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Gary A. Carver[1], Sean P. Bemis[2,3], Diana N. Solie[2], Kyle E. Obermiller[2,4] and Ray J. Weldon[3]

ABSTRACT

During the 2006-07 field seasons we documented four Holocene faults in or near the proposed Trans-Alaska Gas Pipeline corridor between Delta Junction and Dot Lake. The Panoramic fault northwest of Granite Mountain trends northeast into the Tanana River valley. It has a 4-m-high west-side-up scarp in Holocene alluvium. Its linear trace and northeast orientation suggest it is mostly strike-slip.

The left-lateral Canteen fault trends northeast along the Little Gerstle River. The fault horizontally offsets Donnelly-age moraines 32 m and a Delta-age moraine 230 m. Assuming OIS stage 2 (~20 ka) and stage 6 (~180 ka) for the ages of the moraines, the fault's horizontal slip rate is 1.3 to 1.6 mm/yr. Trenches and pond sediment cores revealed at least three episodes of Holocene faulting. Two sigma ^{14}C ages of 4800-4627, 3206-2897, and 1370-1177 cal BP constrain the maximum ages of these faulting events.

The Dot "T" Johnson fault borders the south side of the Tanana River valley east of the Johnson River. West of Dot Lake the fault forms a mole track scarp on a deformed fluvial terrace. Trenches exposed a 20° south-dipping thrust and evidence of two faulting events, each with more than 3 m of dip-slip displacement. Maximum 2-sigma limiting ^{14}C ages for the events are 12,089-11,655 and 9287-9015 cal BP. The direction of tilting and sense of terrace offset suggest the fault is a back-thrust of a thrust wedge on a major south-dipping range-front fault, and an eastern extension of the Northern Foothills Fold and Thrust Belt.

The Billy Creek fault is north of the Tanana River along a northeast-trending topographic lineament. A trench across a southeast-facing scarp shows at least three faulting events represented by vertically offset colluvial wedges on a high-angle fault. The colluvial wedges lack evidence of periglacial reworking and thus presumably are Holocene.

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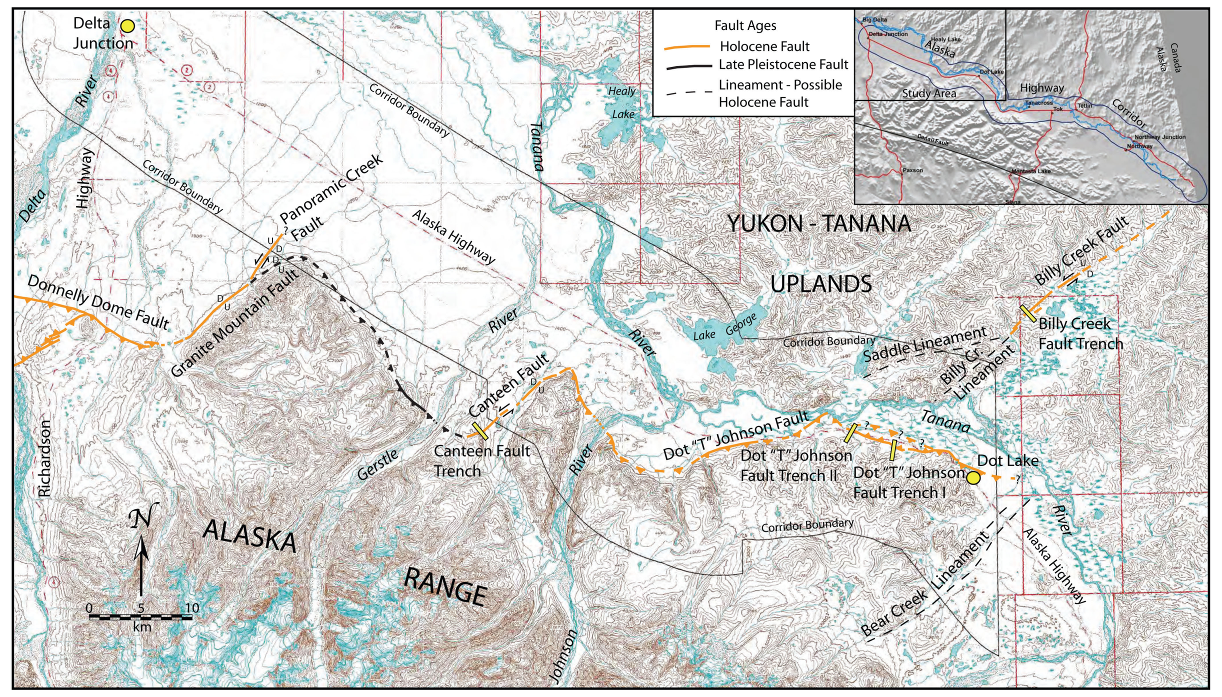

Figure 1. Active and potentially active faults in and near the Alaska Highway corridor study area. The field investigations for this study were conducted along the western part of the Alaska Highway corridor in the Tanana River valley and adjacent areas between Delta Junction and the village of Dot Lake. Four late Pleistocene and Holocene faults were documented. Trenches across three of these, the Canteen, Dot "T" Johnson, and Billy Creek faults, exposed the fault and offset late Pleistocene and Holocene stratigraphy that reflect multiple episodes of faulting. The Panoramic fault was not trenched, but measured profiles across the fault show the alluvial surface cut by the fault is vertically offset 2 to 3 m.

INTRODUCTION

The Alaska Highway Corridor, a 25 km wide 320 km long swath centered on the Alaska Highway in the Tanana River valley between Delta Junction and the Canadian border includes proposed routes for an Alaska-Canada natural gas pipeline, an extension of the Alaska Railroad through Canada, and other significant development in eastcentral Alaska (Solie and Burns, 2007). In order to allow informed decisions regarding these projects the State legislature in 2006 authorized the Alaska Division of Geological and Geophysical Surveys to conduct geologic assessments of the corridor including the potential for active faulting. This poster summarizes preliminary results of work to date regarding active faults and surface faulting potential in the western section of the corridor between Delta Junction and Dot Lake.

