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ACTIVE AND POTENTIALLY ACTIVE FAULTS ALONG THE ALASKA HIGHWAY CORRIDOR, TETLIN JUNCTION TO THE CANADA BORDER

by
Rich D. Koehler and Gary A. Carver

Rolling hills and fireweed along the Caribou Creek lineament, northeast of Tetlin Junction, Alaska. Photo by Rich D. Koehler.

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Rich D. Koehler[1] and Gary A. Carver[2]

Abstract

Helicopter and field reconnaissance surveys to assess seismic hazards along the Alaska Highway corridor between Tetlin Junction and the Yukon (Canada) border were conducted by the Alaska Division of Geological & Geophysical Surveys. Faults previously identified as having "suggestive or suspicious" evidence of Quaternary deformation were evaluated, including the Dennison Fork, Caribou Creek, Midway Lake, Northway Junction, and Airs Hills faults, and the Tetlin Lake and Ladue River lineaments. The results indicate that all of the faults are characterized by mature to absent geomorphic expression, lack features indicative of Holocene and/or Quaternary deformation, and should not be considered active faults in future hazard assessments. We speculate that the locus of active deformation follows the southeast curvature of the Alaska Range and Denali fault and is concentrated south of the Alaska Highway.

INTRODUCTION

The Alaska Highway corridor between Delta Junction and the Yukon Territory border has been the focus of a multi-year geologic framework assessment program authorized by the Alaska State Legislature in 2005 and administered by the Alaska Division of Geological & Geophysical Surveys (DGGS) (fig. 1). The project encompasses a 25-km-wide, 320-km-long transect centered along the highway and is designed to provide baseline geologic information to assist engineering design decisions related to the proposed Alaska–Canada natural-gas pipeline and other developments within the corridor. The study area has been divided into three parts: segment 1 (Delta Junction to Dot Lake), segment 2 (Dot Lake to Tetlin Junction), and segment 3 (Tetlin Junction to the Yukon Territory [Canada] border). Maps and reports describing the surficial geology, bedrock geology, engineering geology, and permafrost conditions in the highway corridor have been published, including: Reger and others (2008), Reger and Solie (2008a; b), Reger and others (2011), Hubbard and Reger (2010), Reger and Hubbard (2010), Reger and others (in press, a; b), Reger and others, 2012, Werdon and others (in press, a; b; c; d), and Elliott and others (in press, a; b). Focused studies of active and potentially active faults along the corridor have been published for segments 1 and 2 (Carver and others, 2008; 2010). This report presents our characterization of active and potentially active faults in segment 3, including an assessment of previous fault studies in the area.

Early active fault studies performed in support of natural-gas transportation infrastructure investigations identified numerous potentially active faults in the study area (Woodward–Clyde Consultants [WCC], 1979; 1981). These studies identified the Midway Lake faults, Northway Junction faults, and the Tok River lineaments (later referred to as the Dennison Fork and Caribou Creek faults) as candidate significant faults, defined as "*an active fault or lineament that exhibits geomorphic features characteristic of active faults at a distance from the pipeline route but cannot be crossed across the pipeline route.*" The Woodward–Clyde studies also identified the Tetlin Lake lineaments, Ladue River lineament, and Airs Hills faults as major lineaments. The identification of these faults was based primarily on previous bedrock mapping, and inferences of Quaternary deformation were typically based on tectonic geomorphic evidence described as "*suggestive.*" Definitive evidence in support of active deformation was generally lacking. Based on information developed in the Woodward–Clyde studies, the Caribou Creek and Dennison Fork lineaments were classified as "*suspicious*" faults on the Neotectonic Map of Alaska published by Plafker and others (1994) (fig. 2). The Plafker map defines suspicious faults as "*Age of fault or lineament displacement is unknown. Nearby shallow seismicity, and/or known Neogene faults with similar orientation indicates the possibility of Neogene displacement.*"

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In light of renewed interest in proposed natural-gas pipeline transmission routes from Alaska to the Lower 48 and uncertainties in the level of activity associated with previously identified faults, we reviewed and re-evaluated the Woodward–Clyde reports. Additionally, we performed new studies, including helicopter and field reconnaissance, along the Alaska Highway from Tetlin Junction to the Yukon Territory (Canada) border. New lidar data along the highway corridor were inspected for evidence of active faulting. For the purpose of this investigation, an active fault is defined as showing displacement in the Holocene (last 11,000 years). Because our investigation focused on assessing faults identified in previous studies and involved only limited reconnaissance in areas not crossed by these features, additional active faults could be identified in the general vicinity of the corridor with more detailed investigations, particularly along the southern margin.

REGIONAL PHYSIOGRAPHIC, TECTONIC, AND GEOLOGIC SETTING

Segment 3 of the Alaska Highway corridor project extends southeast ~100 km between Tetlin Junction and the Yukon border (fig. 1). The corridor roughly follows the northeastern margin of the Tanana River valley and is bordered on the north by the Yukon–Tanana Upland (Wahrhaftig, 1965), the physiographic region between the Denali and Tintina faults. To the south, the corridor is bordered by the alluvial valleys of the Chisana, Nabesna, and Tanana rivers and the rugged foothills of the eastern Alaska Range.

Tectonic deformation in interior Alaska is the result of oblique subduction of the Pacific plate and Yakutat microplate beneath the North American plate at a rate of ~5.5 cm/yr. As part of this process, southern Alaska is deforming along the subduction margin by translation along the Fairweather fault and by fold-and-thrust-belt tectonics across the Chugach/St. Elias Mountains (fig. 3). Plate boundary forces that are not accommodated by

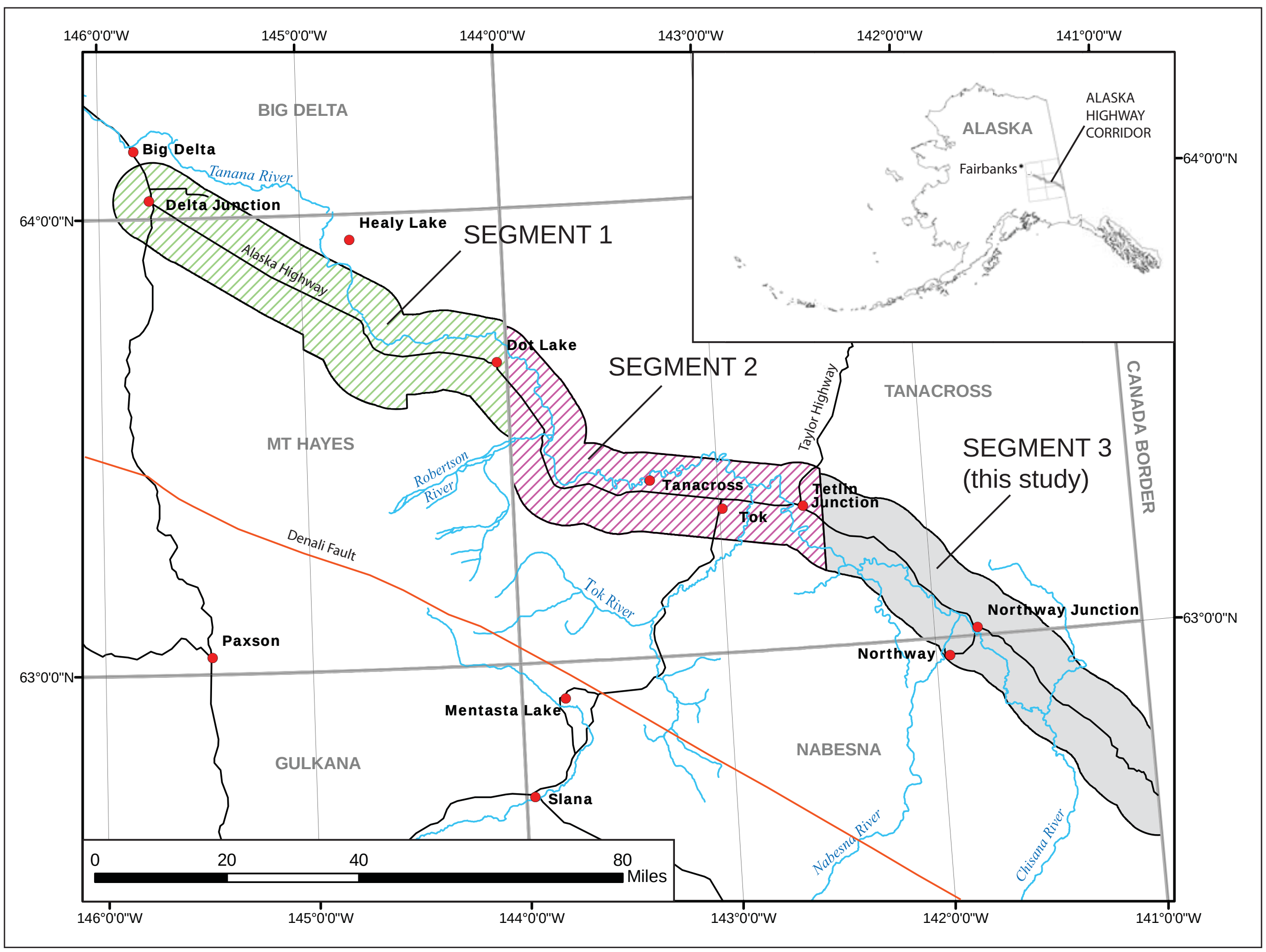


Figure 1. Location map showing segment boundaries of the Alaska Highway corridor project between Delta Junction and the Yukon border. Segment 3 (this study) is shaded light grey.

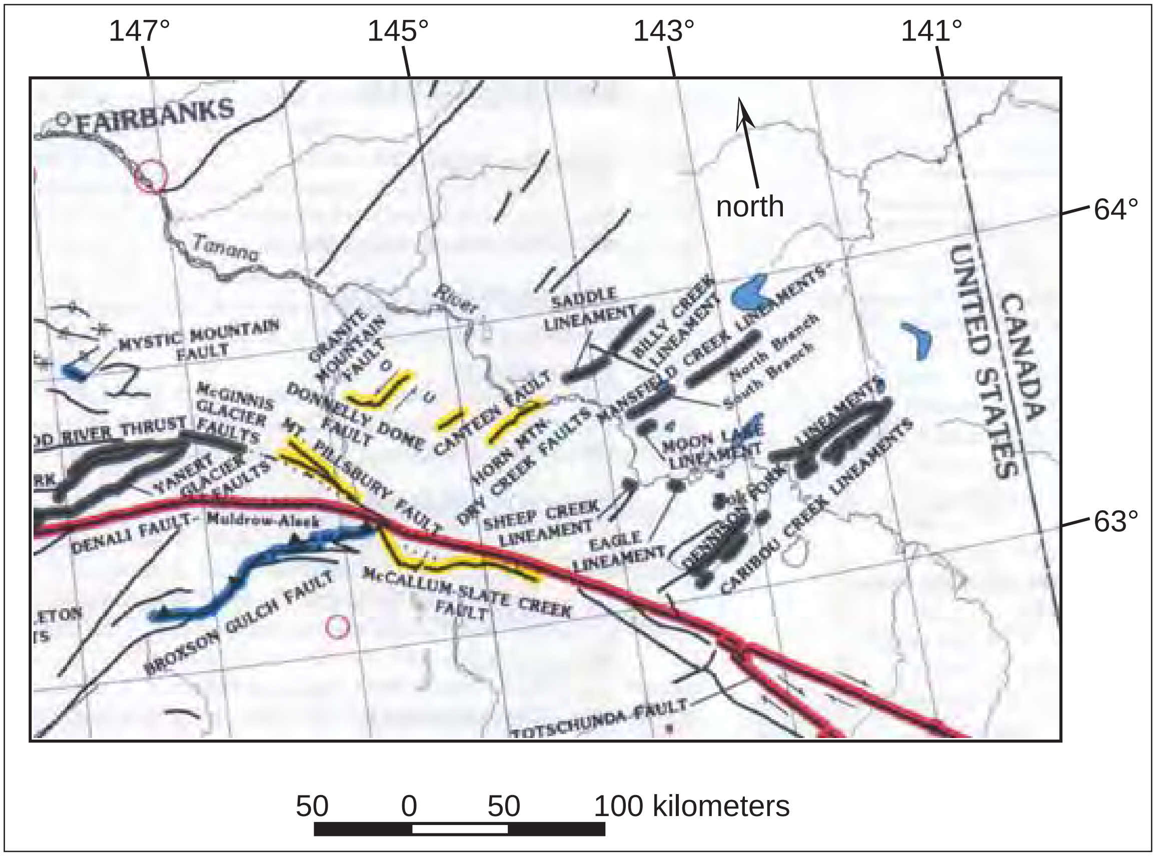


Figure 2. A section of the Neotectonic Map of Alaska (Plafker and others, 1994) showing the Caribou Creek and Dennison Fork lineaments as "suspicious" faults (shaded black).

