Application of lidar to mapping geologic hazards along gas pipelines in Alaska

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1 Introduction

The Alaska Division of Geological & Geophysical Surveys (DGGS) is in the process of acquiring high-resolution lidar data within a 1-mile-wide corridor along the entire length of proposed natural gas pipeline corridors from Prudhoe Bay to the Canada border and from Delta Junction to Valdez. This data will complement our previous geologic mapping and other field efforts aimed at understanding of the location and types of geologic hazards that could potentially impact pipeline alignments and design.

Lidar data provides a means to perform improved analysis of the landscape and facilitates efficient identification and characterization of geologic hazards in regions where other methods have been ineffective due to rugged topography, limited access, dense vegetation, and inadequate imagery.

Here I present several relatively easy techniques that can be applied to lidar data in ArcMap that can be used to reveal subtle topographic features and assess geologic hazards. The focus here is on the evaluation of the Dot "T" Johnson fault at two sites, Sam Creek and Sears Creek, where previous trenching studies have uncovered evidence for several Holocene earthquakes (Carver et al., 2008; 2010). The techniques have also proven effective in assessing landslides, permafrost, flooding, and other hazards.

2 Tectonic setting and Dot "T" Johnson fault

North-northwest relative motion (~5.3 cm/yr) of the Pacific plate and Yakutat microplate and subduction beneath North American has resulted in a broad zone of compression and shear that extends over 500 km into the interior of Alaska. The Denali-Totchunda fault system accommodates part of this deformation by transpressive shear along the arcuate southern margin of the Alaska Range and was the source of the 2002 Mw=7.9 Denali fault earthquake. Geodetic, InSar, geochonologic, and paleoseismic studies indicate a right-lateral slip rate of ~9-14 mm/yr (Fletcher, 2002; Biggs et al., 2007; Matmon et al., 2006; Meriaux et al., 2009).

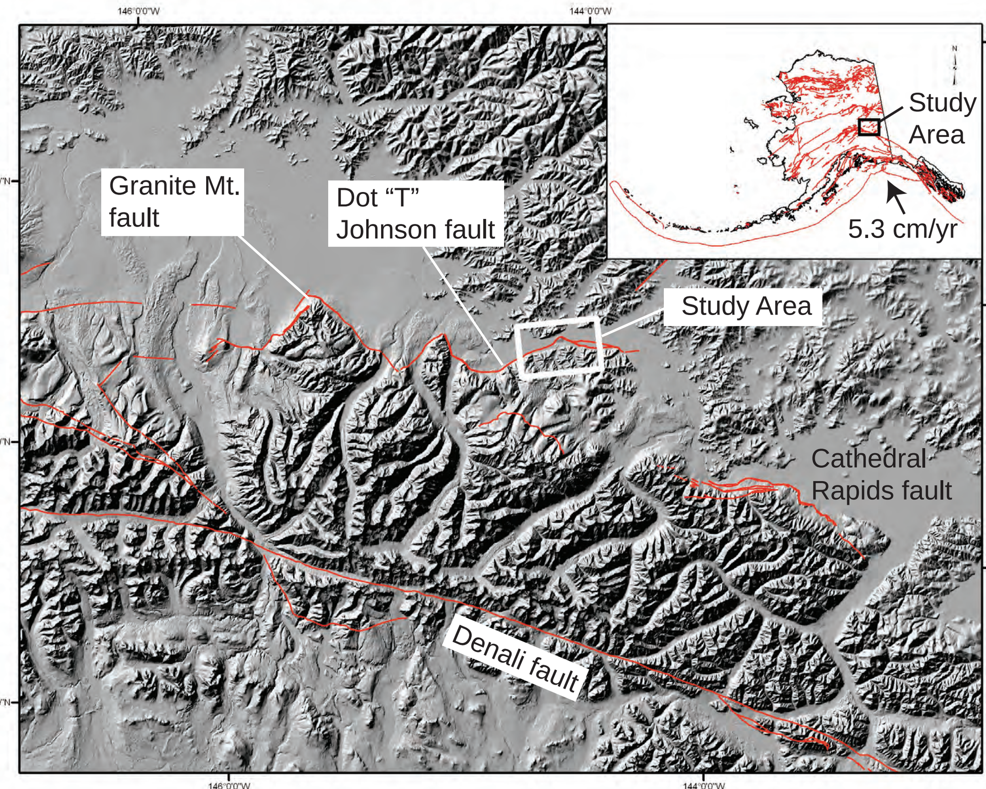
Drainages of the Nenana and Delta rivers flow north across the crest of the Alaska Range indicating that they are antecedent to regional uplift. The Pliocene Nenana Gravel outcrops on both sides of the range and was deposited by north flowing rivers (Wahrhaftig et al.,1969; Thoms, 2000; Ridgeway et al., 2007). Thus, in addition to shear along the Denali fault a compontent of compression is exerted across the Alaska Range and has played a significant role in the uplift of the range.

