GEOLOGIC AND GEOMORPHIC CHARACTERIZATION OF FROZEN DEBRIS LOBE CATCHMENTS ALONG THE DALTON HIGHWAY, SOUTHERN BROOKS RANGE, ALASKA

Spangler, E.[1], Hubbard, T.D.[1], Daanen, R.P.[1], Darrow, M.M.[2], Simpson, J.M.[2], and Southerland, L.[2]

1. Alaska Division of Geological & Geophysical Surveys, 3354 College Rd., Fairbanks, AK 99709
2. Mining and Geological Engineering Department, University of Alaska Fairbanks, Box 755800, Fairbanks, AK 99775

1. ABSTRACT

Frozen debris lobes (debris mass-movement features on permafrost slopes) are present along the Dalton Highway corridor in the southern Brooks Range, Alaska. Active downslope movement of these features presents potential hazards and geologic-engineering challenges to the highway as well as the adjacent Trans Alaska Pipeline System. To better characterize frozen debris lobes and assess their associated geologic hazards, we initiated a focused study along a 20-mile stretch of the Dalton Highway between Wiseman and Chandalar Shelf. Here we present observations of the bedrock geology and geomorphology of eight frozen debris lobe catchments, based on ArcGIS analysis of multi-date remotely sensed imagery and 2013 summer field work.

Preliminary results indicate that frozen debris lobes form in gullies, cored by less-competent material such as phyllite, slate, and chloritic schist and flanked by ridges of competent bedrock such as limestone, marble, metasandstone, and gneiss. Catchment areas are characterized by solifluction lobes, fractures, slumps, channels, standing water, permafrost, and minimal vegetative cover. Debris is contributed to the frozen debris lobes by a variety of slope processes, including solifluction, rockfall, slope failure, and runoff. Characterizing the geologic attributes of the catchment area is an important component to understanding the hazard potential of the frozen debris lobes. Our observations and results will provide new information useful for maintenance of current infrastructure and planning for future development in the corridor.

2. INTRODUCTION

In the south-trending Dietrich River Valley of the south-central Brooks Range of Alaska, USA, are a series of frozen debris lobes that pose potential geologic hazards and maintenance issues for transportation and resource infrastructure connecting Interior Alaska with the North Slope (Figure 1A). These frozen debris lobes are located along the Dalton Highway transportation corridor, the adjacent Trans Alaska Pipeline System, and a proposed natural gas pipeline about 40 km north of Wiseman (Figure 1B). The frozen debris lobes are actively sliding features and impacting infrastructure (Daanen et al., 2012; Darrow et al., 2012) (Figure 1C).

The Alaska Division of Geological & Geophysical Surveys (DGGS) and the University of Alaska Fairbanks, are conducting an ongoing evaluation of the geologic hazards associated with eight frozen debris lobes identified along a 30km stretch of the Dalton Highway (Figure 1B). These studies include the collection of multi-date differential GPS data to help understand the style and rate of frozen debris lobe movement (Daanen et al., 2012; Darrow et al., 2012), and a preliminary frozen debris lobe geologic hazards classification scheme (Hubbard, 2013). This study evaluates the geologic and geomorphic characteristics of the frozen debris lobe catchment areas which is an important component in understanding the hazard potential of the frozen debris lobes.

The objectives of this study are to:

1) Map bedrock geology at a large scale to improve our understanding of the lithologic variations in the bedrock geology.

2) Describe and document the geomorphology and active slope processes.

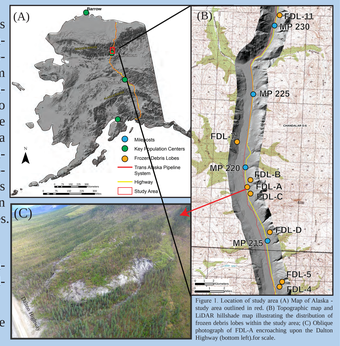

Figure 1. Location of study area (A) Map of Alaska - study area outlined in red. (B) Topographic map and LiDAR hillshade map illustrating the distribution of frozen debris lobes within the study area; (C) Oblique photograph of FDL-A encroaching upon the Dalton Highway (bottom left),for scale.