During the 2006 and 2007 field seasons, helicopter and fixed-wing reconnaissance augmented by interpretation of air photos, remote-sensed images, and aeromagnetic and electromagnetic (EM) data identified a number of linear geologic features in or near the corridor indicative of possible youthful surface faulting. Field studies, including ground reconnaissance and mapping, topographic profiling, trenching, coring and ^{14}C dating of surficial sediments on several of the lineaments resulted in documenting four faults with late Pleistocene and Holocene surface offset. Additional field investigation of the eastern section of the corridor is planned for 2008 and, contingent on continued State funding, 2009.

HISTORIC, HOLOCENE, AND LATE PLEISTOCENE FAULTS AND SHALLOW SEISMICITY IN THE TANANA RIVER VALLEY REGION OF ALASKA

Upper crustal seismicity in the Tanana River valley region includes many earthquakes west of the study area and modest seismicity along the Denali fault south of the corridor, but few earthquakes have been located in the corridor. The seismicity shown on the regional map is from the National Earthquake Information Center (NEIC) database for the period 1979 to 2002. In order to provide a view of the regional background seismicity we have not included the main shocks or aftershocks from the 2002 M 7.9 Denali fault earthquake sequence. Noteworthy is seismicity in the Northern Foothills region west of the study area that is similar to the northern slope of the Alaska Range adjacent to the corridor, and the northeast trending Minto Flats, Fairbanks, and Salcha seismic zones that produce left-lateral focal mechanism solutions.

The 2002 Denali Fault earthquake sequence generated surface displacement on the Susitna Glacier fault, the central section of the Denali fault, and the northern part of the Totschunda fault (Eberhart-Phillips et al., 2003). Surface displacement also occurred on part of the central section of the Denali fault in the vicinity of the Delta River in 1912 (Carver et al., 2004). No other historic surface faulting events are known in central Alaska.

Recent mapping in the Northern Foothills of the Alaska Range has identified a number of faults with late Pleistocene and Holocene displacement (Carver et al., 2006). The majority of these are relatively low-slip-rate thrust faults interpreted to accommodate regional north-south directed compression resulting from convergence of the Pacific plate and collision of the Yakataga block in southeast and southcentral Alaska with the North American plate north of the Denali fault.

In the study area we documented four faults with Holocene displacement. These are the Panoramic, Canteen, Dot "T" Johnson, and Billy Creek faults. The Dot "T" Johnson fault is a generally east-west-trending south-dipping low-angle thrust that borders the northern flank of the Alaska Range along the southern margin of the Tanana River valley. It is interpreted to be the eastern extension of the Northern Foothills thrust system. The Panoramic and Canteen faults are north-trending left-oblique-slip faults that join left-stepping segments of the Dot "T" Johnson thrust. The Billy Creek fault is a left-lateral strike-slip fault on the north side of the Tanana River valley. The fault has a northeast trend parallel to the Minto Flats, Fairbanks, and Salcha seismic zones.