A system of south-dipping imbricate thrust faults bound the northern flank of the Alaska Range and are responsible for Quaternary active uplift and folding. West of the Delta River, the system comprises the Northern Foothills Fold and Thrust Belt (NFFTB), a 50-km-wide zone of east-west trending thrust faults that warp and displace late Neogene and Quaternary alluvial surfaces and fluvial terraces and have accommodated ~3 mm/yr of shortening since latest Pliocene time (Ridgway et al., 2002; Bemis, 2004; Carver et al., 2008). East of the Delta River faults of the system include the Donelley Dome, Granite Mountain, Canteen, Dot "T" Johnson, and Cathedral Rapids faults.

The Dot "T" Johnson fault is a south dipping thrust fault that extends ~80 km between Granite Mountain and Dot Lake. The fault is connected to the Donnelly Dome fault across the left-normal-oblique Granite Mountain fault and is interpreted to be the eastern extension of the Northern Foothills Fold and Thrust Belt.

Paleoseismic trenching studies and geologic mapping along the Dot "T" Johnson fault at Sears Creek and Sam Creek indicate that the fault is active and has experienced at least one latest Pleistocene and one Holocene earthquake (Carver et al., 2008; 2010). At Sears Creek, Carver et al. (2010) identified at least 3 m of dip slip displacement of fluvial gravels along a 12°-14° south dipping fault plane. The displacement event was estimated to have occurred more recently than 4,430-3,230 cal BP.

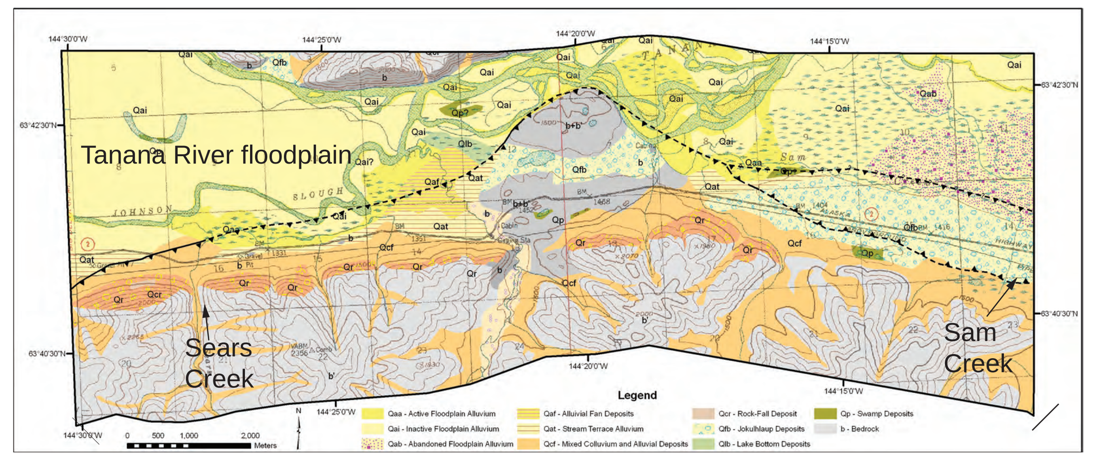
At Sam Creek, hanging wall deformation along a north dipping back thust has caused progressive deformation of a large outburst flood deposit of early Donnelly age (Reger et al., 2008-3a) and abandonment of the Sam Creek channel (Carver et al., 2010). Trenches near Sam Creek exposed south- and north-dipping, secondary conjugate thrusts in the hanging wall above a primary thrust, which consits of a low-angle zone of closely spaced micro-faults and shears (Carver et al., 2010). Radiocarbon analyses of charcoal in displaced deposits indicate the occurrence of an earthquake after 7,980-7,850 cal BP and several older latest Pleistocene events.



