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SURFICIAL GEOLOGY OF THE ALASKA HIGHWAY CORRIDOR, TETLIN JUNCTION TO CANADA BORDER, ALASKA

by
Richard D. Reger, Trent D. Hubbard, and Patricia E. Gallagher

Oblique view of flooded meander scroll topography along the Chisana River, Nabesna Quadrangle.
Photograph taken 07-31-08 by T.D. Hubbard.

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CONTENTS

Page

FIGURES

TABLES

SHEETS

SURFICIAL GEOLOGY OF THE ALASKA HIGHWAY CORRIDOR, TETLIN JUNCTION TO CANADA BORDER, ALASKA

by

Richard D. Reger[1], Trent D. Hubbard[2], and Patricia E. Gallagher[2]

INTRODUCTION

During 2009, the Alaska Division of Geological & Geophysical Surveys continued reconnaissance mapping of surficial geology begun in 2006 in the proposed natural-gas pipeline corridor through the upper Tanana River valley (Combellick, 2006; Solie and Burns, 2007). This program linked with the mapping of surficial geology completed in the corridor through the western Tanacross Quadrangle to the vicinity of Tetlin Junction (fig. 1) (Reger and others, 2011; Reger and Hubbard, 2010; Hubbard and Reger, 2010).

Surficial geology was initially mapped by interpreting ~1:65,000-scale, false-color, infrared aerial photographs taken in July 1978 and August 1981, and plotting unit boundaries on acetate overlays. Special attention was given to identifying geologic processes and conditions with the potential to negatively impact future development in the corridor, including faults, permafrost, mass-movement features, and areas prone to flooding and liquefaction. Potential sources of construction materials were also identified (Hubbard and Reger, in press). Information from previous geologic reports was incorporated. Verification of photo mapping was completed during the 2008 and 2009

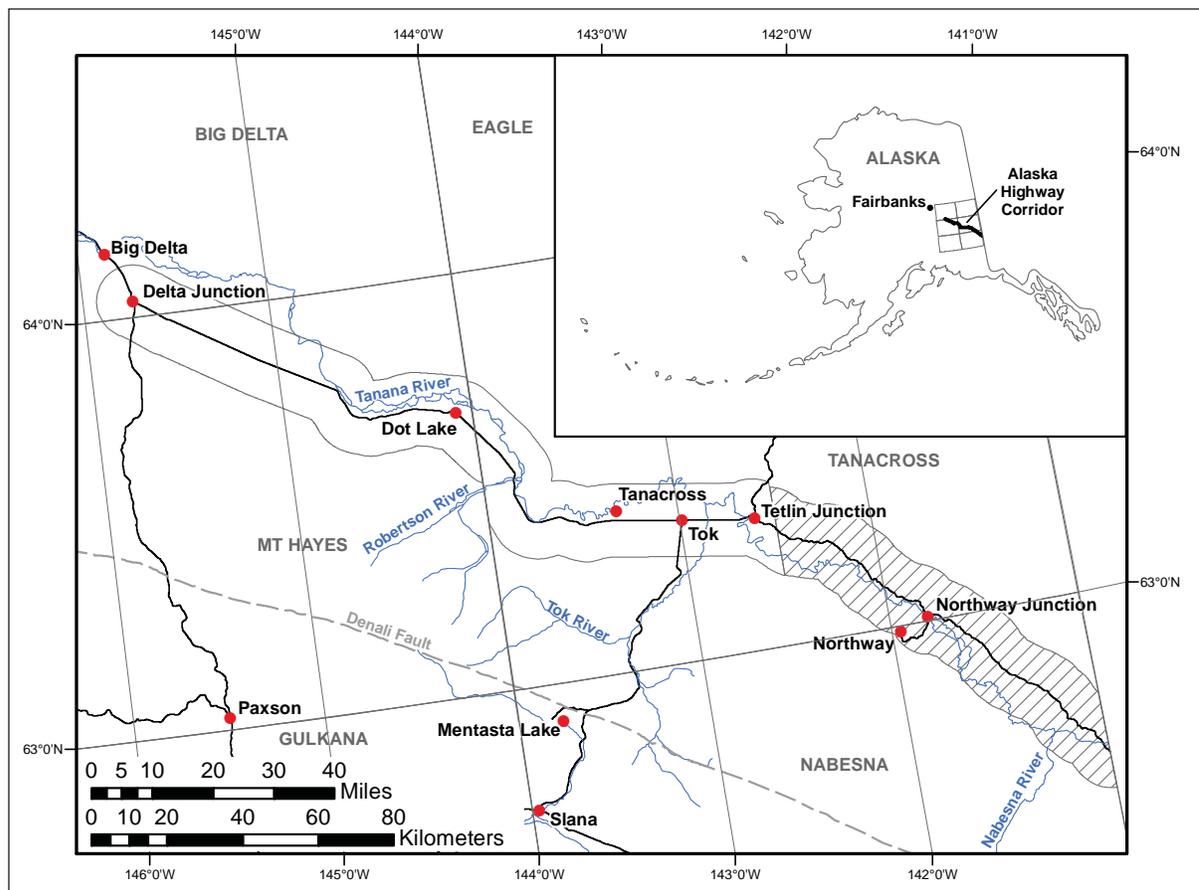
Figure 1. Location of study area in Tanacross and Nabesna quadrangles.

