°C over 0°C to 70°C range
Water pressure	Geokon Model 4500C-350 kPa vibrating wire piezometer (2 piezometers)	Range: 0 to 350 kPa; Resolution: 0.05% FS Linearity: <0.5% FS; Accuracy: 0.1% FS Over-Range: 2 x FS; OD: 11.1 mm; Length: 165 mm Temperature range: -20°C to +80°C
Matric potential	Delmhorst 223-L82 (15 sensors)	Measurement range: 0.1 to 10 bars
	CS CR1000 datalogger (1)	
	CS CR800 datalogger (2)	
	CS CSC sonic ranging sensor (1)	
	CS SR50A mounting kit (1)	
	Vaisala weather sensor (1)	
	Right angle mounting kit (1)	
	10ft tripod w/ grounding kit (3)	
	Weather-resistant 16x18" enclosure (1)	
	Weather-resistant 14x16" enclosure (2)	
	50W solar panel (1)	
	10W solar panel (2)	
	12V power supply (2)	
	PS200 SDI-12 interface cable (2)	
	16 or 32 channel relay multiplexer (3)	
	CS 900MHz spread spectrum radio (3)	
	CS 900MHz 1dBd dipole antenna (3)	
	MorningStar SunSaver 10A 12V control regulator (1)	
	12V deep cycle batteries, 100 Amp-hour (4)	