Hillshade of the Alaska Range showing the Denali fault and thrust faults that bound the north side of the range. Inset shows location of study area relative to Alaska and the distribution of faults. Only a fraction of these faults have been documented to have Quaternary deformation (See poster # 30-1 this session).

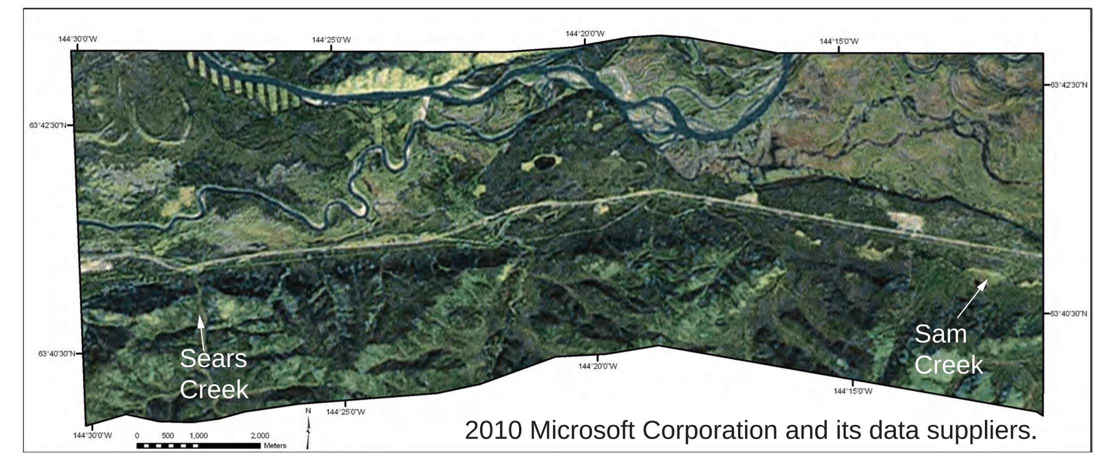
3 Map products derived from geologic mapping, commercial imagery, and lidar data in ArcGIS.

Surficial geologic map



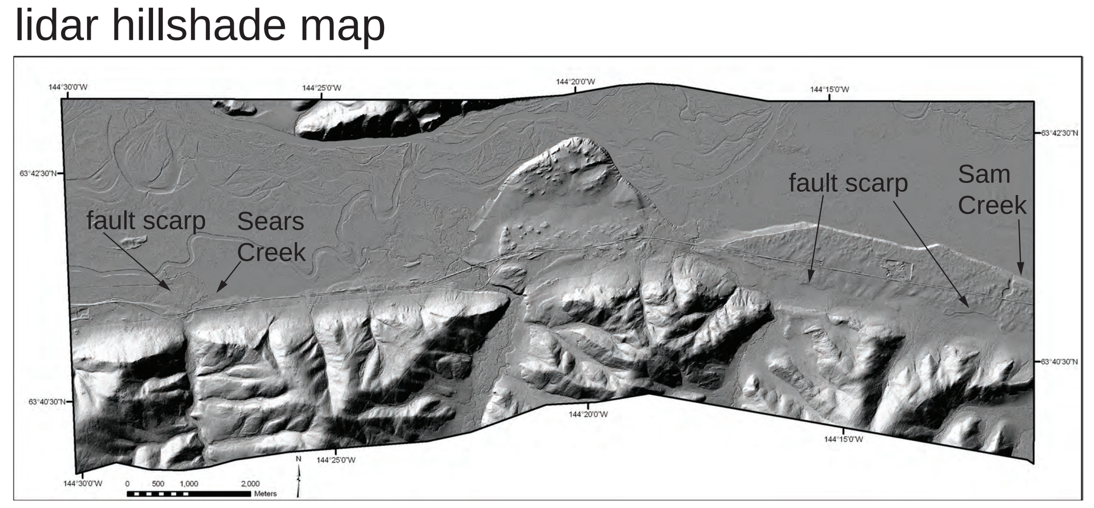
Geologic map along the Dot "T" Johnson fault modified from Reger et al., 2008-3a. Geologic mapping indicates that the trace of the fault has been eroded along the margin of the Tanana River floodplain.The fault cuts alluvial deposits and outburst flood deposits in the vicinity of Sears Creek and Sams Creek, respectively.