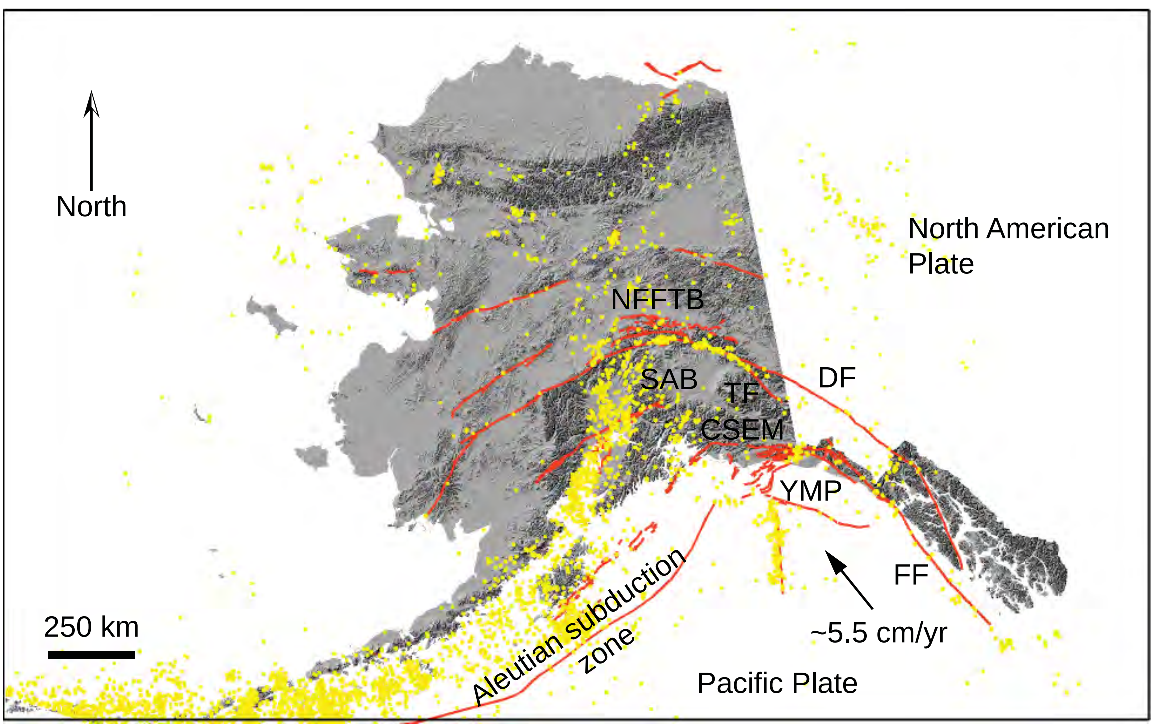


Figure 3. Regional tectonic map of Alaska. Yellow circles represent epicenters of earthquakes greater than magnitude 4 since 1980. FF=Fairweather fault; DF=Denali fault; TF=Totshunda fault; NFFTB=Northern Foothills Fold and Thrust Belt; SAB=Southern Alaska Block; YMP=Yakutat microplate; CSEM=Chugach/Saint Elias Mountains.

deformation along the subduction front are transmitted northward and distributed across a broad zone extending more than 500 km into interior Alaska. Counterclockwise rotation of the Southern Alaska Block, the area of crust between the Yakutat microplate and the Denali fault, is responsible for right lateral slip along the Totschunda and Denali faults of around 9–13 mm/yr. Curvature of these faults around the south side of the Alaska Range produces a north-directed component of compression that is accommodated by uplift and thrust faulting along the Northern Foothills Fold and Thrust Belt (NFFTB). The NFFTB is a 50-km-wide, 500-km-long zone of active thrust faults that bounds the northern flank of the Alaska Range (Bemis and others, 2012) and accommodates ~3 mm/yr of dip-slip displacement (Bemis, 2004). Specific details about individual splays of the NFFTB are described in Bemis and others (2012) and Carver and others (2008; 2010).

Yukon–Tanana metamorphic complex and intrusive rocks dominate the bedrock geology of the Yukon–Tanana Upland north of the Tanana River valley along the Alaska Highway corridor in the segment 3 study area. Metamorphic lithologies consist of PreCambrian to Paleozoic biotite gneiss and schist, quartzite, and chert (Foster, 1970). The metamorphic complex has been intruded by batholith-scale Mesozoic intrusive granites and minor Tertiary gabbro and felsic volcanic rocks. Similar metamorphic rocks are present south of the Tanana River; however, metamorphic grade is lower and greenschist-facies Paleozoic phyllite and schist dominate the foothills of the eastern Alaska Range (Foster, 1970; Richter, 1976). Quaternary cover sediments bury and obscure bedrock relations through much of the Tanana River valley.

QUATERNARY GEOLOGY

During the late Quaternary, the northern Alaska Range was sculpted by multiple glacial advances characterized by large valley glaciers that extended to the north down major river valleys. South of the segment 3 study area, end moraines and drift that mark the ice limit of the late Wisconsin Jatahmund Lake (Donnelly) glaciation were documented in the Nabesna and Chisana River drainages by Richter (1976) and Fernald (1965). Pre–late Wisconsin drift associated with the penultimate glaciation (Delta or Black Hills) is also present south of the study area but is less prominent and exists as isolated remnants beyond the extent of late Wisconsin drift (Richter, 1976). Ice associated with the penultimate glaciation may have blocked the lower Scottie Creek drainage and impounded a meltwater lake in the lowland (Duk-Rodkin and others, 2002). However, more recent investigations indicate a lack of evidence for glaciation in the Desper–Scottie and Mirror Creek lowlands north of the Black Hills (Delta) moraines originally mapped by Richter (1976)(R.D. Reger, written commun.).

West of the study area, Pleistocene glacial outburst floods sourced from glacial Lake Atna in the northeastern Copper River basin flowed down the Tok River valley and created flood-related geomorphic features including gravel expansion fans associated with exceptionally large boulders downstream from the broad Tok fan in the upper Tanana River drainage (Reger and others, 2008). East of the Tok/Tanana River confluence, Post and Mayo (1971) described the Nabesna River as being affected by modern outburst floods. In contrast, Reger and others (in press, a) found no evidence of flood deposits or flood scouring associated with riverside exposures along the upper Tanana River east of the Tanana River bridge, indicating that outburst floods did not affect the Nabesna or Chisana River drainages. Based on these observations, Reger (written commun.) suggests that thick, discontinuously to sporadically frozen, fine-grained slackwater deposits in the Desper–Scottie creeks lowland are not related to outburst floods. Thus the modern, relatively flat valley topography was likely created by northward growth of voluminous granular outwash fans sourced in the late Wisconsin and penultimate glacial ice margins that prograded across the Northway–Tanacross lowland. These outwash fans have been subsequently modified by late Holocene fluvial and eolian processes.

The Quaternary sediments in the segment 3 study area generally consist of fluvial and alluvial sediments deposited by major rivers in the Northway–Tanacross and Tanana River lowlands and colluvial and eolian sediments that blanket the Yukon–Tanana Upland (Reger and others, in press, a). Southwest of the Alaska Highway, stream terrace alluvium, abandoned floodplain alluvium, and swamp deposits dominate the lowlands. Thaw lakes on abandoned floodplain surfaces are common, and larger lakes have natural levee–lake delta deposits related to floodwater discharge. Northeast of the Alaska Highway, a thin veneer of eolian deposits covers the mature bedrock topography of the Yukon–Tanana Upland. The uplands are characterized by underfit stream valleys that have been partially filled with retransported silt and sand complexly mixed with lowland loess and colluvium. Prominent eolian sand deposits occur nearly continuously along the southwestern slope of the Yukon–Tanana Upland and in scattered pockets in the lowlands. Specific information on the sedimentological characteristics, surficial geomorphology, and map extent of the various Quaternary deposits in the segment 3 study area are detailed in Reger and others (in press, a).

2009 FIELD INVESTIGATION

Investigation of potentially active faults in the segment 3 study area consisted of review of the published and unpublished literature, inspection of pertinent maps, aerial photographs, and orthoimagery, as well as helicopter surveys and ground traverses. The field work was based at a tent camp in Northway Junction during July 2009. Our initial efforts focused on an approximately 10-mile-wide zone centered along the section of the Alaska Highway corridor between Tetlin Junction and the Canada border. We inspected roadcuts along the highway to obtain information on Quaternary deposits. Where access permission could be acquired from the Tetlin Native Corporation, we documented geomorphic features along previously mapped fault traces on the ground. Additionally, we inspected the landscape from the air to determine the presence or absence of linear features indicative of geologically youthful faulting. Previously identified faults along the Alaska Highway that were the focus of our studies include the Dennison Fork and Caribou Creek faults[3], Midway Lake faults, Northway Junction faults, and the Airs Hills faults.

Subsequent to our investigation along the highway corridor, we expanded our survey to the north and south to assess the relative activity of several additional previously identified faults including the Tetlin Lake lineaments, Ladue River lineament, and the northeastern projections of the Dennison Fork and Caribou Creek faults (WCC, 1979; 1981; Griscom, 1976; Foster, 1970). Following the field investigation, recently acquired lidar data were inspected to substantiate and verify our field observations.

RESULTS

TOK RIVER LINEAMENTS AND FAULT ZONE

The Tok River lineaments were originally identified by Woodward–Clyde Consultants (1979) as a candidate significant fault zone extending northeast from the Tok River valley and into the Yukon–Tanana Upland (fig. 4). In their report the southwestern part of the zone was named the "Tok River lineament" and the northeastern part of the zone was divided into a northwest trace named the Dennison Fork lineament and a southeastern trace named the East Fork Aeromagnetic Anomaly. The Tok River lineament includes traces along both the northwestern and southeastern margins of the Tok River valley (WCC, 1979). The two traces were interpreted based on the linear valley margins and the presence of 4- to 7-m-high scarps along the bedrock/Quaternary alluvial contact. The possibility of active tectonic displacement along these inferred structures led Woodward–Clyde (1981) to perform more detailed field studies to further characterize the features. In their 1981 report, the system was called the Tok River fault zone and further subdivided into the upland and Tok Valley segments of the Dennison Fork fault and Caribou Creek fault (formerly the East Fork Aeromagnetic Anomaly). In this report, we use the later nomenclature to summarize the air photo and field observations of Woodward–Clyde Consultants (1979; 1981) and the results of this study.