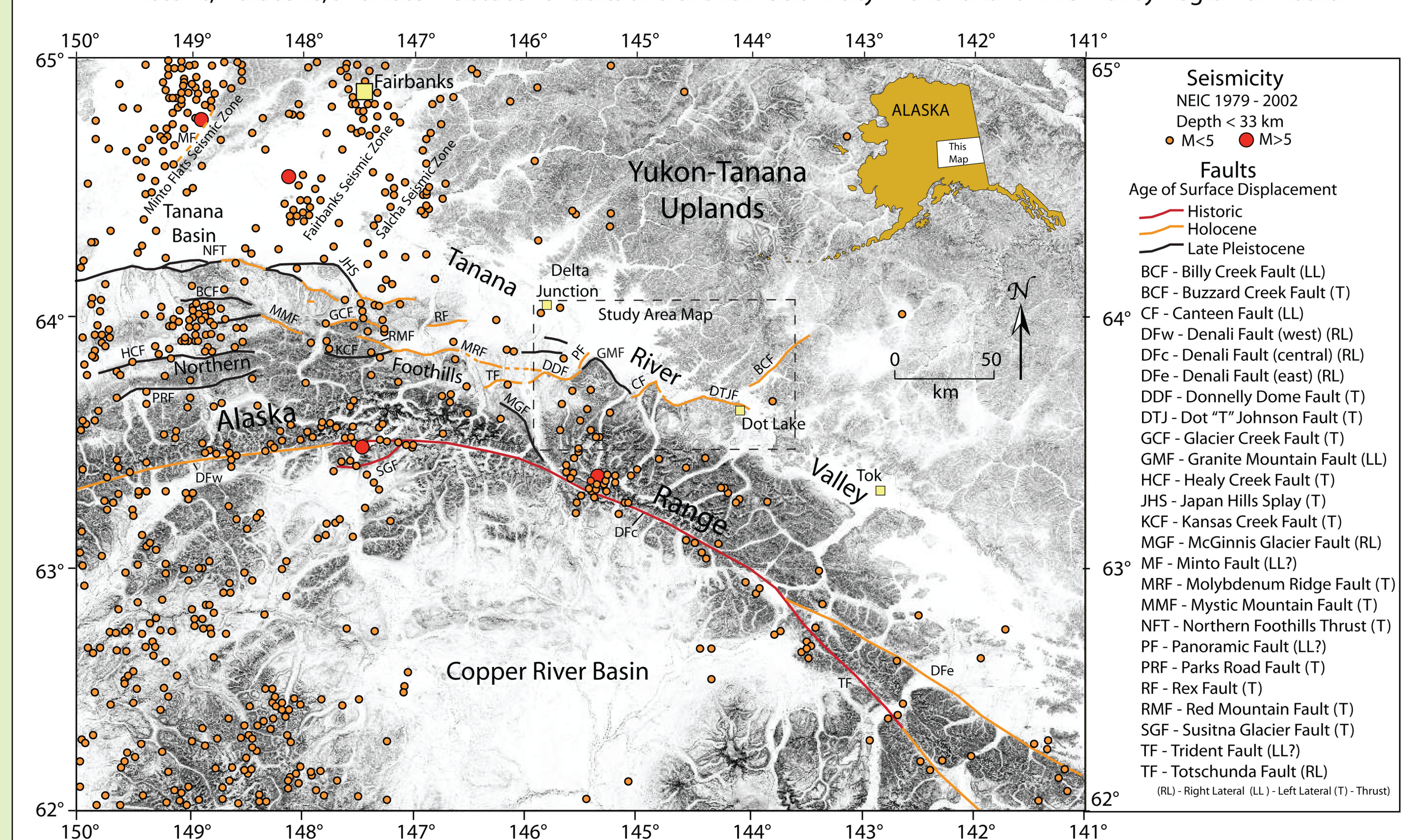

Figure 2. During the period 1979 to 2002, many upper crustal earthquakes were located in the region west of the study area, but in the vicinity of the Alaska Highway corridor shallow seismicity was sparse, with most earthquakes located in the foothills on the north flank of the Alaska Range. Three of the youthful faults documented in this study in and near the corridor, the Dot "T" Johnson, Canteen, and Panoramic faults, are interpreted to make up an eastern extension of the Northern Foothills Fold and Thrust Belt, a system of thrusts and associated strike-slip faults in the foothills of the Alaska Range west of the study area. The Billy Creek fault is interpreted to reflect left-lateral faulting driven by clockwise rotation of fault-bounded crustal blocks that make up the Yukon-Tanana Uplands.

BILLY CREEK FAULT

The Billy Creek fault trends northeast for at least 35 km along the linear Billy Creek valley and into the upper Mosquito Fork of the Fortymile River drainage. To the southwest, the Billy Creek fault may project into the Tanana river valley along the Billy Creek lineament or the Saddle lineament. The fault is marked by intermittent linear scarps, prominent vegetation lines, and linear drainage along most of its length. In the lower part of the Billy Creek valley southwest of T Lake the crest-lines of southeast-trending spur ridges cut by the fault are offset left-laterally and youthful appearing scarps up to 7 m high are east-facing on the south slopes and west-facing on north slopes of ridges. A trench across the fault southwest of T Lake exposed a steep west-dipping fault and several subsidiary strands cutting cobble-rich colluvium and interbedded fine-grained slope wash sediments and loess. Three distinct colluvial wedges separated by the fine-grained deposits were exposed in the trench. In the footwall the interbedded colluvial wedges and fine-grained sediments are rotated down toward the fault. The amount of rotation progressively increased in older layers.

No datable material was recovered from the trench. Weak A-C soil profiles a few 10's of cm thick were found at the surface and beneath the upper colluvial wedge. No evidence of cryoturbation or penetrative frost reworking of the deposits was evident in the trench. The lack of periglacial reworking of the sediments exposed in the trench, the poorly developed soils, and the steep scarp on the fault suggest the faulting is post-glacial and probably at least in part Holocene.

Figure 13. Oblique air photograph of the Billy Creek fault at the trench site. The northeast-trending fault forms a prominent scarp about 2 to 3 m high, marked by a vegetation contrast between trees to the northwest and tundra to the southeast, probably reflecting differences in shallow groundwater across the fault. The trench (covered by a white weather shelter) is in the upper right corner of the photograph. This area burned in a forest fire in 2004. The photograph was taken in 2007.

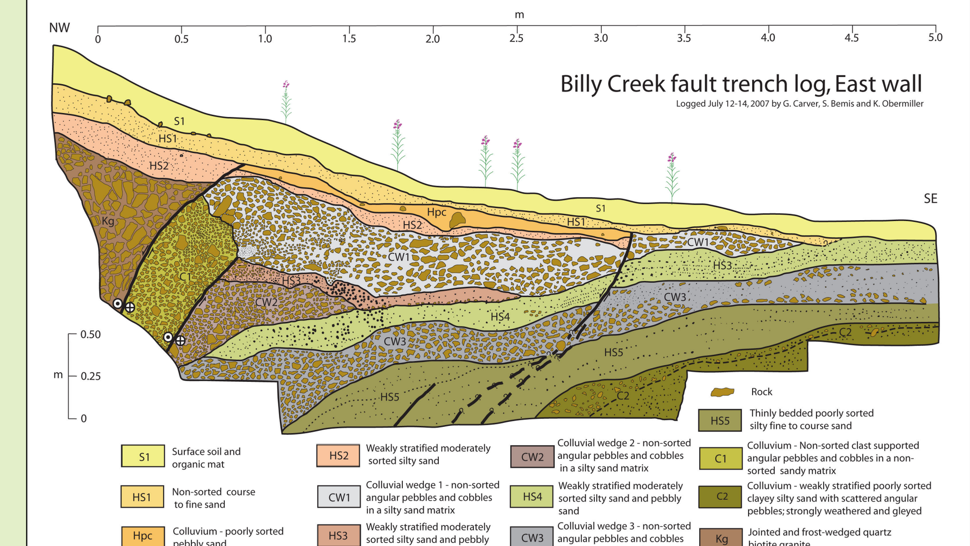

Figure 14. A trench across the Billy Creek fault exposed several high-angle left-lateral faults that offset cobble-rich colluvium and interbedded fine-grained eolian and slope-wash sediments. The cobble-rich colluvium forms three distinct colluvial wedges that lack soil development and evidence of periglacial reworking that are common in Pleistocene sediments in the non-glaciated region north of the Alaska Range. The lack of soils and periglacial reworking suggests a latest Pleistocene or Holocene age for the faulting.