Aerial image



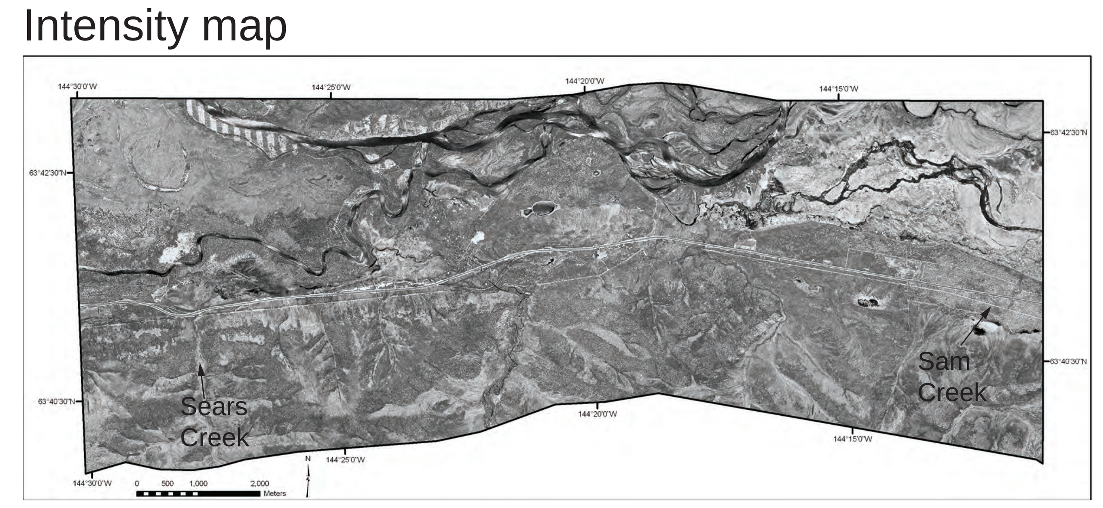
Available satellite and aerial imagery in Alaska lacks the necesary resolution to evaluate topographic features related to active tectonics. On-going efforts at the University of Alaska Fairbanks are underway to acquire and make publically available higher quality imagery. Although this imagery will provide a great resource, dense vegetation in some areas will remain problematic in assessing tectonic features obscured beneath the forest canopy. Lidar data can aleviate this problem by removing the vegetative cover illuminating the bare topography.

lidar hillshade map



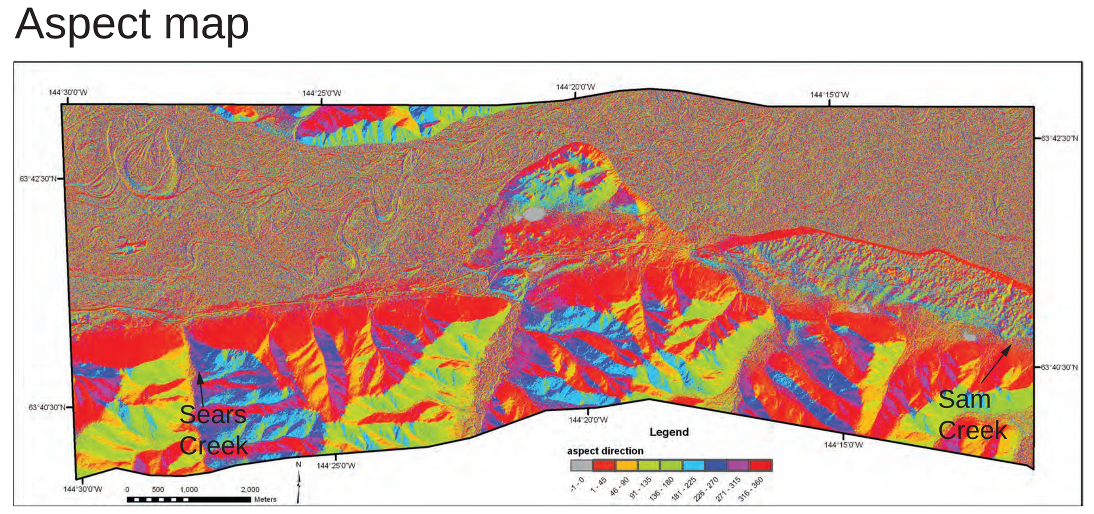
Bald earth hillshade models have become the industry standard base maps for pipeline design and construction, as well as neotectonic research. By interpreting hillshade models, steep terrain, landslides, floodplain configuration, areas of permafrost, and tectonic geomorphology can all be rapidly mapped and evaluated. In this map, fault scarps at Sears Creek and Sam Creek are easily recognizable.