Despite sparse evidence presented in the Woodward–Clyde Consulting reports (1979; 1981) for Quaternary displacement along the upland and Tok Valley segments of the Dennison Fork and Caribou Creek faults, and the lack of recognition of these faults on previous bedrock mapping (Foster, 1970), the Quaternary fault map of Alaska (Plafker and others, 1994) shows both faults as "suspicious." Consequently, the engineering-geologic community has continuously considered both faults to be potentially active, and costs associated with assessing them have continued to impact infrastructure projects.

Upland segment of the Dennison Fork fault

The upland segment of the Dennison Fork fault extends along the southwestern side of the Dennison Fork alluvial valley (fig. 5). Mesozoic granite and Paleozoic metamorphic rocks occur on the southeastern side of the valley in contrast to the Tertiary volcanic and Cretaceous sedimentary rocks on the northwest (Foster, 1970). Woodward–Clyde Consultants (1979; 1981) mapped the upland segment of the Dennison Fork fault in Dennison Fork valley as an alignment of vegetation contrasts, subtle topographic breaks, and subtle changes in hillslope angle, several distinct scarps, and pingos on or adjacent to the fault. They also suggested that the fault extends across a series of ridges and valleys with scarps up to 1 m, well-developed benches, and springs.

We inspected the upland trace of the Dennison Fork fault by helicopter along the southern rangefront of the Dennison Fork valley between the Taylor Highway and Pingo Valley (fig. 5). Our observations indicate that the

[3]See Results section for a description of the different naming schemes for the Dennison Fork and Caribou Creek faults used by different investigators. The system has been called many different names including Tok River lineaments, Dennison Fork and Caribou Creek lineaments, East Fork Aeromagnetic Anomaly, Tok River fault zone, and the upland and Tok Valley segments of the Dennison Fork and Caribou Creek faults.

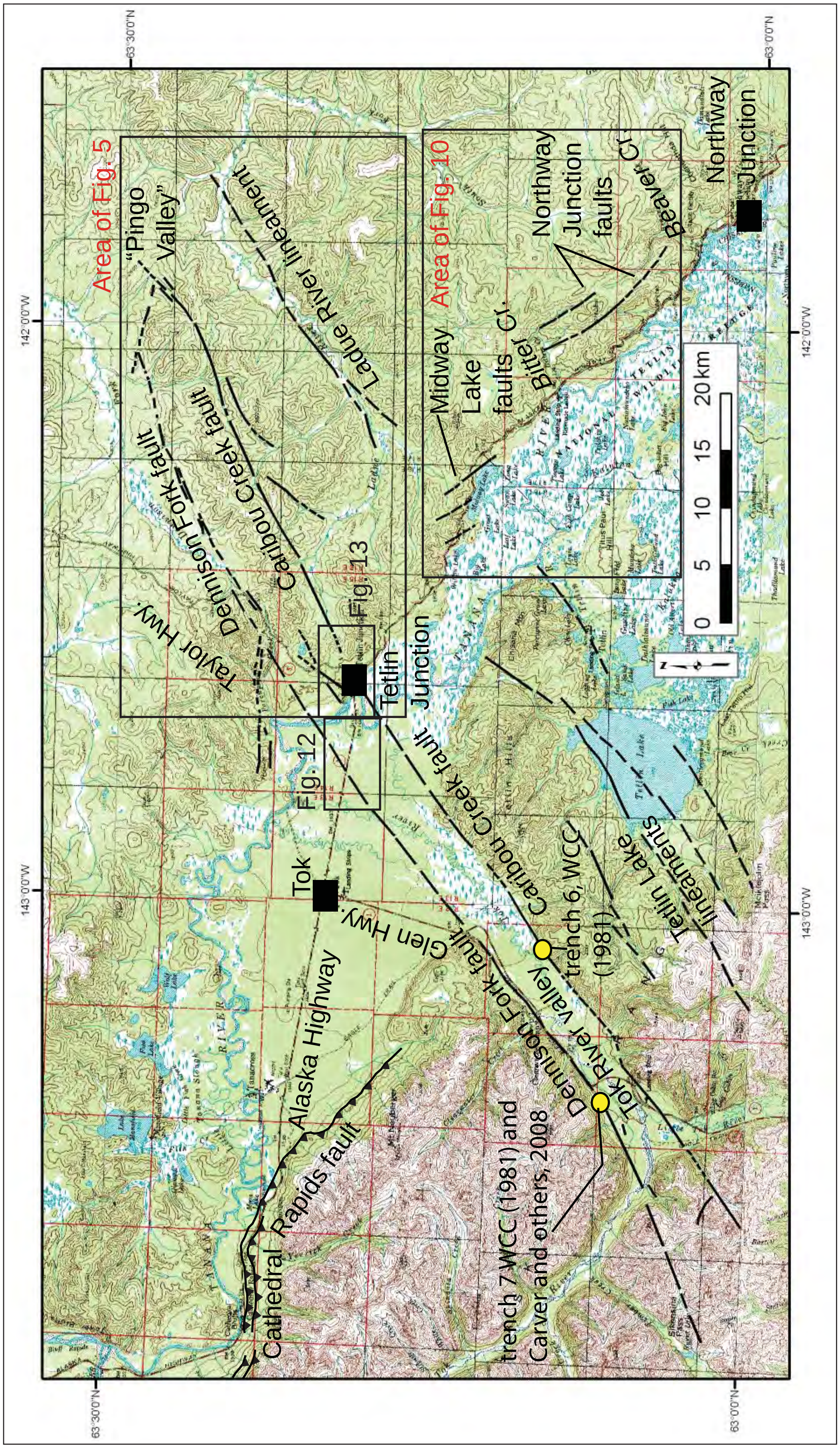


Figure 4. Topographic map of the western part of the segment 3 study area showing faults investigated and the locations of previous trenches of Woodward–Clyde Consultants (1981) and Carver and others (2010).

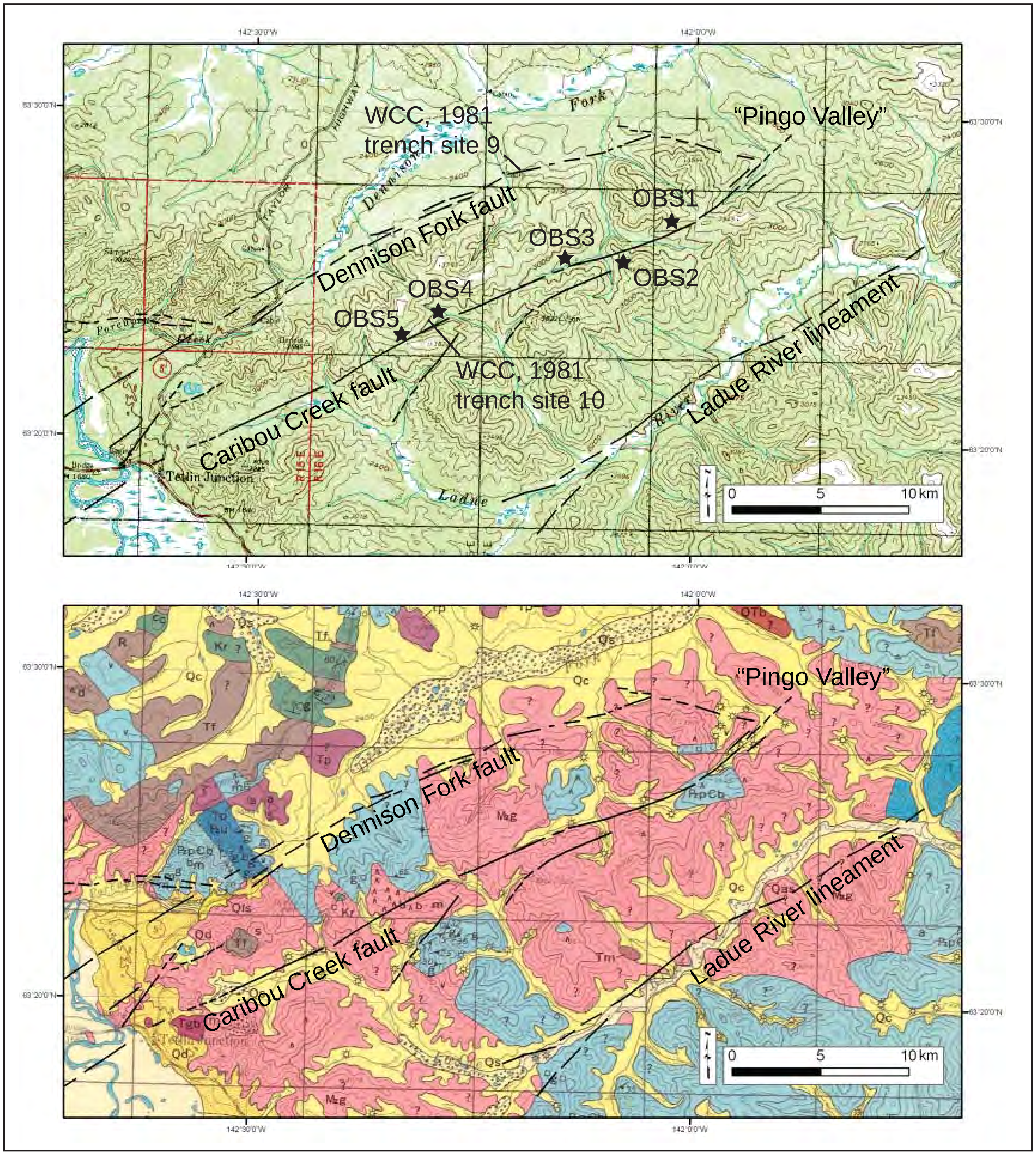


Figure 5. Topographic map (top) and geologic map (bottom) showing locations of the upland segments of the Dennison Fork and Caribou Creek faults and the Ladue River lineament. Also shown are observation points (OBS 1–OBS 5) from this study and locations of previous trenches by Woodward–Clyde Consultants (1981). Geologic map from Foster and others (1970).

rangefront is characterized by rounded subdued slopes, a well-developed drainage network, and low-gradient alluvial fans that grade into the Dennison Fork valley flats. Recent fires have cleared vegetation, providing for unobstructed views of surface morphology. We were unable to verify the majority of geomorphic features shown on the Woodward–Clyde (1981) map, and infer that these features were either modified and/or removed by surface processes over the last 30 years, were too subtle to definitively attribute their formation to active fault displacement, or were originally misinterpreted. Several vegetation lineaments may have been destroyed by fires.

A single fault trench (trench site 9, WCC, 1981) was excavated across the fault where it coincides with a subtle break in slope and crosses an inset terrace surface (fig. 5). The trench exposed granitic bedrock overlain by grus and alternating layers of silt and organic soils. Woodward–Clyde Consultants (1981) identified several faults in the granitic bedrock; however, they could not trace the faults into the overlying sediments, and none of the stratigraphic units depicted in the log are displaced. The alternating layers of silt and soils were interpreted by Woodward–Clyde (1981) to represent individual left-lateral offset events with surface faulting occurring as recently as 7,950 ± 250 yr BP (sample 9-C-5, plate C-4, WCC, 1981). Alternatively, the buried soils could be produced by airfall tephras or variable eolian loess deposition over time, or both. Further, the plan view map of site 9 (WCC, 1981) does not show a lateral offset of the terrace riser, which is inconsistent with repeated Holocene earthquakes. We infer that the stratigraphic relations are depositional and that the trench does not record Holocene surface-rupturing earthquakes. This inference is consistent with the weak tectonic geomorphology and absence of youthful surficial scarps at the trench site. We did observe a short bedrock scarp preserved on a bedrock knob outboard of the rangefront directly north of trench site 9. This scarp is oriented slightly more westerly than the mapped trace of the fault and does not continue into the alluvium to the west.