DOT "T" JOHNSON FAULT

The Dot "T" Johnson fault is a south-dipping thrust at the base of the Alaska Range foothills bordering the south side of the Tanana River valley. It extends from Granite Mountain east at least as far as Dot Lake. The fault is marked by several segments separated by large left steps, including one at its western end where it is connected with the Donnelly Dome fault by the northeast-trending left-lateral Panoramic and Granite Mountain faults and another at the Little Gerstle River where the northeast-trending left-lateral Canteen fault connects the segments. In the field the fault is expressed by discontinuous scarps, truncated spur ridges and moraines, and vegetation lineaments at the base of the Alaska Range foothills.

West of Dot Lake the fault forms a conspicuous scarp along the south side of a large pop-up thrust wedge. Two trenches were dug across the fault in this section, one on the mole track scarp at the abandoned channel of Sam Creek, and a second about 4 km to the west across a steep 3- to 4-m-high south-facing scarp. Both trenches were excavated into loess-capped late Pleistocene fluvial terrace sediments deposited by the Tanana River, probably during Donnelly age jökulhlaup floods (Reger et al., 2008). The eastern trench, trench I, excavated across the mole track scarp, revealed a ~20° south-dipping thrust terminating upward into two deposits of collapsed fault tip rubble. The rubble grades into colluvial wedges that inter-fingered with the loess. Each wedge represents a faulting event that involved more than 3 m of dip-slip displacement. The bottom finger of loess and lower rubble deposit are dragged into a tight overturned syncline adjacent to the fault.

Two sigma ^{14}C ages of 12,870 - 12,690 cal BP (west wall) and 12,100 - 11,720 cal BP (east wall) from detrital charcoal in the top of the finger of loess underlying the lower colluvial wedge constrains the maximum age of the earlier faulting event. A charcoal age of 12,380 - 11,980 cal BP from the center of the overlying finger of loess constrains the minimum age of the earlier faulting event. The maximum age of the colluvial wedge produced by the more recent episode of faulting is limited by ^{14}C ages of 9740 - 9540 and 9290 - 9010 cal BP from charcoal in the uppermost part of the underlying loess. Its minimum age is unconstrained.

Trench II across the south-facing scarp ~ 4 km west of trench I also exposed a south-dipping low angle thrust. Bedded sand and silt in the hanging wall of the fault is tightly folded and locally disrupted into chaotic rubble. At the fault tip the hanging wall sediments are overturned. No datable material was recovered from this trench.

Figure 3. The mole track scarp on the Dot "T" Johnson fault at trench I viewed looking to the east. The scarp on this section of the fault exhibits a distinct "mole track" morphology indicative of a near-surface thrust wedge at the tip of a shallow-dipping thrust fault.

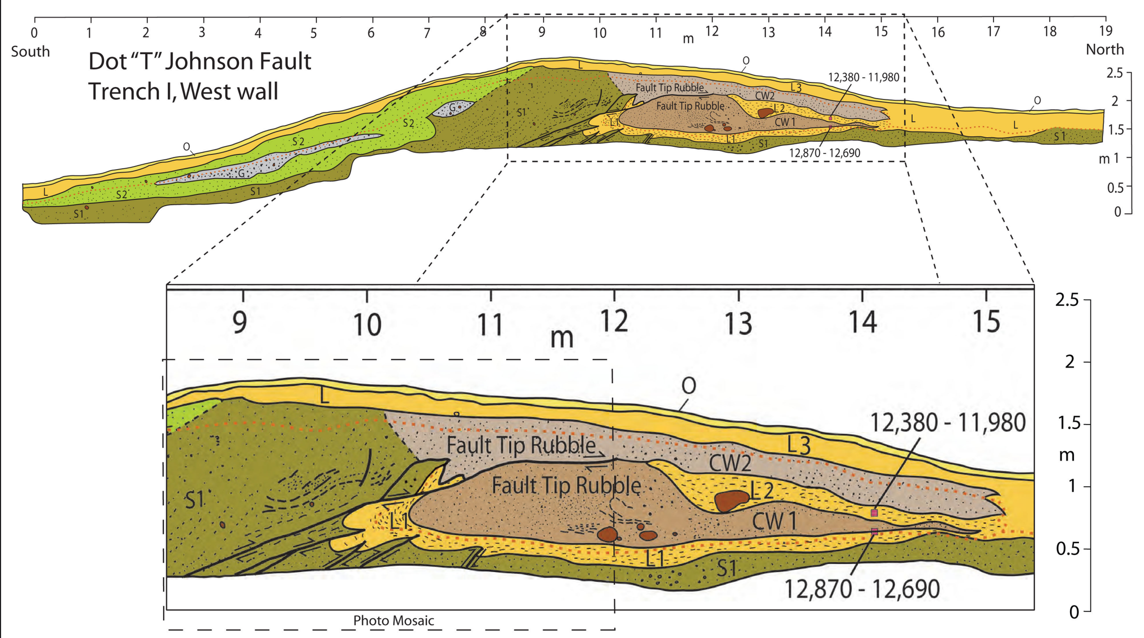

Figure 4. Log of the west wall of trench I on the Dot "T" Johnson fault with an enlarged section at the fault. Stratigraphy in the trench consists of stratified sand with gravel lenses overlain by loess. The trench exposed a shallow-dipping (~20°) thrust. Two faulting events are evident in the trench, each represented by fault tip rubble and an associated colluvial wedge which interfingers with the loess. In the foot wall of the fault the lower finger of loess and the overlying fault tip rubble have been dragged along the fault and are overturned. The timing of the two faulting events is constrained by a ^{14}C age of 12,870 - 12,690 cal BP from detrital charcoal at the top of the loess layer (L1) directly under the lower colluvial wedge, and a ^{14}C age of 12,380 - 11,980 cal BP from charcoal in the middle of the second loess layer (L2) between the two colluvial wedges.