Intensity map



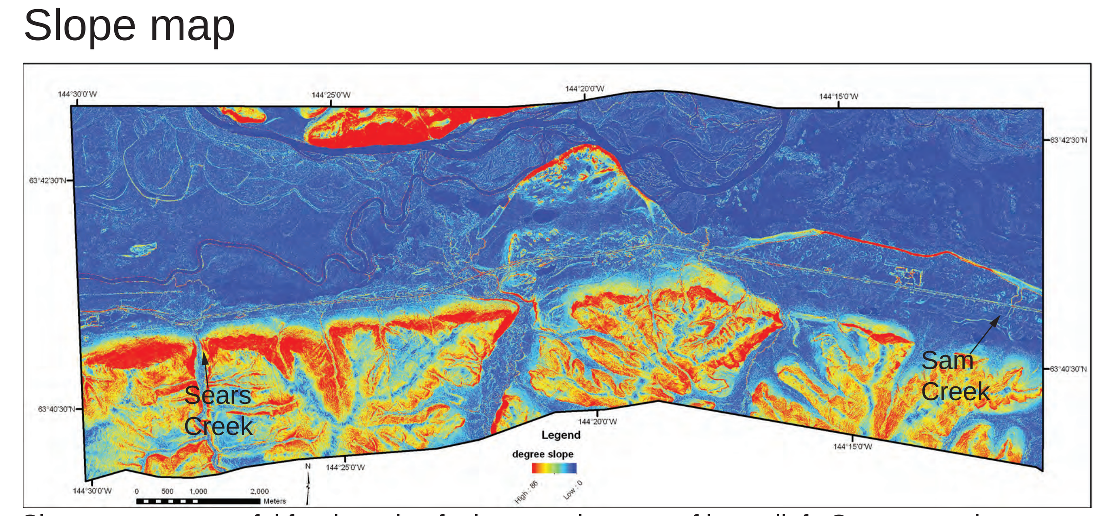
In areas with poor air photo coverage, intensity maps can be derived from lidar point cloud data. Intensity maps can highlight subtle differences in Quaternary geologic units and their surface reflectance intensities. The ease of creating intensity images in ArcMap allows the user to generate air photo "like" images rapidly over broad regions.