Based on the lack of youthful, continuous tectonic indicators, the presence of a sinuous, well-degraded rangefront, and a reinterpretation of the trench log of site 9, we infer that the upland trace of the Dennison Fork fault has not been active during the Holocene, and likely the Quaternary. We further infer that the location of the fault on previous maps is poorly constrained and may be buried somewhere in the Dennison Fork valley consistent with bedrock differences across the valley. Some of the lineaments discussed in the Woodward–Clyde Consultants report (1981) could be related to bedrock bedding contrasts or old faults.

Upland segment of the Caribou Creek fault

The upland segment of the Caribou Creek fault (East Fork Aeromagnetic Anomaly of WCC, 1979) extends through Mesozoic granitic and Paleozoic metamorphic rock and was interpreted from aeromagnetic anomalies as a fault by Griscom (1976). In the vicinity of Caribou Creek, Woodward–Clyde Consultants (1979; 1981) identified hillside benches, aligned saddles, aligned pingos, springs, truncated valleys, vegetation contrasts, linear drainages, and a left-laterally offset ridgeline along the fault that suggest active faulting, but noted that southwest of Caribou Creek, definitive surface expression of the fault is generally lacking.

Aerial reconnaissance was performed along the upland segment of the Caribou Creek fault in the low hills south of the Dennison Fork valley between Pingo Valley and Tetlin Junction (fig. 5). In general, the fault extends along several semi-linear drainages and saddles and is characterized by subtle tectonic features in several places. Because the fault traverses terrain without landmarks, we summarize our observations by referencing specific features labeled OBS 1 to OBS 5 (fig. 5).

Approximately 9 km southwest of Pingo Valley, an alignment of pingos and a well-expressed south-facing scarp extends along the northern side of an east- to west-trending valley (OBS 1, fig. 5). This scarp is slightly misaligned with the mapped trace of the fault and appears to be confined to bedrock. Southwest of this feature, the fault projects across a spur ridge that is not deformed (OBS 2) and continues southwest along another linear valley (OBS 3) characterized by intermittent subtle to moderately expressed northwest-facing scarps along the base of the slope on the south side of the valley. Piles of boulders have accumulated at the base of the scarps and bedrock is exposed in the scarp faces.

At OBS 3, a north-facing alluvial fan emanates from a broad colluvial hollow that occurs along the alignment of scarps (figs. 5 and 6). From the air, we noted the possibility of the fault extending part way across the eastern side of the fan. Subsequently, we conducted ground traverses along the fault and surveyed several topographic profiles to evaluate the recency of faulting in more detail. A semi-continuous bedrock scarp ranging from 2 to 10 m high extends along the base of the slope on either side of the fan (figs. 6 and 7). Scattered tabular boulders averaging 1–2 m in diameter are present at the base of the scarp. Profiles 1 and 2 were surveyed across the scarp west and east of the fan, respectively. These profiles show the scarp is gently sloping, but contains several subtle breaks in slope (bevels?). Profile 2 has an oversteepened base; however this feature is localized. Profile 3 was surveyed across the projection of the scarp in the older part of the alluvial fan (surface Hf2, fig. 6), where we observed two

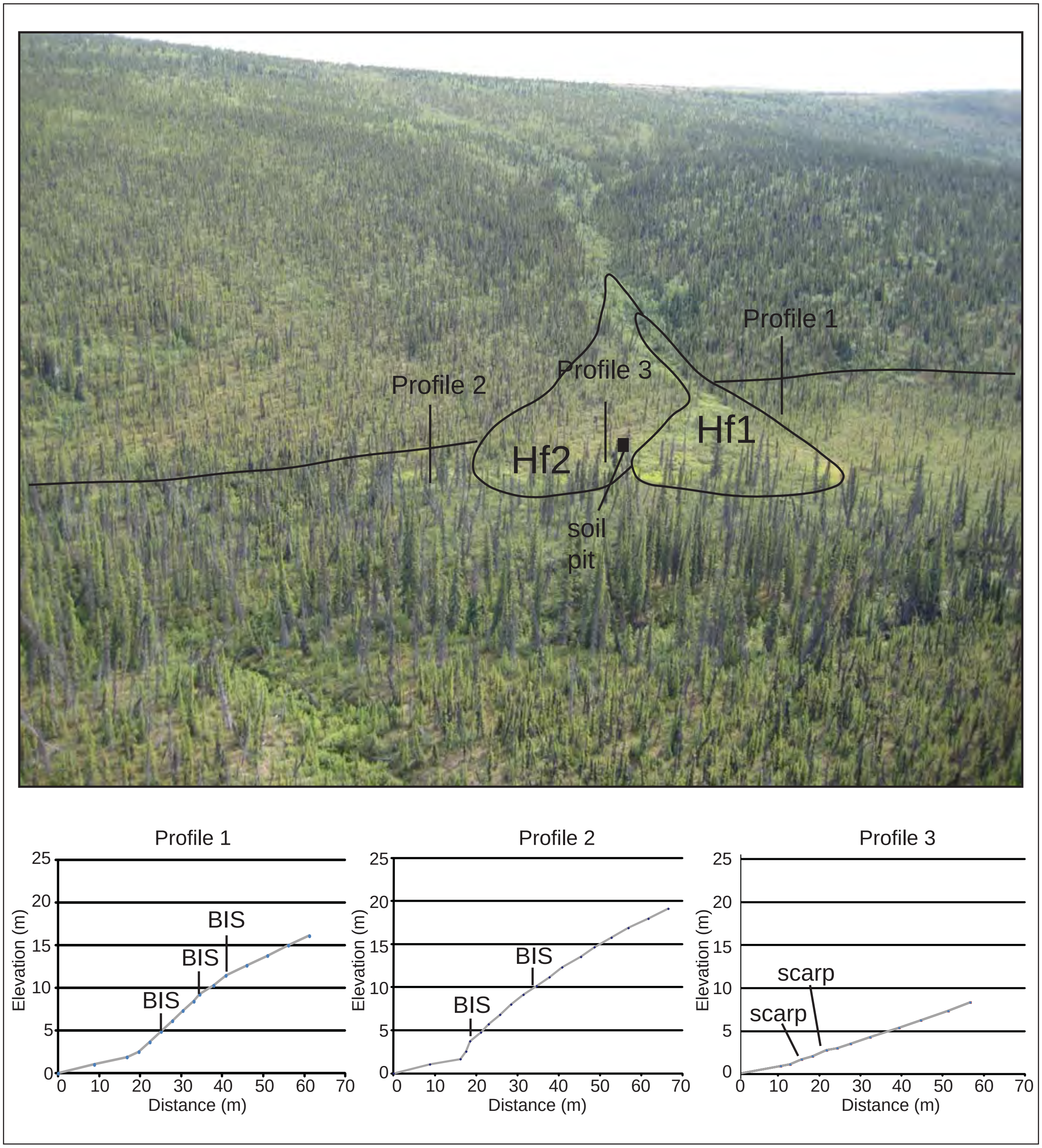
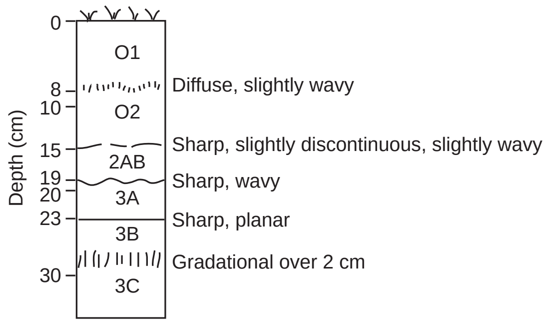


Figure 6. Photograph of alluvial fan crossing the upland segment of the Caribou Creek fault, showing locations of profiles 1, 2, and 3 and soil pit on Hf2 *surface. Location of alluvial fan shown in figure 5 as OBS3. BIS; break in slope. Coordinates for endpoints of profiles are: Profile 1, 63.4226, -142.1488 and 63.4231, -142.1490; Profile 2, 63.4247, -142.1439 and 63.4241, -142.1435; and Profile 3, 63.4240, -142.1459 and 63.4236, -142.1456.*

Figure 7. Photograph of scarp at Profile 2, showing oversteepened base. Geologist and 2.25 m survey rod for scale. Location of Profile 2 shown in figure 6.

semi-parallel breaks in slope. The profile indicates that the breaks in slope occur across two <1-m-high scarps. The scarps do not continue across the inset fan surface (surface Hf1). A soil pit excavated into the Hf2 surface adjacent to profile 3 indicates that the surface is likely Holocene in age (fig. 8). Although we cannot preclude that the scarps are tectonic in origin without subsurface observations, the lack of similar scarps along the length of the fault indicates that an alternative mechanism is responsible for their formation. Possible mechanisms include erosion by floodwaters emanating from the mouth of the canyon, fan deposition associated with draping over a preexisting bedrock scarp, or game trails, or both.

Southwest of OBS 3, the fault projects across a saddle, where it is expressed by a small bedrock escarpment that does not continue into the headwater region of the next valley southwest. A linear trough on a northwest-facing side slope marks the position of the fault farther to the southwest (OBS 4, figs. 5 and 9). OBS 5 is a broad saddle that appears to bend slightly in a left-lateral sense at the fault crossing. No youthful scarps cut across the saddle. Extensive hydrothermal quartz crystals and healed brecciation observed along the fault at OBS 5 suggests an old fault. Tectonic geomorphic features are absent in the valley of the Ladue River headwaters between OBS 5 and Tetlin Junction.



Soil horizon	Description
O1	Coarse peat, light to medium brown with dead identifiable sphagnum and plant fragments.
O2	Decomposed, fibrous plant material with trace plant fragments, dark brown to black.
2AB	Silt with trace fine sand and very fine gravel, very dark grayish brown (2.5Y 3/2), slightly plastic, non-sticky, possible tephra.
3A	Silt loam, very dark brown (10YR 2/2), nonsticky, nonplastic.
3B	Sandy silt loam, dark yellowish brown (10YR 3/4), slightly sticky, slightly plastic.
3C	Sandy clay loam, dark grayish brown (10YR 4/2)

Interpretation
Holocene soil buried by possible tephra below modern peat mat.

Figure 8. Soil profile and description of soil pit excavated adjacent to profile 3 on the Hf2 alluvial fan surface along the Caribou Creek fault zone. Soil pit coordinates: 63.4238, -142.1457; location shown in figure 6.