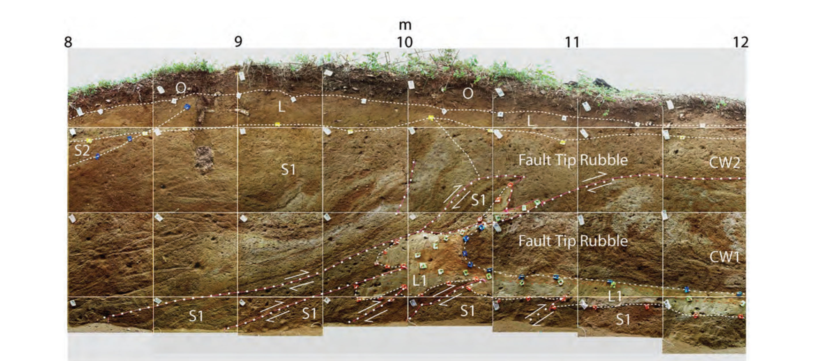

Figure 5. Photomosaic of the section of the west wall of trench I at the fault. The loess layer L1, offset by several small subsidiary thrusts, can be seen in the footwall of the fault. The top of the loess layer is iron-stained. The photomosaic clearly shows the faulted nose of the tight fold and overturning of the loess bed at the fault. Grid spacing on the trench wall is 0.5 m.

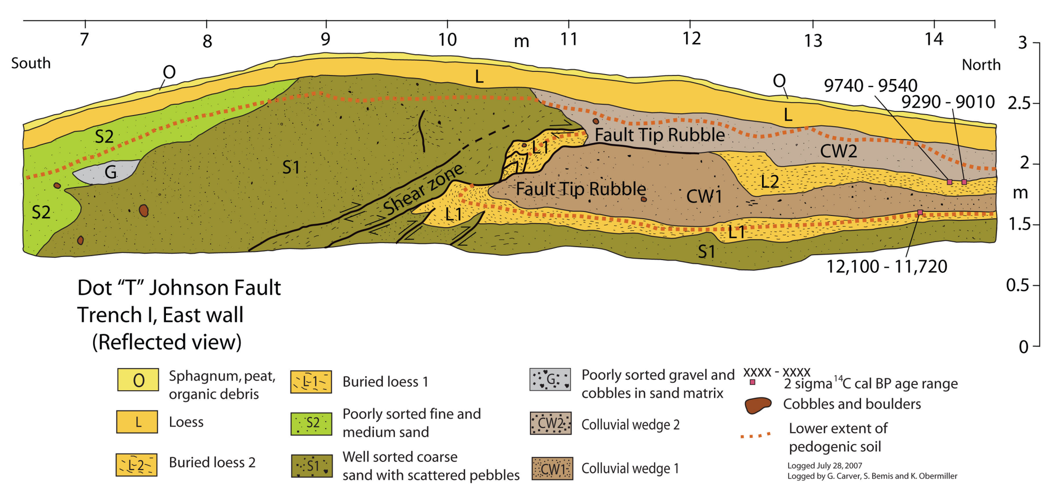

Figure 6. The east wall of trench I on the Dot "T" Johnson fault shows the same fault pattern as the west wall, and yielded additional ^{14}C ages of 12,100 - 11,720 cal BP from detrital charcoal at the top of the lower loess (L1) underlying the older colluvial wedge (CW1), and 9740 - 9540 and 9290 - 9010 cal BP from detrital charcoal at the top of the second loess layer (L2) between the two colluvial wedges.

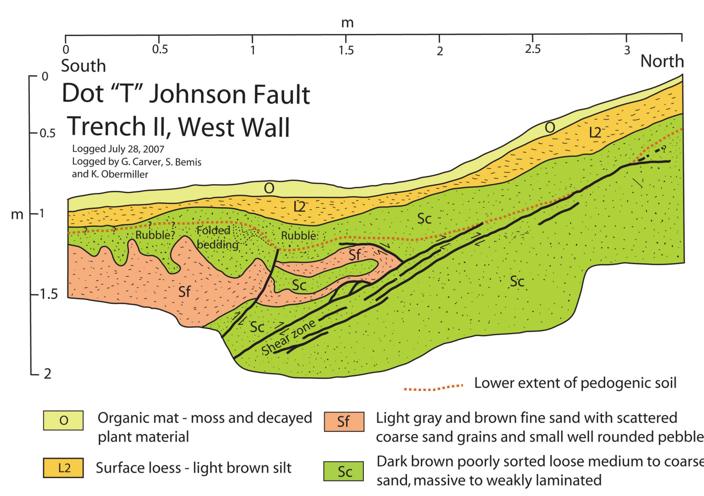

Figure 7. Log of the west wall of trench II on the Dot "T" Johnson fault. Trench II, about 4 km west of trench I, was excavated across a prominent down-to-the-south 3- to 4-m-high scarp. Like trench I, trench II exposed a south-dipping low-angle thrust indicative of a near-surface thrust wedge. The stratigraphy in the trench consists of stratified coarse sand in the foot wall, and fine to coarse poorly sorted sand and silt in the hanging wall. The sands are capped by loess. The sand and silt in the hanging wall are tightly folded and at the fault tip they are overturned. No datable material was found in the trench.

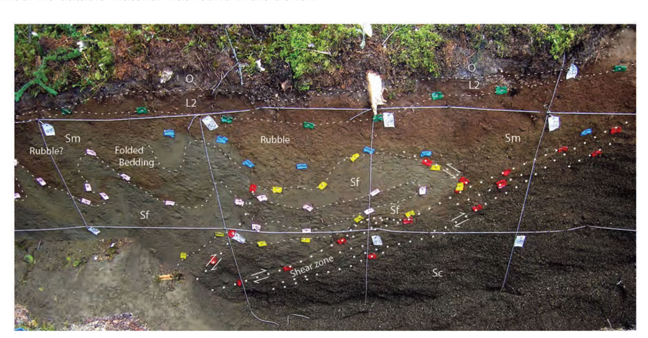

Figure 8. Photograph of the west wall of trench II on the Dot "T" Johnson fault. Grid spacing is 1 m.