Aspect map



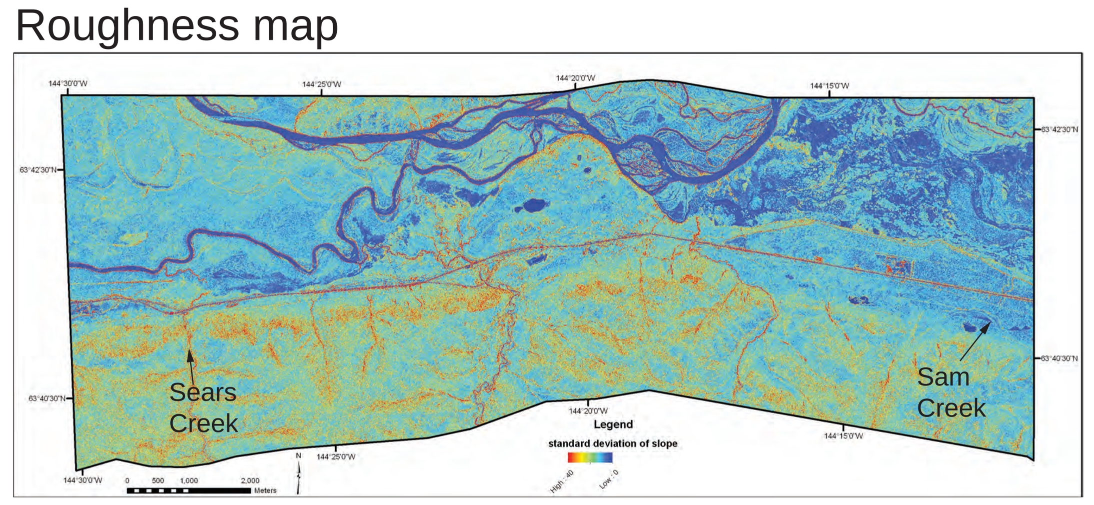
Aspect maps can be created to illuminate specific slope aspects. Here the color ramp supports our interpretation that the outburst flood deposit terrace at Sam Creek is warped on the hanging wall above a north dipping back thrust fault (See section 5, 3D view of Sam Creek).

Slope map



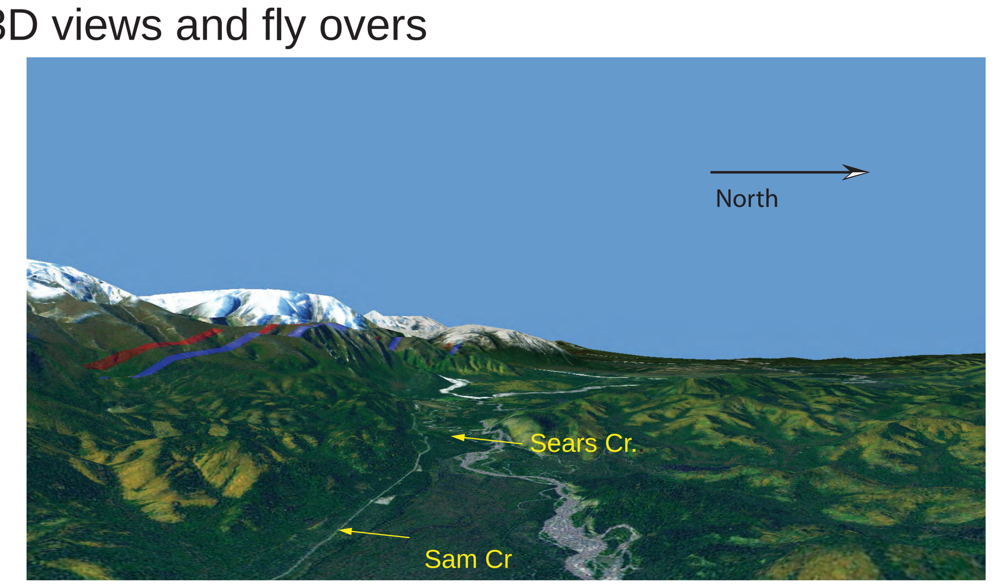
Slope maps are useful for detecting fault scarps in areas of low relief. Scarps may be expressed as lineations of bright color due to their significantly steeper faces as compared to the surrounding topography.

Roughness map



Estimates of surface roughness can be used to quantitatively compare alluvial deposits and aid in correlation, mapping, and assessment of relative age. The basic premise is that alluvial surfaces become smoother with increasing age and subtle differences in surface texture can be determined by averaging the slope over a set grid size. This roughness map was produced using the FocalStatistics tool in ArcMap and calculating the standard deviation of slope over a 3 X 3 m grid. The method was modified from Frankel and Dolan (2007).