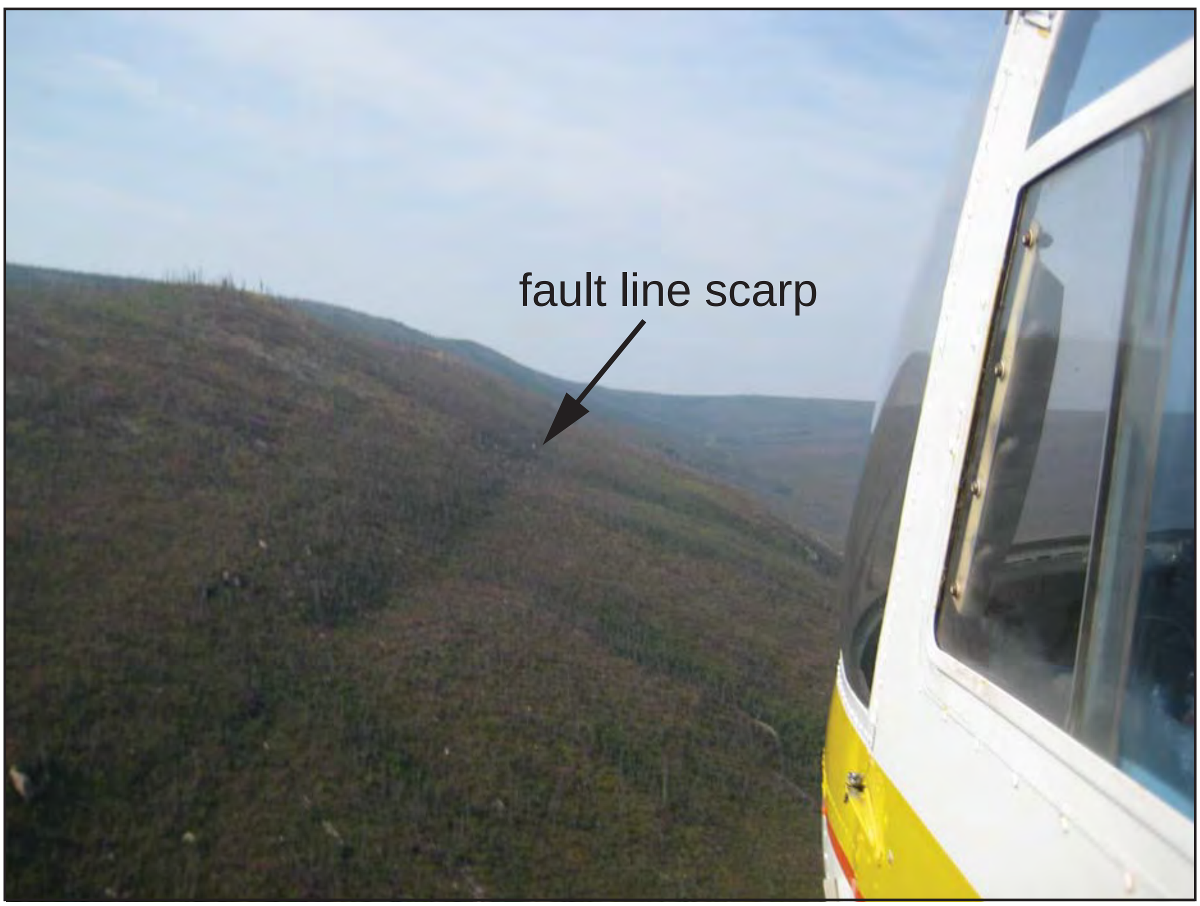


Figure 9. View westward along the upland segment of the Caribou Creek fault, showing fault-line scarp traversing gently north-facing slope. Location of scarp is shown in figure 5 (OBS4). Photo taken from the air near coordinates 63.3967, -142.2726.

Woodward–Clyde Consultants (1981) cleared off of a stream bank exposure perpendicular to the fault (trench site 10, WCC, 1981, fig. 5). This exposure provided an incredibly complex stratigraphy including laterally variable ice-cemented silts, sandy silts, and minor gravels. Minor offsets, folded strata, and a zone of doming in the center of the exposure were interpreted by Woodward–Clyde (1981) to be the result of lateral tectonic deformation; however, they acknowledge that many of the features could be related to cryoturbation, slumping, or other processes. They infer that the most recent earthquake occurred more recently than 2,100 yr B.P. based on a radiocarbon date from a peat layer that is not continuous across the trench. However, due to the complexity of the trench log, we cannot preclude that the documented deformation is tectonic, but note that our surficial geologic observations (described above) are not consistent with youthful rupture. We infer that the chaotic mixture of Carbon-14 (^{14}C) dates collected from the trench are consistent with soil mixing and cryoturbation processes and that the sediments have not been faulted.

Along the entire length of the fault, streams that cross orthogonal to the fault are in well defined, broad valleys that are not offset. Large ridges crossed by the fault at several places are not visibly displaced. The fault crosses several large, flat-floored valleys filled with Quaternary sediments without scarps or other tectonic geomorphic features. Where the fault extends along linear valleys, the valley margins have a curvilinear morphology. Surface geomorphic observations in the vicinity of a previous trench study support the lack of youthful rupture. Thus, based on this evidence, we infer that the fault is an old bedrock structure and not a Holocene active fault. We further suggest that the subtle tectonic features present intermittently along the fault are fault-line erosional features.

Tok Valley segment of the Dennison Fork and Caribou Creek faults

The Tok Valley segment of the Dennison Fork and Caribou Creek faults projects along the northwest and southeast sides of the Tok River valley, respectively, and align with the upland segments of the Dennison Fork and Caribou Creek faults (fig. 4). Woodward–Clyde Consultants (1981) identified lineaments along the Tok Valley segment of the Dennison Fork, and found only weak evidence that suggested active faulting. Linear terrace margins were interpreted as possibly being fault controlled; however, the margins are coincident with curvilinear outwash terrace margins, making a fault origin suspect. Along the Tok Valley segment of the Caribou Creek fault, Woodward–Clyde Consultants (1981) noted hillside benches, aligned saddles, truncated ridges, and linear outwash terrace margins among other features along the valley margin. The majority of these features were inferred to be only suggestive of faulting.

An exploratory trench (trench 6, WCC, 1981) was excavated across a low scarp and vegetation lineament along the Tok Valley segment of the Caribou Creek fault (fig. 4). Although a step in a cobble gravel unit at the base of the trench is suggestive of faulting, the trench did not contain shear zones. Thus, no unequivocal evidence of faulting was identified, and Woodward–Clyde Consultants (1981) inferred that the stratigraphic features may be sedimentary in origin.

Woodward–Clyde also excavated a trench (trench 7, WCC, 1981) across the Tok Valley segment of the Dennison Fork fault (fig. 4). This trench was excavated across the base of a steep slope that marks the linear northwestern margin of the valley and coincides with the back edge of a Donnelly glacial outwash terrace inset to a Delta outwash terrace. The trench showed several organic layers that abruptly terminate against the Delta deposits beneath the break in slope inferred to be the fault trace; however, no distinct fault plane, fractures, or offsets were observed. Toward the center of the trench, Woodward–Clyde (1981) identified several steplike offsets along a zone of subvertical faults, which they infer to be related to antithetic motion on the fault. They infer that the stratigraphic relations suggest the formation and subsequent filling of a small basin along the fault; however, sediment deposition or cryoturbation cannot be ruled out to explain the stratigraphic relations.

Carver and others (2010) re-evaluated the tectonic origin of scarps along the Tok Valley segment of the Dennison Fork fault and excavated two trenches in the vicinity of the Woodward–Clyde (1981) trenches (fig. 4). The trenches of Carver and others (2010) were excavated across a 4-m-high scarp in an alluvial fan and exposed stacked interbedded debris flows and loess deposits in depositional contact with alluvial fan deposits that constitute the scarp. Shear zones or faults were not observed in the trenches. Carver and others (2010) infer that the scarp was created by erosion caused by large glacial outburst floods from glacial Lake Atna (Reger and others, 2011), which catastrophically flowed down the Tok River valley during the Donnelly glaciation. A similar origin was proposed for scarps associated with the Tok Valley segment of the Caribou Creek fault across the valley, based on a similar elevation of the scarps. We briefly visited the Carver and others (2010) trench site during our field reconnaissance. Our observations indicate that the scarp is characterized by a subdued colluvial slope and does not exhibit features indicative of Holocene displacement. Thus, based on the trench results of Carver and others (2010) and our field observations, we favor the outburst flood hypothesis for the origin of the scarp and infer that the Tok Valley segment of the Dennison Fork fault has not been active in the Holocene.

TETLIN LAKE LINEAMENTS

The Tetlin Lake lineaments consist of a series of northeast-trending lineaments in the vicinity of Tetlin Lake (fig. 4). The lineaments are mapped based on several aeromagnetic anomalies (Griscom, 1976), bedrock mapping along one strand (Foster, 1970), and interpretation of LANDSAT imagery and black-and-white air photos (WCC, 1979). Woodward–Clyde Consultants (1979) describe subtle vegetational or topographic expressions along parts of all five lineaments; including linear valleys and drainages. Although the Tetlin Lake lineaments occur outside of the segment 3 corridor study area, we performed limited helicopter reconnaissance along the southern margin of the Tanana River floodplain along the northern projection of the system near Chisana Mountain where two traces of the system project northeast into the Tanana River floodplain. There, the lineaments project across stream terrace alluvium, swamp deposits, and floodplain alluvium (Reger and others, 2011). No scarps or other linear features were observed along the projection of the lineaments in the Tanana River floodplain. Additionally, no tectonic geomorphic features were observed in bedrock along the east and west sides of Chisana Mountain. Thus, we infer that the Tetlin Lake lineaments are not Holocene active faults.

LADUE RIVER LINEAMENT

The Ladue River lineament occurs in the Ladue River headwaters area ~20 km east of Tetlin Junction and extends northeastward (N60°E) for ~29 km along the Ladue River drainage basin (fig. 4). Griscom (1976) interpreted a bedrock fault along the trace of the Ladue River lineament based on aeromagnetic data that showed a northeast grain in the magnetic pattern and apparent offsets of magnetic anomalies. The bedrock geology map of Foster (1970) does not show a fault along the lineament. Woodward–Clyde Consultants (1979) noted linear valleys and vegetation anomalies on black-and-white air photos but could not trace these features through Tertiary volcanic rocks to the southwest and did not observe geomorphic features indicative of active faulting.

We flew the entire length of the Ladue River lineament. Although the valley is quite linear, it exhibits characteristics of a long history of incision and gradual filling by colluvial, alluvial, and eolian processes. Approximately 22 km northeast of Midway Lake, the Ladue River valley widens considerably to about 1.5 km and is characterized by broad, shallow-gradient alluvial fans that have coalesced across the valley from both sides. Sparse small spruce trees and tundra characterize the vegetation on the fan surfaces. There, the mapped trace of the fault projects along the lower third of the gentle, rounded sideslopes that bound the southeastern side of the valley. From the air, we did not observe any linear troughs, saddles, scarps, or other features cutting orthogonal to valley sideslope ridges along the fault strike. Additionally, we inspected the interface between the base of the valley sideslopes and alluvial fans. The alluvial fans appear to have smooth, unbroken, long profiles and are not associated with scarps or other linear features. On the basis of the lack of tectonic geomorphic features and landforms along both the valley sideslopes and in the valley-fill sediments, we infer that the Ladue River lineament has not been active in the Holocene, consistent with the observations of Woodward–Clyde Consultants (1979).

MIDWAY LAKE FAULTS

The Midway Lake faults consist of three roughly parallel N30°W- to N35°W-trending faults that occur north of Midway Lake, approximately 15 km southeast of Tetlin Junction (figs. 4 and 10). In this report we refer to the traces of the Midway Lake faults as Midway Lake East, Midway Lake Central, and Midway Lake West faults. The faults were mapped by Foster (1970) as approximately located and concealed, extending short distances (~3 to 5 km) across granitic and metamorphic rocks. We performed independent ground and aerial reconnaissance along the Midway Lake faults. Topographically, the faults are not well defined, although several poorly developed saddles and sidehill drainages are noted (WCC, 1979). Woodward–Clyde (1979) did not observe geomorphic, hydrologic, geologic, or vegetational features suggestive of active faulting along the Midway Lake faults or along their projection into Quaternary and Holocene surficial deposits.