CANTEEN FAULT

The Canteen fault is a northeast-trending left-oblique-slip fault that connects the eastern end of the monocline and thrust on the northeast flank of Granite Mountain with the west end of the Dot "T" Johnson fault where the range front steps to the left along the Little Gerstle River. Near its southwest end the Canteen fault offsets two well-defined sharp-crested lateral moraines of Donnelly age (Bemis, et al, 2005), one large Delta age lateral moraine and the west wall of the Little Gerstle River valley. The left-lateral offset of Donnelly moraines is 32 m. The age of the moraines, formed during the maximum extent of the Donnelly glaciation, is about 20 ka, resulting in a late Pleistocene-Holocene slip rate for the fault of 1.6 mm/yr. The slip rate over the longer interval represented by the offset Delta moraine is less well-constrained because the amount of offset of the Delta moraine is not well defined in the field; the moraine is largely absent in the Little Gerstle River valley on the south side of the fault. Assuming the Delta moraine south of the fault was located at the same place as the later Donnelly moraines its horizontal separation across the fault is about 230 m. We consider this to be a maximum estimate. The minimum horizontal separation of the Delta moraine, measured from the valley wall margin south of the fault is about 110 m. Additionally, the age of the Delta moraine is not well constrained. Previous estimates assigned the Delta glaciation to OIS 4 (~ 65 ka), OIS 6 (~180 ka) and even OIS 8 (~240 ka). Recent cosmogenic exposure dating by Young et al. (2007) of Delta moraines in the Delta River valley west of the study area and Fish Lake valley, east of the Canteen fault, indicate an OIS 4 age of ~ 65 ka. Assuming the OIS 4 age for the Delta Glaciation and the 230 m offset for the moraine, the fault's slip rate would be about 3.5 mm/yr, far greater than the rate derived from the offset Donnelly moraines. The OIS 6 age and 230 m offset yields a rate of 1.3 mm/yr. The 65 ka age (Young et al., 2007) and 110 m offset results in a slip rate of 1.7 mm/yr. We favor this latter interpretation.

The left-lateral offset of the upper Donnelly moraine produced a "shutter ridge" that impounded the local drainage and generated a pond and marsh over the fault. Analysis of sediments from an array of cores from the marsh show two fault strands with multiple episodes of displacement. ^{14}C ages from the cores place age constraints for the multiple events to less than about 8 ka with the most recent event(s) less than 1 to 4 ka.

A trench about 20 m east of the marsh exposed the main trace of the fault and three subsidiary fault strands that offset interbedded colluvium and loess. In the trench at least three faulting events are represented by the lateral termination of loess L2 and colluvium C2 by fault 1, the upward termination of fault 4 by colluvium C1, and the upward termination of faults 1, 2, and 3 at the base of the surface peat layer P1. A tephra in the surface peat, interpreted to be the northern lobe of the White River ash, circa 1500 - 1900 yBP (Lerbekmo et al., 1975), constrains the minimum age of the most recent displacement event. Two sigma ^{14}C ages of 4800 - 4660 and 3200 - 2950 cal BP (earliest displacement event(s), 2960 - 2780 cal BP (penultimate event) and 2300 - 1180 cal BP (most recent event) provide maximum age limits for the faulting.

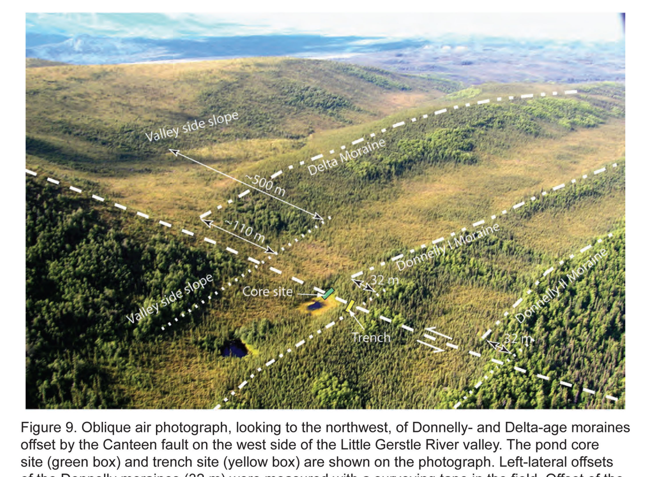

Figure 9. Oblique air photograph, looking to the northwest, of Donnelly- and Delta-age moraines offset by the Canteen fault on the west side of the Little Gerstle River valley. The pond core site (green box) and trench site (yellow box) are shown on the photograph. Left-lateral offsets of the Donnelly moraines (32 m) were measured with a surveying tape in the field. Offset of the Delta moraine (~110 m) was determined from a GPS survey. The offset of the side slope of the river valley (~500 m) was estimated from a vertical air photo.