3. BACKGROUND

BEDROCK

The surficial and bedrock geology of the south-central Brooks Range has been previously mapped at scales of 1:250,000 (Brosgé and Reiser, 1964; Hamilton, 1978; Brown and Kreig, 1983) and 1:63,360 (Hamilton, 1979; Dillon et al., 1988; Dillon and Reifenstuhl, 1995). For the purposes of this study, larger scale, higher resolution geologic mapping of the frozen debris lobe catchments was needed to identify lithologic variations within the catchments to understand how those variations affect debris contribution to the frozen debris lobes.

GEOMORPHOLOGY

Hamilton (1978) was the first to recognize and map the frozen debris lobes as active lobate mass wasting features, which he called flow slides. Other authors mapped the frozen debris lobes as mostly inactive rock glaciers (Kreig and Reger, 1982; Brown and Kreig, 1983), glacial drift and morainal deposits (Brosgé and Reiser, 1964), and as undifferentiated colluvial deposits (Dillon, et al., 1988). Frozen debris lobes can be described as permafrost-regulated, actively moving, elongate, frozen mass movement features found on mountain slopes that are comprised primarily of frozen soil, rock, and debris. These features move down slope by a variety of gravity driven mechanisms, including permafrost creep, basal sliding, and active layer movement such as gelifluction and sliding of frozen slabs (Daanen et al., 2012; Darrow et al., 2012).

Figure 3. Bedrock ridge on the southern catchment boundary of FDL-11.

4. METHODS

ArcGIS was used to visualize and analyze multi-date remotely sensed imagery, including LiDAR-derived data such as DEMs, hillshades (Figure 2), slope maps, and contours; AHAP (Alaska High Altitude Photography); and satellite photography. Catchment area boundaries for each frozen debris lobe were delineated using the ArcGIS Watershed Spatial Analyst Tool and LiDAR DEMs.

Field work conducted during June and August of 2013 consisted of traversing ridges that defined catchment boundaries (Figure 3) in order to map geologic contacts and collect, describe, and identify rock samples. Catchment area geomorphology and active slope processes were visually identified during traverses and documented with GPS, photography, and videography. All collected field data (GPS points, photos, sample sites, and note locations) were managed in ArcGIS and Excel.

Catchment area geologic maps were digitized in ArcGIS. Multiple datasets were utilized in the generation of catchment area geologic maps, including existing geologic maps, field observations and rock sample identification and LiDAR-derived hillshades, contours, and slope maps. These data were used for refining placement of geologic contacts and to extrapolate contacts beyond observation points.

5. DATA & RESULTS

5.1. LiDAR IMAGERY

In 2011 DGGS acquired high resolution LiDAR data for an area of ~7,700 square kilometers along proposed natural gas pipeline routes (Hubbard et al., 2011). This LiDAR data encompasses many of the frozen debris lobe catchment areas adjacent to the Dalton Highway and provides a high resolution dataset useful for geologic mapping, especially in areas of heavy vegetation where access is difficult and aerial photography is ineffective.

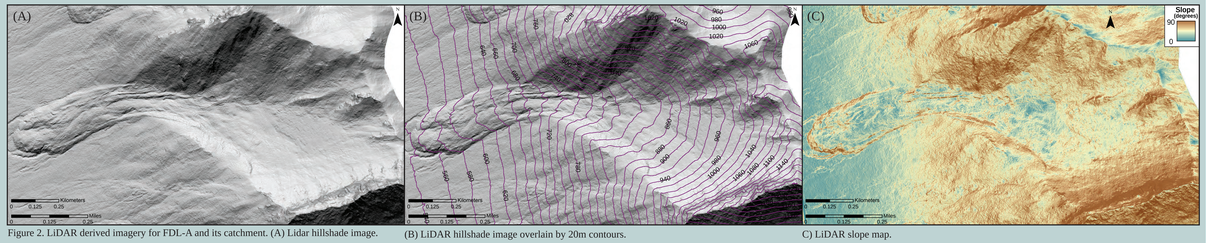

Figure 2. LiDAR derived imagery for FDL-A and its catchment. (A) Lidar hillshade image. (B) LiDAR hillshade image overlain by 20m contours. C) LiDAR slope map.

LEGEND

QUATERNARY DEPOSITS

- Qu — Undifferentiated Quaternary deposits.