In the hills along the southern side of the Yukon–Tanana Upland, the Midway Lake faults are only expressed by broad, subdued saddles in the crests of bedrock knolls. The Midway Lake West fault projects southeast from a broad saddle in a rounded ridge, down a south–southeast-trending gully and into the Tanana River floodplain between Swan Lake and Long Lake. A roadcut (milepost 1291) approximately 100 m west of the fault reveals granitic bedrock overlain by 1–2 m of loess. A well-developed cambic soil has developed into the loess, which is unbroken across the length of the roadcut. Ground traverses were conducted across the mapped trace of the Midway Lake West fault northwest of the highway. Several old roads were encountered, however, no scarps or other geomorphic indicators of the presence of a youthful fault were observed. A volcanic outcrop on the east side of the gully, which contrasts with the granitic rock observed to the west, indicates the presence of a bedrock fault contact beneath the gully.

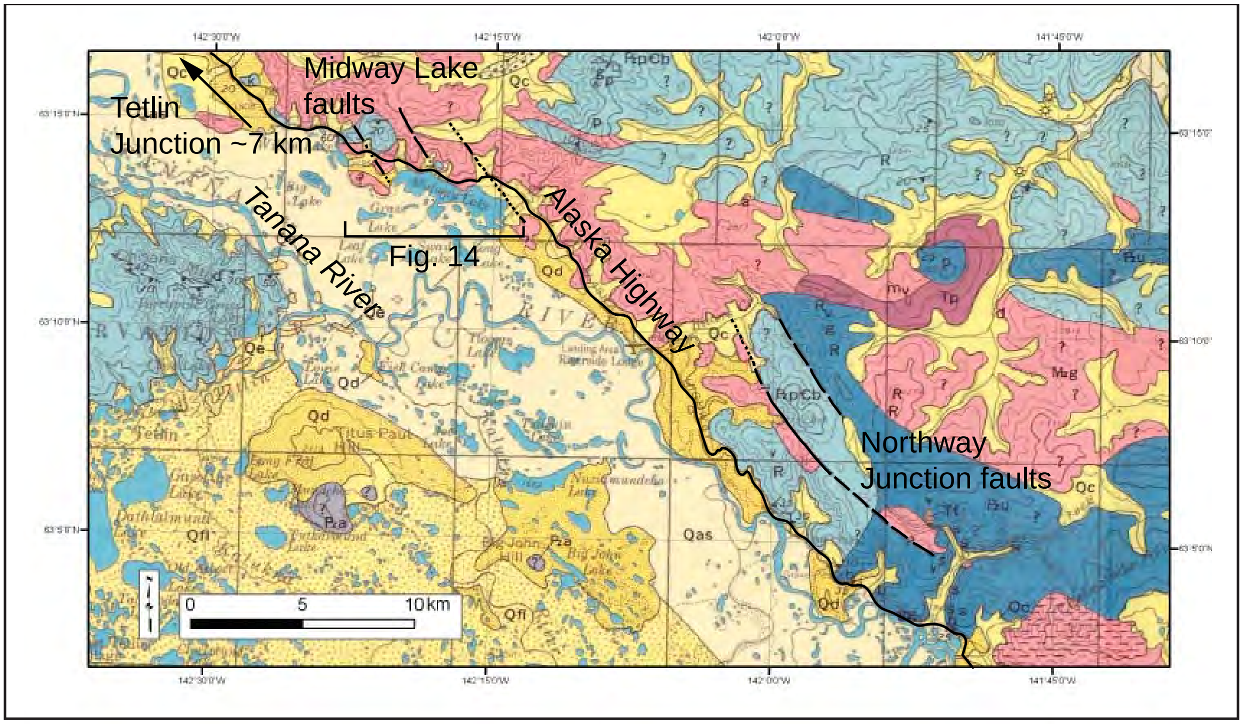


Figure 10. Location of the Midway Lake and Northway Junction faults shown in the geologic map of Foster and others (1970).

The Midway Lake Central fault trends along a gently sloping, southeast-trending valley north of the highway and projects into Midway Lake. In the Tanana River floodplain the fault projects along the southeast side of Long Lake. We performed several ground traverses across the fault approximately 100–200 m north of the highway. Although we discovered several old, overgrown roads, the floor of the valley was observed to be flat to gently rolling, with no indication of scarps or other tectonic features trending south–southeast down the valley. Both the Midway Lake West and Central faults project across Quaternary deposits of the Tanana River floodplain, including abandoned and inactive floodplain alluvium, stream terrace alluvium, swamp, and eolian deposits (Reger and others, 2011). Aerial observations indicate that these sediments are not displaced along either fault, and continuous lineaments oriented south—southeast are absent.

The Midway Lake East fault projects along the southwestern side of a broad, gently sloping valley and continues along the northeastern side of Midway Lake. The fault crosses deposits mapped by Reger and others (2011) as eolian sand and retransported silt and sand mixed with lowland loess deposited on gentle slopes at the base of the Yukon–Tanana Upland. Although we were denied access to perform ground traverses due to permit restrictions, aerial reconnaissance indicates scarps or other lineaments are absent along the fault trace and that the slope deposits are not faulted.

Our observations are in accordance with the conclusions of Woodward–Clyde Consultants (1979) that none of the Midway Lake faults are expressed at the surface and Holocene deposits are not deformed. Therefore, the Midway Lake faults have not been active in the Holocene.

NORTHWAY JUNCTION FAULTS

As originally mapped by Foster (1970), the Northway Junction faults consist of two splays that extend N45°W between Beaver Creek and Bitters Creek northwest of Northway Junction (figs. 4 and 10). In general, the faults mark contacts between gneiss–schist, shist–quartzite, and granitic bedrock units. From air photo observations, Woodward–Clyde Consultants (1979) described linear drainages, vegetation patterns, and an alignment of scarps in bedrock. Along the southwestern splay, Woodward–Clyde (1979) described a 46-m-high scarp in bedrock, suggesting north-side-up displacement, and noted that drainages eroded through the scarp were not associated with nickpoints.

The northeastern splay extends southeast ~6.5 km along a linear tributary to Bitters Creek, across a broad saddle, and projects toward a linear tributary to Beaver Creek. During our helicopter reconnaissance, no obvious scarps were observed from the air along the northeastern splay. The southwestern splay is ~16 km long and extends along the crest of a rounded ridgetop. During our helicopter surveys, we observed the large scarp in bedrock described by Woodward–Clyde (1979). This feature is not continuous, only about 1 km long, and not associated with other tectonic geomorphic features. A linear trough extends across a saddle approximately 0.5 km north of the mapped trace of the southwestern splay. This trough is characterized by a subdued morphology and lacks youthful indicators of recent tectonic activity. One vegetation lineament, characterized by tall and dwarfed spruce trees on either side of a lineament in the general proximity of the fault, was observed. Based on aerial observations, this lineament is not associated with visible scarps. Although the faults do not cross youthful deposits (generally confined to bedrock and colluvial slopes), the lack of scarps and visible fault traces suggests that the Northway Junction faults have not been active in the Holocene.

AIRS HILLS FAULTS

The Airs Hills faults generally bound Airs Hill and consist of two subparallel N70°W-trending faults originally mapped by Richter (1976) in Alaska and by Tempelman-Kluit (1974) across the border in the Yukon Territory (fig. 11). In Alaska, the faults are primarily concealed beneath alluvium and their locations are inferred from bedrock relations exposed in the hills on either side of the fault traces. The northern fault trace juxtaposes lower Paleozoic quartz–mica schist on the north against Devonian massive greenstone on the south. The southern fault separates Devonian phyllite and metaconglomerate on the north from Tertiary or Cretaceous conglomerate and sandstone on the south. The Chisana River crosses each fault trace at a high angle and is not laterally displaced. Woodward–Clyde Consultants (1979) suggested that tonal and vegetation anomalies may align with drainages, but determined that geomorphic features indicative of active faulting were absent along the faults.

Helicopter reconnaissance was conducted along the entire length in Alaska of both traces of the Airs Hills faults. Near the vicinity of the Canada border along the northeastern side of Airs Hill, the northern fault trace is mapped along a sideslope of a broad, gently sloping valley. A second linear vegetation lineament occurs south of the mapped trace. No scarps or other tectonic geomorphic features were observed along the mapped trace and the

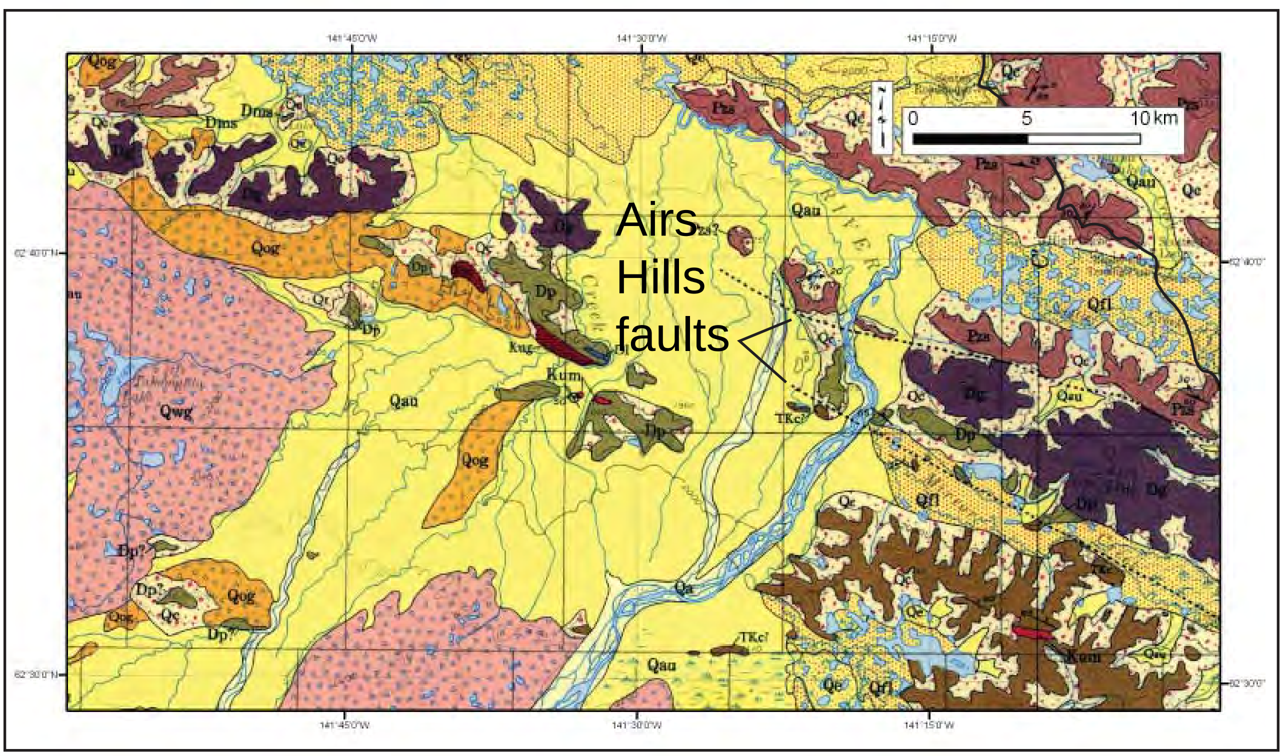


Figure 11. Location map of the Airs Hills faults shown in the geologic map of Richter (1976).

vegetation lineament was determined to be an embankment related to stream-channel incision. Farther west, the northern trace extends across a broad tributary valley to Scottie Creek. There, the topography along the fault trace is characterized by a slight topographic high that appears to deflect headwater-draining streams to the east about 30 m. However, based on smooth, gentle-gradient slopes along the fault directly east and west of the topographic high and the absence of clear scarps, we infer that the topographic high may be related to variable differences in erosion of the bedrock and not related to youthful faulting. The southern fault trace extends along the alluvial valley of Mirror Creek and is mapped as concealed along its entire length (Richter, 1976). We observed several linear stream segments along Mirror Creek; however, the valley floor is flat, devoid of scarps, and does not appear to be deformed along the fault trace. The southern rangefront of Airs Hill along the southern trace is deeply eroded by a well-developed drainage network and is not straight. Several isolated, partially buried bedrock knobs along the fault trace may be evidence of older deformation along the fault. Geomorphic indicators of youthful tectonic deformation are not present along either trace of the Airs Hills faults, indicating that these faults have not been active in the Holocene.