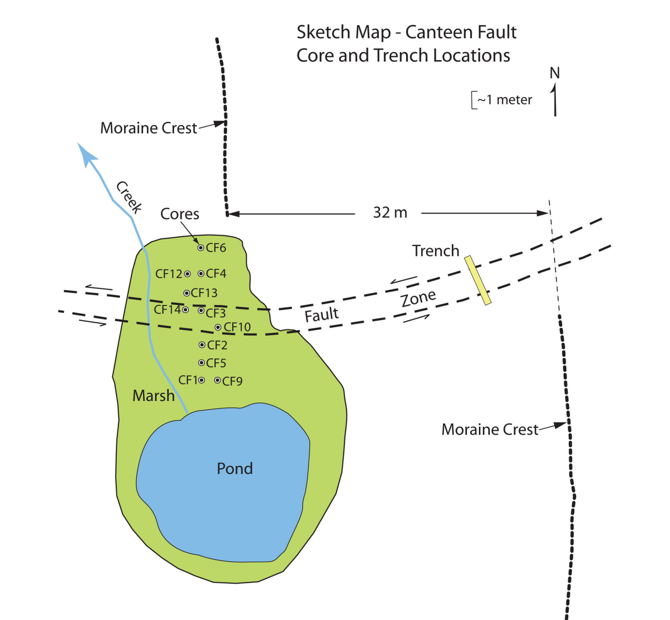

Figure 10. Sketch map showing the location of the trench and the array of cores across the Canteen fault that were obtained from the pond and adjacent marsh impounded by a shutter ridge formed by the offset Donnelly moraine.

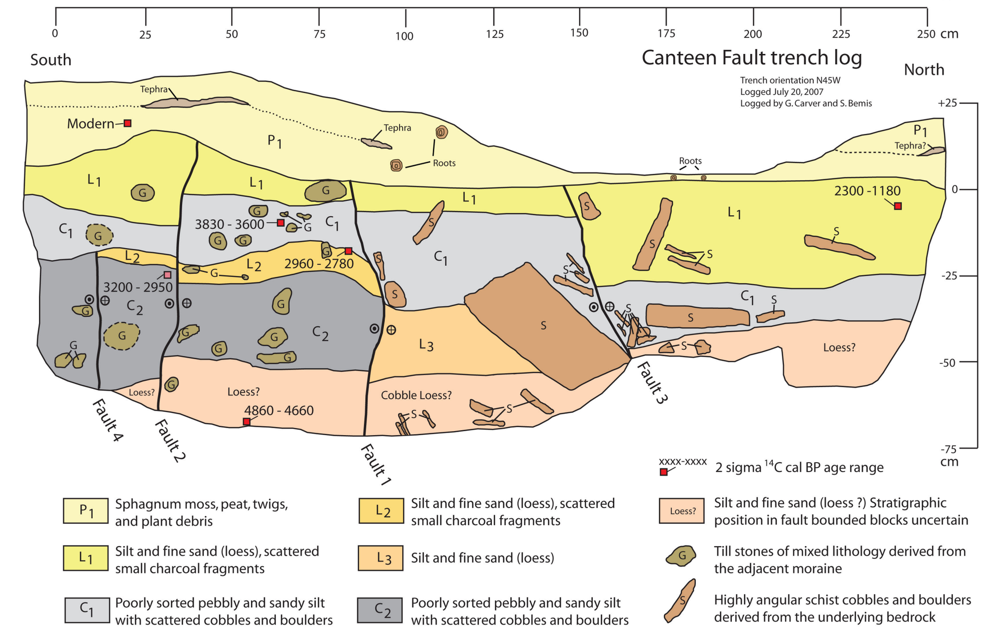

Figure 11. Log of a small trench across the Canteen fault at the offset moraine site. Stratigraphy exposed in the trench, excavated by hand in frozen ground, consists of layers of eolian silt and fine sand interbedded with colluvium. Fault 1, the main fault strand, juxtaposes colluvium exposed in the north section of the trench that contains only large angular clasts of schist derived from the local bedrock against colluvium in the south section that contains only rounded and sub-rounded till stones derived from the moraine. At least three faulting events can be interpreted from the trench. The event(s) generated lateral terminations of colluvium C2 and loess L2 at fault 1. Another episode of faulting is represented by the upward truncation of fault 4 by layer C1 that is more recent than layers C2 (3200 - 2950 cal BP) and L2 (2960 - 2780 cal BP) and predates layers C1 and L1 (2300 - 1180 cal BP). More recent faulting offsets layer L1 on faults 1, 2 and 3. The base of the surface peat P1 that contains a tephra, interpreted to be the circa 1500 - 1900 yBP White River ash postdates the most recent surface rupture. The apparent inverted age for layer C1 (3830 - 3600 cal BP) is interpreted to reflect reworking of older charcoal into the colluvium.