DEVONIAN METASEDIMENTARY AND METAVOLCANIC ROCKS

- Dsp — Predominantly dark gray to black and brown slate and phyllite; subordinate interbedded graphitic phyllite and metasiltstone to metasandstone.
- Dls — Massive, dark gray limestone interbedded with thin, platy, black phyllite.
- Ds — Predominantly gray and black slate; subordinate phyllite.
- Dcsp — Predominantly interbedded platy, purple and green-blue chloritic schist and phyllite subordinate black to gray phyllite.
- Dbcp — Platy to massive, black to green metasiltstone to metasandstone.
- Dbp — Platy, brown to black phyllite; previously mapped as the Hunt Fork Shale (Hamilton , 1978; 1979; Dillon, 1988).

DEVONIAN IGNEOUS AND THERMALLY METAMORPHOSED ROCKS

- Dim — Platy, to massive, green to dark gray and black igneous and metamorphic calcium-rich rocks; previously mapped as diabase, gabbro, and diorite sills; and tremolite skarn, calc-silicate hornfels, and siliceous hornfels (Hamilton, 1978; 1979; Dillon, 1988).

LOWER PALEOZOIC METASEDIMENTARY ROCKS

- Ols — Platy to massive, brown and gray limestone.
- Op — Platy, black phyllite.
- Cgms — Interbedded platy to massive, gray-brown to green greywacke, metasandstone and metasiltstone.
- SCpm — Predominantly interbedded platy, brown to gray-black phyllite, metasiltstone, metasandstone and greywacke; subordinate slate.
- Catchment area boundaries

*Unit age designations based on previous geologic maps and reports (Brosge and Reiser, 1964; Hamilton, 1978; Dillon et al., 1988; Dillon and Reifenstuhl, 1995).

Point Load Index Test Results (Table 1)

Sample #	σc (psi)	σc (MPa)	FDL-#
1	7308.52	50.40	FDL-A
2	11210.87	77.32	FDL-B
3	4977.31	34.33	FDL-D
4	4762.68	32.85	FDL-D
5	3731.51	25.73	FDL-D
6	2207.61	15.22	FDL-D
7	2987.07	20.60	FDL-D
8	6637.44	45.78	FDL-D
9	7648.91	52.75	FDL-11
10	5844.50	40.31	FDL-11

The point load index test was used here to determine the uniaxial compressive strength of ten collected samples (Figures 4; 5; and 6). It should be noted, however, that the point load index test is not recommended for platy or weak rocks, and that most of the collected samples fall into this category. Given this caveat, these results do illustrate that all of the tested samples are fairly weak.

Point load index sample location

5.2. FDL- A, -B & -C

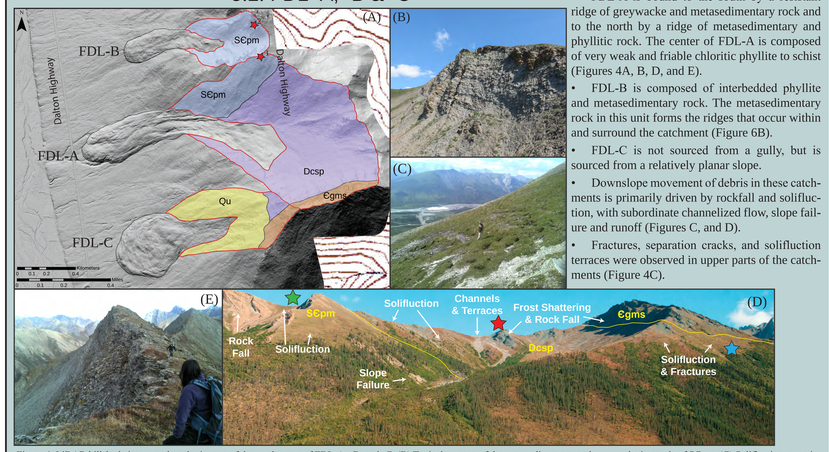

Figure 4. LiDAR hillshade image and geologic map of the catchments of FDL-A, -B, and -C. (B) Typical outcrop of the metasedimentary and greywacke intervals of SCpm. (C) Solifluction creep in unit SCpm. (D) Annotated photo of catchments of FDL-A (red star), FDL-B (green star), and FDL-C (blue star); geologic units are in yellow and geomorphic and active slope processes are labeled in white. (E) Walking the southern competent bedrock ridge of FDL-A, which is composed of unit Cgms.