LIDAR OBSERVATIONS

Subsequent to our reconnaissance field surveys, DGGS acquired high-resolution lidar data along potential natural-gas pipeline routes including the Parks Highway and Alaska Highway (Hubbard and others, 2011). In the segment 3 study area, hillshade images processed from the lidar data encompass an approximately 1-mi-wide continuous image centered on the highway corridor in the Nabesna and Tanacross 1:250,000-scale quadrangles (Hubbard and others, 2011a; 2011b). These images cross the projection of some of the potentially active faults investigated in this study and provide the opportunity to inspect the landscape for evidence of active tectonics at a level of detail not previously available.

We inspected the lidar data visually on-screen at a scale of 1:6,000 to determine the presence or absence of scarps, offset deposits, deflected streams, and other tectonically related features. Previously mapped potential faults observed in the field during this investigation and covered by the lidar data include the Dennison Fork fault, Caribou fault, and the Midway Lakes faults. Hillshade images of the mapped traces of these faults are shown on figures 12–14. These figures also show identical images with the faults removed. The Dennison Fork fault extends across several floodplain deposits of different age associated with the Tanana River and is not expressed in the hillshade image (fig. 12). The Caribou fault also extends across Tanana River floodplain deposits as well as terraces on the north bank of the river, and sand dunes deposited on the south-facing slope of the uplands, none of which show any evidence of displacement (fig. 13). Similarly, the Midway Lakes faults are not expressed across bedrock hills, colluvial sideslopes, and floodplain deposits along their mapped traces (fig. 14). Observations derived from inspection of the lidar images, including the lack of displacement of youthful sediments and negligible topographic expression, further substantiate our field observations and demonstrate that the Dennison Fork fault, Caribou fault, and Midway Lakes faults have not been active in Holocene and likely Quaternary time.

Several lineaments observed on the lidar hillshade images are of suspicious origin. A north–northwest-trending lineament was observed extending across the bedrock hills 2.2 km north of Northway Junction southeast of the Northway Junction faults (fig. 15A). This feature is approximately 1 km long and is characterized by a linear valley extending across the crest of a broad bedrock hill, and a subtle linear drainage. The feature is not expressed along the lower colluvial slopes of the hill to the southeast and does not extend across the Tanana River floodplain deposits. Several linear features extend orthogonal to the feature on the crest of the hill. Based on its short length and lack of expression in Quaternary sediments, we suspect that this feature is an inactive bedrock fault and that the orthogonal features may be joints.

Another suspicious lineament was observed approximately 5 km southeast of Northway Junction. This lineament is about 2 km long and extends northwest from the northern side of Eliza Lake (fig. 15B). The lineament is characterized by several south–southwest-facing escarpments in bedrock with a mantle of eolian deposits. The scarp appears to continue to the northwest for a short distance but is diminished in size. A small scarp that may extend across Quaternary deposits is present along the base of the bedrock escarpment near the center of the lineament. Based on the lack of continuity of this small scarp and the length of the bedrock escarpment, as well as the lack of escarpments in the Tanana River floodplain sediments southeast of Eliza Lake, we suspect that the lineament is not a youthful fault. The escarpment may be a relict bedrock escarpment that has been buried by eolian deposition. However, because the lineament was not inspected in the field we cannot preclude it is a tectonic fault. North of this escarpment, a subtle sinuous lineament was observed (fig. 15B); this feature is also discontinuous and may be a game trail or drainage channel.

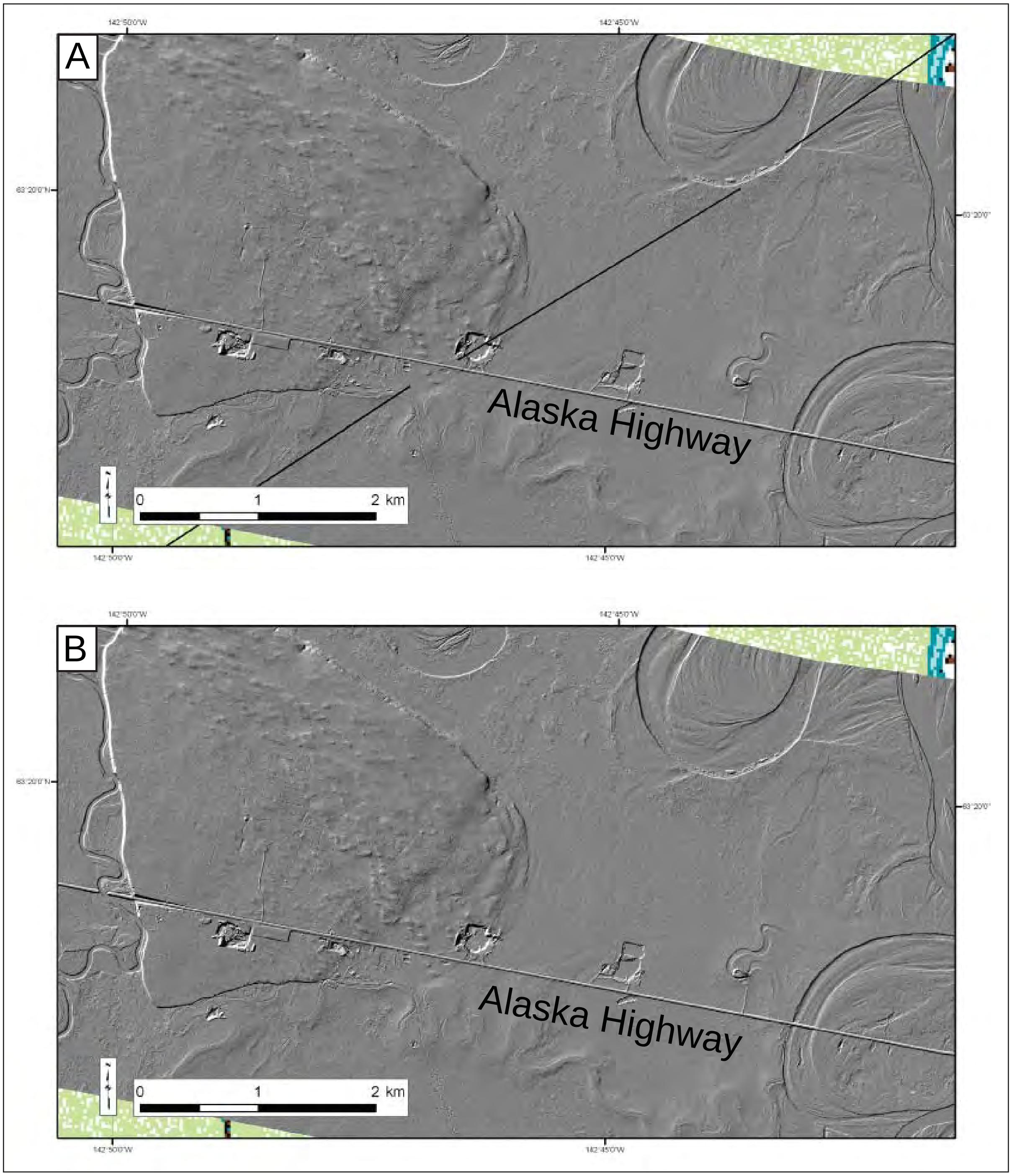


Figure 12. (A) Lidar hillshade images showing the mapped trace of the Dennison Fork fault (Woodward–Clyde Consultants, 1981). (B) Same image as A without the mapped trace, showing the lack of tectonic features in the landscape.

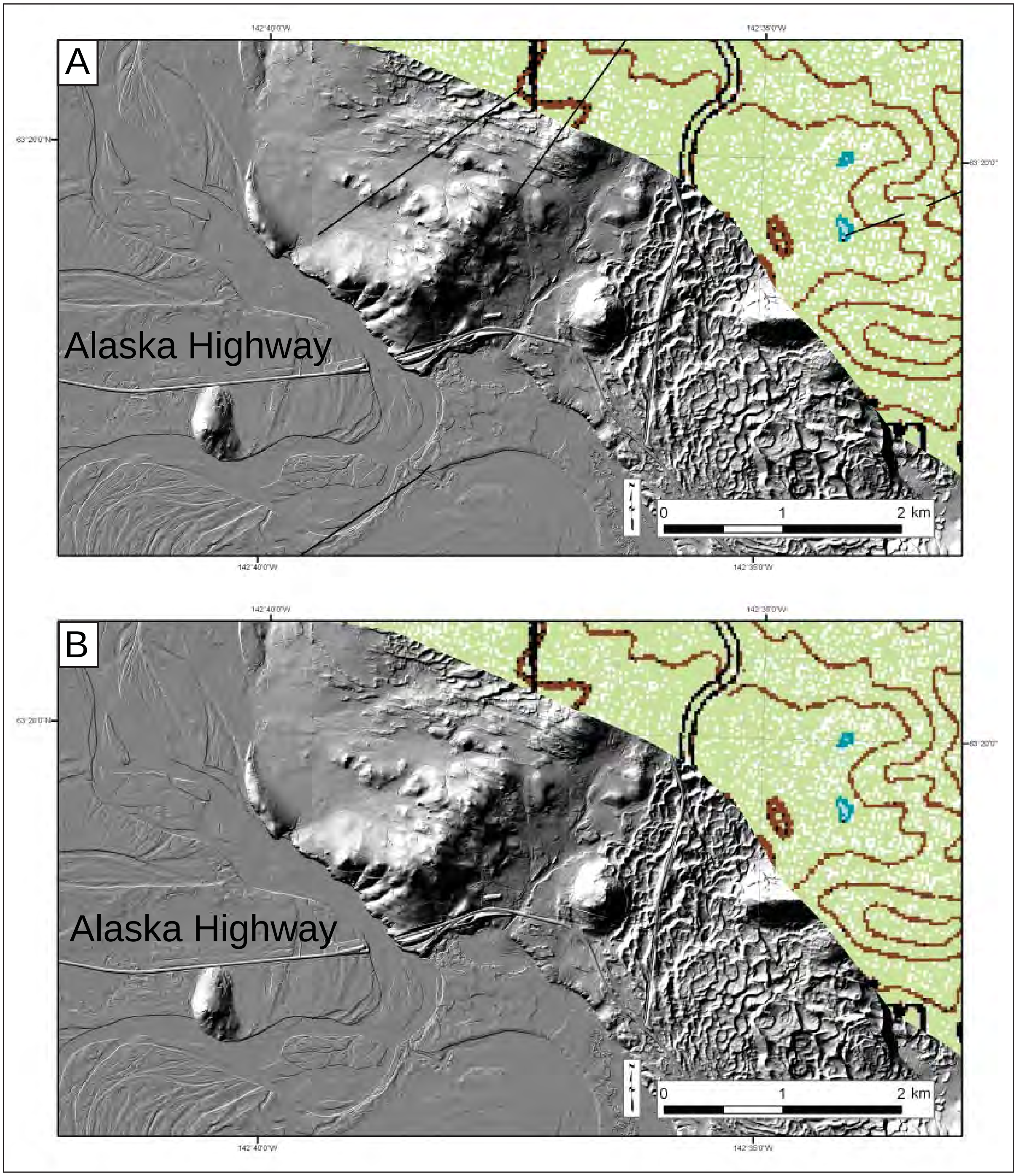


Figure 13. (A) Lidar hillshade images showing the mapped trace of the Caribou Creek fault (Woodward–Clyde Consultants, 1981). (B) Same image as A without the mapped trace, showing the lack of tectonic features in the landscape.