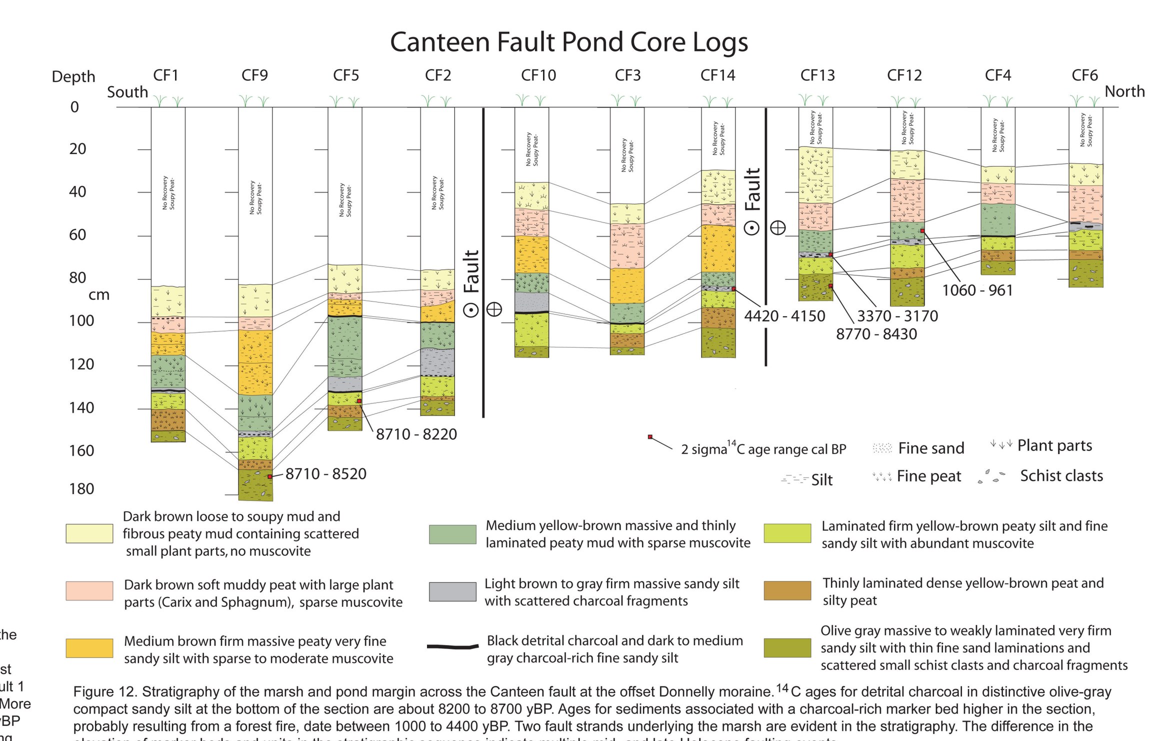

Figure 12. Stratigraphy of the marsh and pond margin across the Canteen fault at the offset Donnelly moraine. ^{14}C ages for detrital charcoal in distinctive olive-gray compact sandy silt at the bottom of the section are about 8200 to 8700 yBP. Ages for sediments associated with a charcoal-rich marker bed higher in the section, probably resulting from a forest fire, are between 1000 to 4400 yBP. Two fault strands underlying the marsh are evident in the stratigraphy. The difference in the elevation of marker beds and units in the stratigraphic sequence indicate multiple mid- and late Holocene faulting events.

PANORAMIC FAULT

The Panoramic fault branches from the Granite Mountain fault on the northwest side of Granite Mountain, and displaces a broad alluvial plain composed of late Pleistocene outwash and Holocene alluvium on the south side of the Tanana River valley. Profiles surveyed across the fault show the alluvial surface is vertically offset up on the valley side 2 to 3 m. The Panoramic fault and its associated Granite Mountain fault join the Holocene Donnelly Dome fault and a poorly defined thrust and large late Cenozoic monocline that form the northeast flank of Granite Mountain.

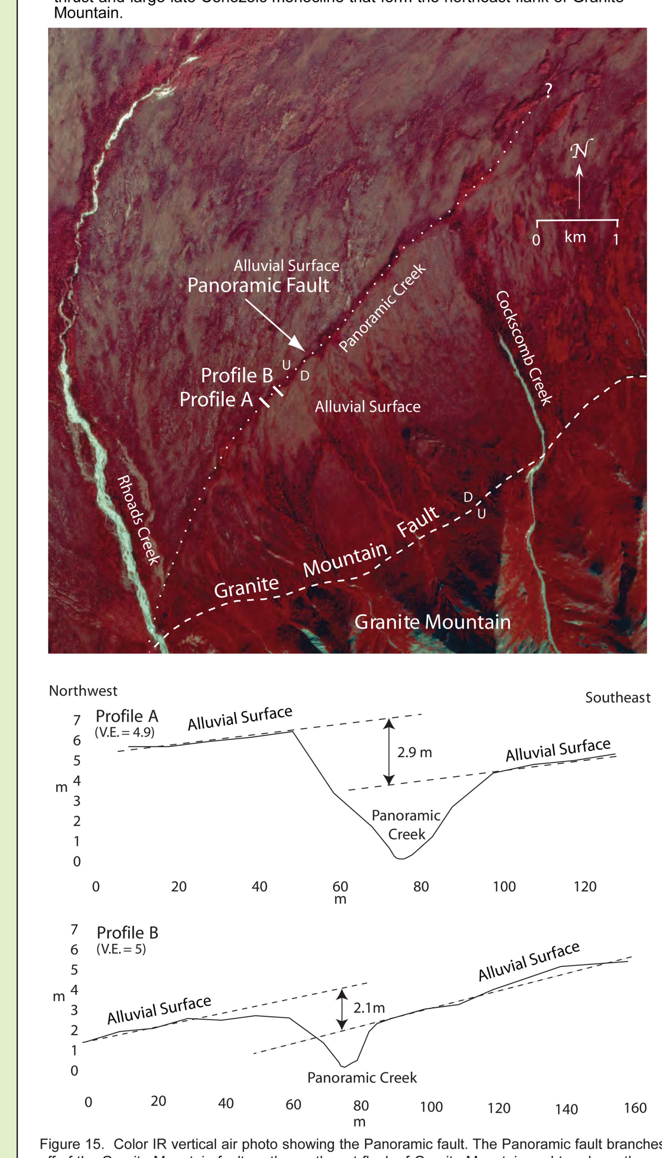

Figure 15. Color IR vertical air photo showing the Panoramic fault. The Panoramic fault branches off of the Granite Mountain fault on the northwest flank of Granite Mountain and trends northwest across a broad alluvial surface of the Tanana River valley. Two profiles of the surface across the fault show about 2 to 3 m of valley-side-up displacement. The linearity of the fault and its northeast trend suggest it has a significant left lateral component.

APPLICATION

Mapping and paleoseismic field investigations of potential active faults in and near the western part of the Alaska Highway corridor by the Alaska Division of Geological and Geophysical Survey in 2006 and 2007 has documented late Pleistocene and Holocene displacements on the Panoramic, Canteen, Dot "T" Johnson, and Billy Creek faults. These faults constitute potential surface faulting hazards to proposed development in the corridor and may be future sources of locally generated strong ground motion and associated seismic hazards including earthquake generated liquefaction and seismically triggered slope failures. To ensure seismic hazards associated with the faults documented in this study are appropriately mitigated, additional detailed regional and site specific studies will be required to develop the information necessary for the routing, design, construction, and operation of future facilities in the Alaska Highway corridor including the proposed Alaska-Canada natural gas pipeline and the Alaska Railroad through Canada.

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