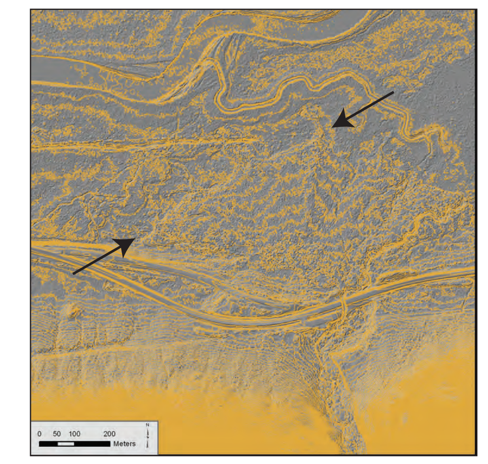
3D views and fly overs



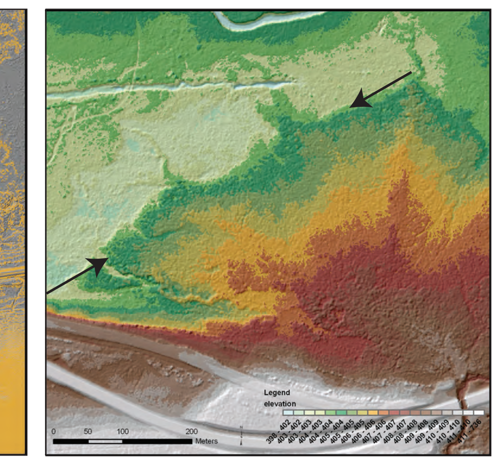
View west along the Dot "T" Johnson fault between Sam and Sears Creeks. Image produced in ArcGlobe using 60 m digital elevation model. 3D views and fly overs can be extremely useful in conveying geologic hazard observations to pipeline project engineers and managers. Images can be viewed from multiple angles to highlight specific features.

4 High precision topograpic maps, elevation color ramps, 3D views, bare earth models, and long profiles.

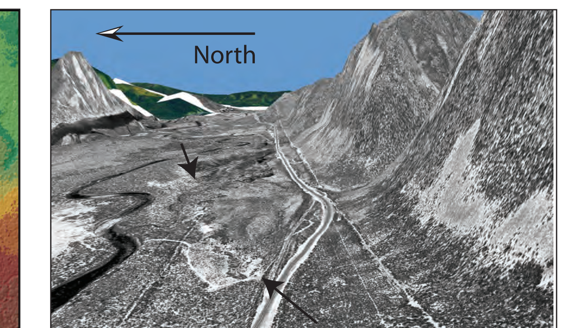
Sears Creek site

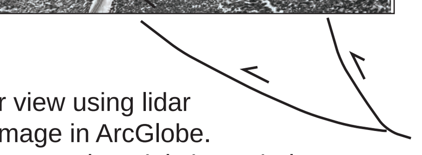


0.5 m contour map indicates the presence of fault scarp shown between arrows.



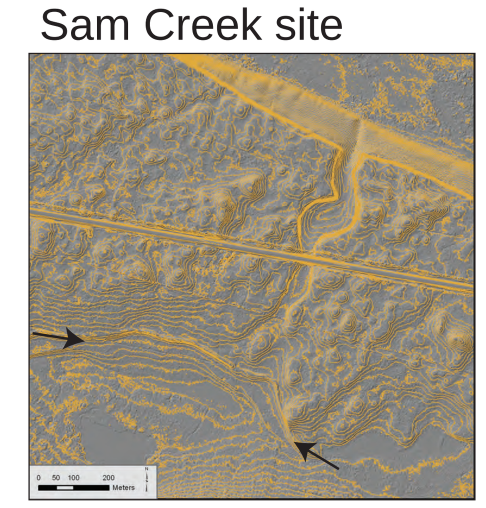
A hillshade map illustrates the contrast between the uplifted and warped alluvial fan and the undeformed floodplain to the north.



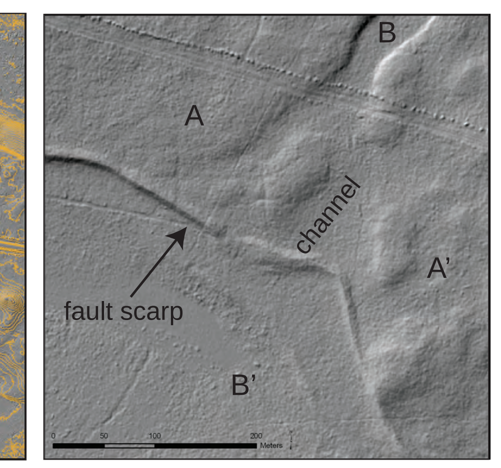


3D flyover view using lidar intensity image in ArcGlobe. Inferred structural model shown below image. Imbricate thrust faulting has created triangular facets along the range front and a Holocene fault scarp north of the range.