- FDL-A is bound to the south by a resistant ridge of greywacke and metasedimentary rock and to the north by a ridge of metasedimentary and phyllitic rock. The center of FDL-A is composed of very weak and friable chloritic phyllite to schist (Figures 4A, B, D, and E).
- FDL-B is composed of interbedded phyllite and metasedimentary rock. The metasedimentary rock in this unit forms the ridges that occur within and surround the catchment (Figure 6B).
- FDL-C is not sourced from a gully, but is sourced from a relatively planar slope.
- Downslope movement of debris in these catchments is primarily driven by rockfall and solifluction, with subordinate channelized flow, slope failure and runoff (Figures C, and D).
- Fractures, separation cracks, and solifluction terraces were observed in upper parts of the catchments (Figure 4C).

5.3. FDL-D

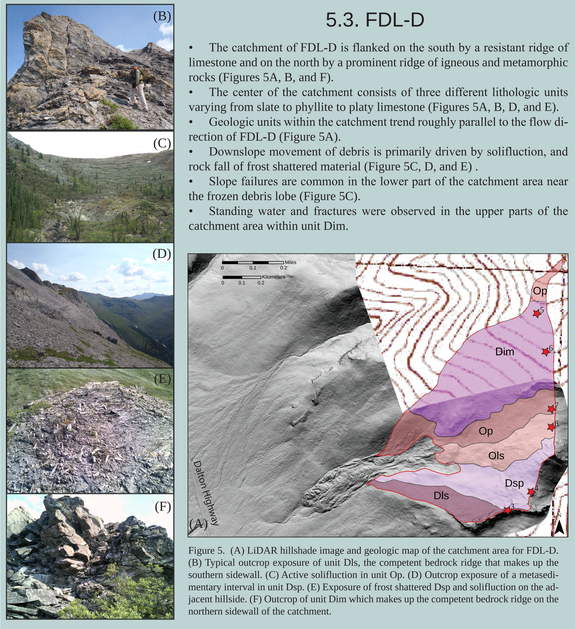

Figure 5. (A) LiDAR hillshade image and geologic map of the catchment area for FDL-D. (B) Typical outcrop exposure of unit Dls, the competent bedrock ridge that makes up the southern sidewall. (C) Active solifluction in unit Op. (D) Outcrop exposure of a metasedimentary interval in unit Dsp. (E) Exposure of frost shattered Dsp and solifluction on the adjacent hillside. (F) Outcrop of unit Dim which makes up the competent bedrock ridge on the northern sidewall of the catchment.

- The catchment of FDL-D is flanked on the south by a resistant ridge of limestone and on the north by a prominent ridge of igneous and metamorphic rocks (Figures 5A, B, and F).
- The center of the catchment consists of three different lithologic units varying from slate to phyllite to platy limestone (Figures 5A, B, D, and E).
- Geologic units within the catchment trend roughly parallel to the flow direction of FDL-D (Figure 5A).
- Downslope movement of debris is primarily driven by solifluction, and rock fall of frost shattered material (Figure 5C, D, and E) .
- Slope failures are common in the lower part of the catchment area near the frozen debris lobe (Figure 5C).
- Standing water and fractures were observed in the upper parts of the catchment area within unit Dim.