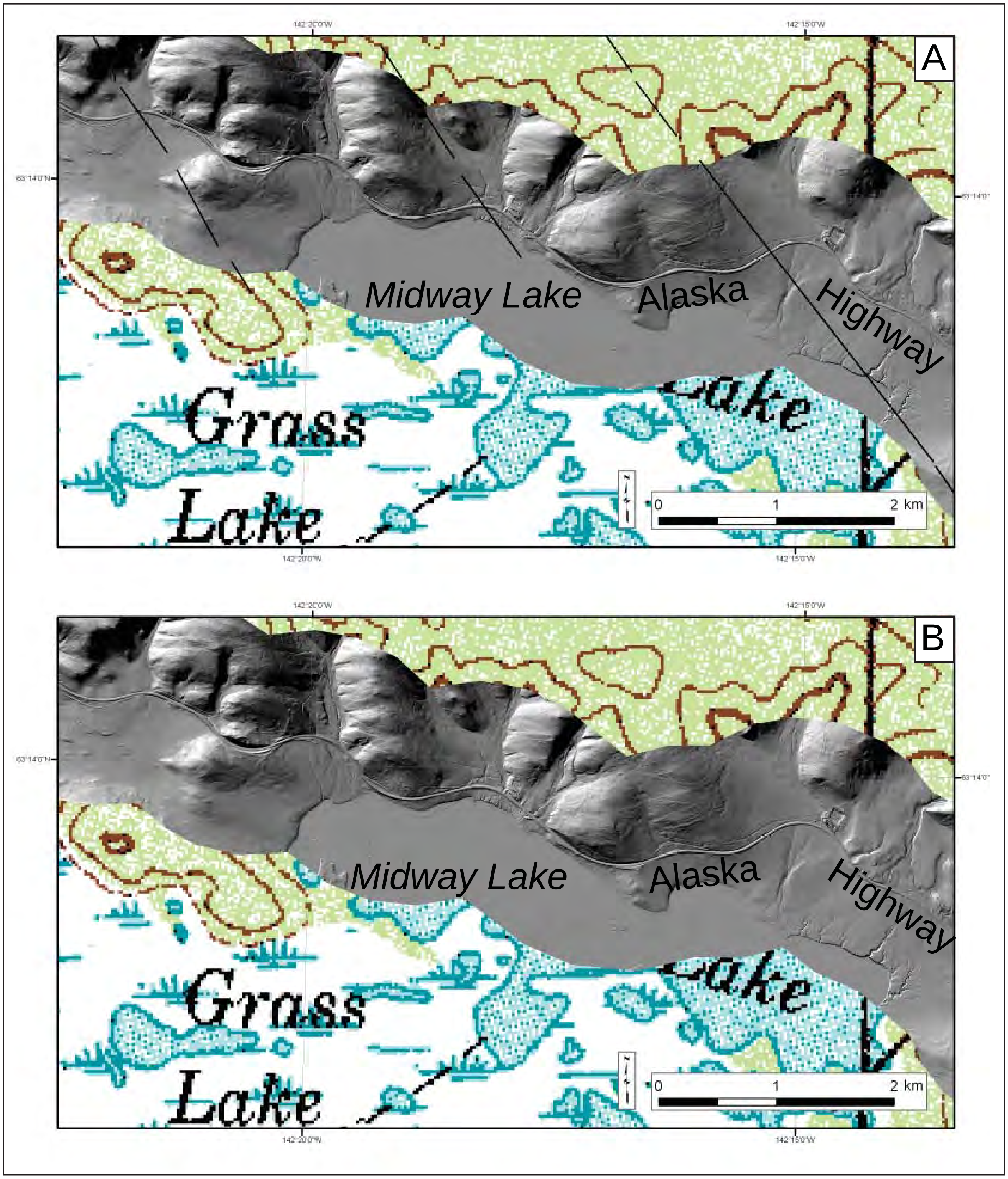


Figure 14. (A) Lidar hillshade images showing the mapped trace of the Midway Lake faults (Woodward–Clyde Consultants, 1981). (B) Same image as A without the mapped trace, showing the lack of tectonic features in the landscape.

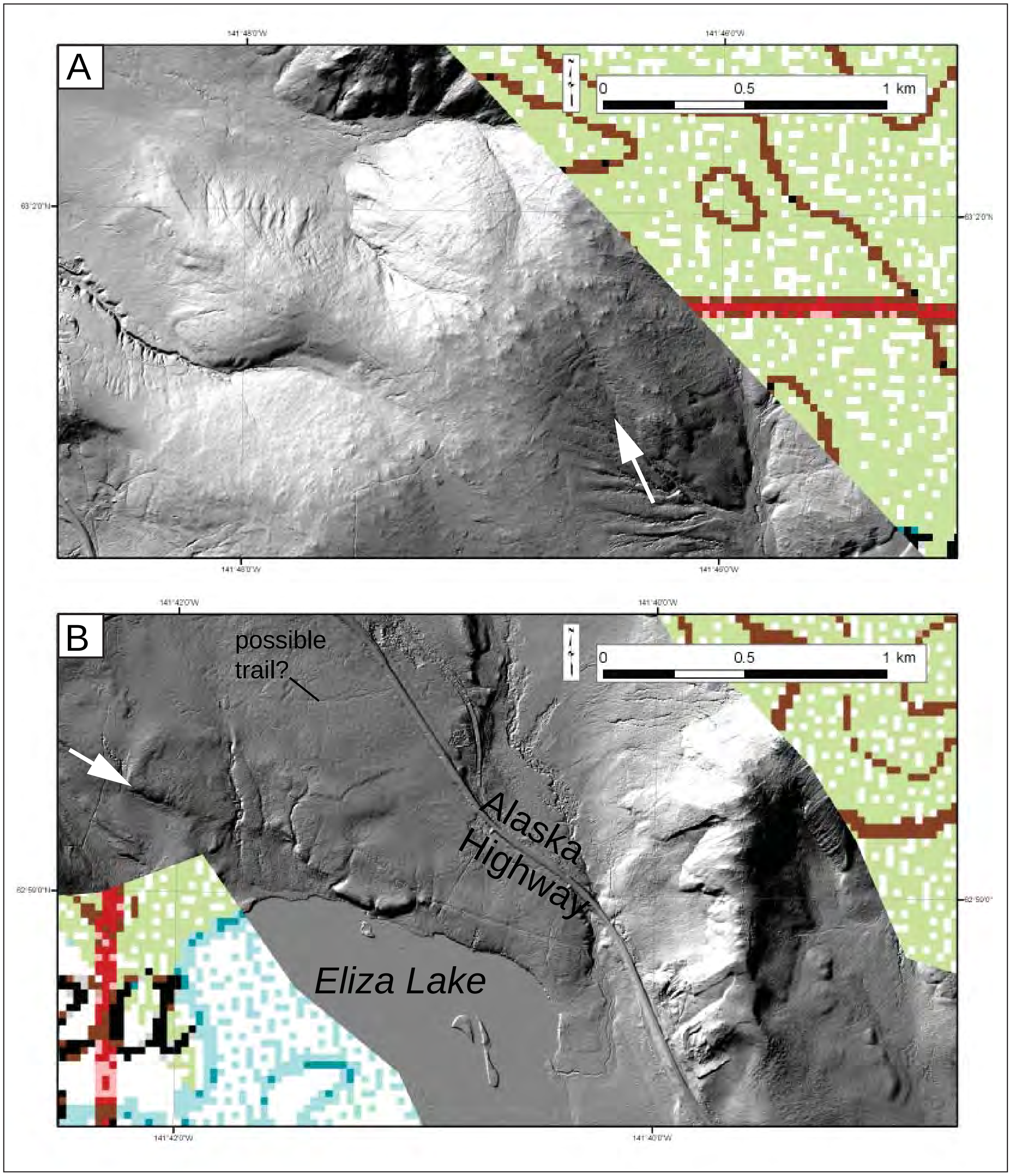


Figure 15. Suspicious features identified during inspection of lidar hillshade images (not field checked). Features indicated by white arrows. (A) Lineament extending across the crest of a rounded bedrock hill 2.2 km north of Northway Junction. (B) Lineament extending parallel to the base of the hills along the northern margin of the lowlands near Eliza Lake about 5 km southeast of Northway Junction.

DISCUSSION AND CONCLUSION

Helicopter and field surveys in and north of segment 3 of the Alaska Highway corridor study have documented the lack of late Pleistocene and Holocene surface ruptures along previously identified faults. Our reassessment of fault hazard studies conducted in the region by Woodward–Clyde Consultants (1979; 1981), combined with our field observations, has determined that the the Midway Lake faults, Northway Junction faults, Ladue lineament, Tetlin Lake lineaments, Airs Hills faults, and the Tok River lineaments (upland and Tok River segments of the Dennison Fork and Caribou Creek faults) are not active faults and should no longer be considered to be candidate significant faults in future hazard assessments. The upland segment of the Caribou Creek fault is the only fault investigated that shows tectonic geomorphic features. These features do not cut Holocene deposits and are consistent with faultline erosional features indicative of a pre-Quaternary fault.

Major active south-dipping imbricate thrust faults that bound the northern margin of the Alaska Range and are associated with the Northern Foothills Fold and Thrust Belt (NFFTB) to the west of the segment 3 study area have been identified and characterized (Carver and others, 2008; 2010; Bemis and others, 2012). These faults accommodate a component of compression across the Alaska Range, driven by convergence of the Yakutat microplate, that is transferred northwest across the Totschunda and Denali faults. The Cathedral Rapids fault is thought to be the easternmost fault of the NFFTB yet has not been described southeast of the Tok River valley, north of the junction of the Totschunda and Denali faults. We infer that the addition of slip from the Totschunda fault to the Denali fault, combined with the bend in the Alaska Range to a more east–west orientation, is responsible for the development of the NFFTB. The comparatively lesser amount of compressive deformation to the southeast of the Tok River valley is supported by the more subdued topography of the Alaska Range, the reduction in Denali fault slip rate, and a bend in the range orientations, which becomes more slip-parallel to the Denali fault.

The locus of active deformation along the northern side of the Alaska Range appears to follow the southeast curvature of the Alaska Range and the Denali fault and bend away from the segment 3 study area. In segment 3 of the highway corridor study, faults are generally northeast- and northwest-trending relict structures in bedrock that are not Holocene active faults. This pervasive structural grain is evident on orthoimagery in areas of thin soil cover across the Yukon–Tanana Upland and may reflect faults, reidel shears, and joints related to the regional pre-Neogene stress field. These relict faults cut straight across rolling gentle topography and juxtapose different bedrock types, suggesting that they are high-angle strike-slip faults. A primarily lateral sense of displacement is supported by the lack of elevated topography and long rangefronts, typical of vertical displacements.

Our findings indicate that the faults in the segment 3 study area are not active Holocene structures and do not pose surface fault-rupture hazards for proposed developments along the eastern part of the Alaska Highway corridor. However, additional site-specific investigations should be conducted to ensure that fault parameters are adequately assessed and adhere to the standard of practice for the routing, design, and construction of future infrastructure along the corridor. Because this study focused specifically on previously identified structures, it is possible that a more comprehensive study could facilitate the discovery of new, unrecognized faults in the region. In particular, the very young deposits in the Northway/Tanacross lowlands and the Tanana River valley may obscure faults that have not ruptured in the late Holocene.

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