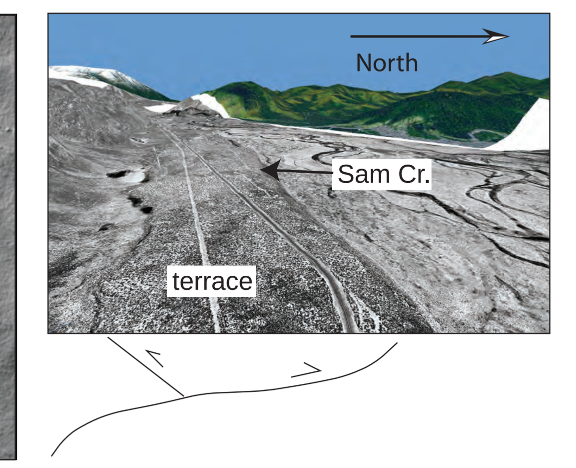
Sam Creek site



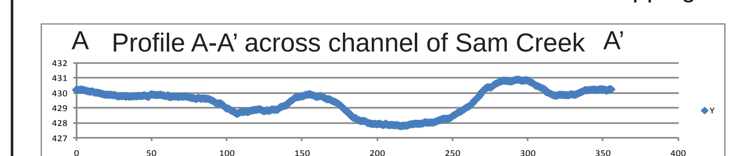
0.5 m contour map indicates the presence of fault scarp shown between arrows.

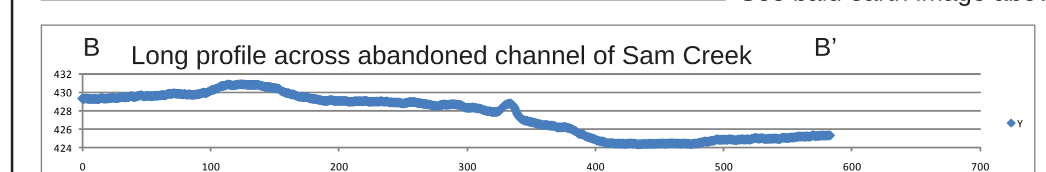


Bald earth hillshade of the Sam Creek site showing the abandoned channel of Sam Creek isolated by uplift on a north dipping backthrust.



3D flyover view using lidar intensity image in ArcGlobe. Inferred structural model shown below image. South-dipping thrust fault and north-dipping back thrust have warped an outburst flood terrace.





Detailed topographic profiles generated from lidar data in ArcMap. See bald earth image above for locations of profiles. Elevation and distance in meters.

5 Discussion

A variety of map products are now easily produced using ArcGIS and lidar data including bald earth, slope, aspect, intensity, and surface roughness maps. Analyses using these map products including generation of detailed contour and hillshade maps, evaluation of topography, and 3D views are valuable tools in mapping Quaternary deposits and assessing geologic hazards.

Slope and aspect maps are best utilized after some preliminary information is developed using bald earth models and field reconnaissance. This is because the slope and aspect maps can be manipulated to highlight particular features. For example, if a fault is determined to be east-west trending aspect maps can be modified to show north and south facing slopes which may reveal small scarps that were initially not recognized during initial investigation.

Advancements in lidar technology are now providing unprecedented opportunities to interpret the surface of the earth. However, the results presented here indicate that multiple methods should be applied to evaluate geologic hazards in a particular area. Detailed field studies are necessary to confirm interpretations based on lidar generated map products.

The analyses shown in this poster will be used to systematically evaluate geologic hazards over the entire proposed natural gas pipeline alignment from Prudoe Bay to the Canadian border and illustrate the potential to rapidly assess broad regions. The techniques are particularly well suited to assess geologic hazards in areas characterized by diverse geologic environments, limited access, and rugged terrain

These relatively new techniques have important implications to hazard assessment, as well as pipeline route selection and refinement, design, and construction in Alaska and around the world.

Acknowledgements

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