5.4. FDL- 11

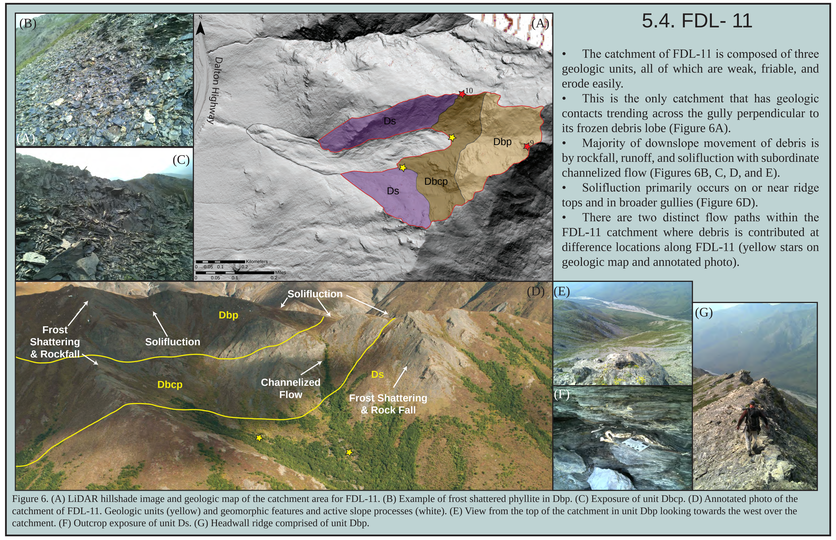

Figure 6. (A) LiDAR hillshade image and geologic map of the catchment area for FDL-11. (B) Example of frost shattered phyllite in Dbp. (C) Exposure of unit Dbcp. (D) Annotated photo of the catchment of FDL-11. Geologic units (yellow) and geomorphic features and active slope processes (white). (E) View from the top of the catchment in unit Dbp looking towards the west over the catchment. (F) Outcrop exposure of unit Ds. (G) Headwall ridge comprised of unit Dbp.

- The catchment of FDL-11 is composed of three geologic units, all of which are weak, friable, and erode easily.
- This is the only catchment that has geologic contacts trending across the gully perpendicular to its frozen debris lobe (Figure 6A).
- Majority of downslope movement of debris is by rockfall, runoff, and solifluction with subordinate channelized flow (Figures 6B, C, D, and E).
- Solifluction primarily occurs on or near ridge tops and in broader gullies (Figure 6D).
- There are two distinct flow paths within the FDL-11 catchment where debris is contributed at difference locations along FDL-11 (yellow stars on geologic map and annotated photo).

6. DISCUSSION

Geologic mapping revealed that three of the five catchments examined (FDL-A, -B, and -D) have geologic contacts that trend parallel to the long axis of the debris lobes (roughly E-W) and coincide with the steep resistant bedrock ridges of limestone, greywacke, metasedimentary and igneous rocks that make up the sidewalls of the catchment gullies. In the central and headwall parts of these catchments, between the resistant bedrock ridges, are geologic units comprised of less resistant, platy, and friable material such as chloritic schist, phyllite, and slate. The resistant bedrock ridges that make up the sidewalls confine the weaker, platier, and more friable units. Eroded debris within the catchments is generally focused towards the of the gully and converges between the confining ridges near the top of the frozen debris lobe.

In the FDL-11 catchment, geologic contacts trend perpendicular to the long axis of the frozen debris lobe (roughly N-S across the catchment) and near the headwall of the catchment is a contact between a more competent unit of phyllite and a less competent unit of metasiltstone and metasandstone (Table 1). Because FDL-11 is not confined by two ridges of resistant bedrock that focus eroded debris towards a central flow path within the catchment, there are two main flow paths within the overall catchment that contribute debris at different locations along the length of FDL-11.

Despite the differences in geologic units and variations in the nature of contacts between the examined catchments, all of the frozen debris lobes and their catchments have a key similarity: they are primarily sourced from, and occur in, geologic units where material is weak, platy, and friable relative to surrounding units.

Although solifluction creep occurs on or near most ridge tops, in areas where bedrock is composed of platy and friable material solifluction appears to be the main mechanism for downslope transport of debris. This is in contrast to areas of competent bedrock where frost shattered material is primarily transported downslope by rockfall and runoff processes.

7. SUMMARY

- Geologic mapping and geomorphic characterization of frozen debris lobe catchments was conducted at five frozen debris lobes located along the Dalton Highway Corridor.
- Catchments for FDL-A, -B, and -D are flanked to the north and south by ridges of resistent bedrock and have centers consisting of less resistent, platy, and friable rocks. In contrast, the catchment for FDL-11 is not flanked by ridges of competent bedrock, but instead a geologic contact near the catchment headwall separates more competent rocks upslope from less competent rocks that make up the catchment sidewalls. FDL-C is the only frozen debris lobe that is not sourced from a gully, but is sourced from a relatively planar slope.
- All of the examined frozen debris lobes are primarily sourced from and occur in geologic units where material is weak, platy, and friable relative to surrounding geologic units.
- Principal active slope processes transporting debris downslope include solifluction, rockfall, and runoff. Subordinate slope processes include channelized flow and slope failures.
- Solifluction creep occurs on or near most ridge tops, and is the foremost mechanism for downslope transport of debris derived from platy, weak, and friable bedrock.
- Rockfall and runoff are the primary mechanisms for downslope transport of frost shattered debris derived from competent bedrock ridges.
- Separation fractures and standing water occur in the upper parts of some catchment areas.

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9.THANKS...

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