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field seasons, when map units were described and samples collected for analyses. Following orthorectification of the aerial photographs and attached acetate overlays, unit boundaries were digitized onscreen using ArcGIS, and the surficial geology map was prepared (sheets 1–2).

PHYSIOGRAPHY

The Northway–Tanacross Lowland is an 8- to 28-km-wide topographic trough that separates the easternmost Alaska Range from the maturely dissected, gentle slopes and broad valleys of the southeasternmost Yukon–Tanana Upland (Wahrhaftig, 1965). This elongate lowland, which has a general elevation of 1,650 to 1,800 ft (500 to 545 m), is dotted with a myriad of lakes and marshlands through which thread the sloughs and channels of the Tanana, Nabesna, and Chisana rivers. Foster (1970) mapped the northern one-third of the lowland as silt and sand alluvium bordered by bands and fields of sand dunes. Foster (1970) and Richter (1976) mapped the southern two-thirds of the lowland as intricately mixed fluvial and lake deposits. On the proximal fan of the Nabesna River, Richter (1976) identified five broad, radiating fingers of active granular floodplains and low fluvial terraces that separate slightly higher and older wedges of mixed fluvial and lacustrine deposits west of Northway. To the east, the granular apron of the combined fans of Stuver Creek and the Chisana River spreads northeastward into scattered bedrock hills of the southeastern Yukon–Tanana Upland. North of these broad alluvial fans in the riverine lowland is a broad complex of fluvial and lacustrine sediments bounded by and containing areas of stabilized and reworked sand dunes in lowlands against and between rounded bedrock hills.

Northeast of the Northway–Tanacross Lowland in the southern Yukon–Tanana Upland, rounded bedrock hills reach elevations of 2,300 to 3,700 ft (700 to 1,120 m) above broad stream valleys with gently sloping walls and a general floor elevation of 2,100 to 2,500 ft (636 to 760 m). Valley walls and floors of lengthy, underfit, low-gradient, upper tributaries of northeast-flowing major streams, such as the Ladue River and the Dennison Fork of the extensive and entrenched Fortymile River network (Yeend, 1996), have generally been buried by undifferentiated eolian sediments, retransported eolian deposits, and slope colluvium. In these ancient, well-integrated drainages, short reaches through narrow bedrock canyons between broad basins hint at complex tectonic and drainage histories[3]. Many valleys have asymmetric cross profiles, perhaps in response to different rates of gelifluction on slopes with different aspects (Hopkins and Taber, 1962; French, 2007, p. 22). In contrast, short, relatively steep, south-flowing tributaries of the Tanana and Chisana rivers are much younger and are eroding headward into the upland. For example, Gardiner Creek displays a prominent elbow of capture at the corridor limit in the central Nabesna D-1 Quadrangle, at the location where that short, headward-eroding tributary of the Chisana River intersected and beheaded the former lengthy course of Scottie Creek, another Chisana River tributary (fig. 2; sheet 2). Just downstream from this elbow of capture Gardiner Creek passes through a distinctive, short canyon where it crosses a sand-blanketed bedrock ridge. This short canyon could be evidence of local deformation that raised the underlying bedrock ridge, causing Gardiner Creek to cut downward through the sediment cover, implying fairly recent uplift and an antecedent origin for this reach (Douglass and others, 2009). Downstream from the bedrock canyon Gardiner Creek is underfit.

SURFICIAL GEOLOGY

LOWLAND FLUVIAL–LACUSTRINE COMPLEX

Although Post and Mayo (1971) identified the Nabesna River as a drainage affected by outburst flooding, we do not recognize evidence of massive outburst flooding upstream of the Tok fan in the upper Tanana River valley. Features like rock-defended terraces, broad gravel expansion fans, massive gravels and sands locally containing exceptionally large boulders, complexes of large flood dunes composed of pebbly coarse sand, flood escarpments, and prow-shaped bedrock outcrops are absent (Reger and others, 2008), indicating that the Tok River valley is the principal source of former massive outburst floods down the Tanana River (Reger and Hubbard, 2009; Reger and others, 2011). In general, floodplain-marginal lakes in the upper Tanana River valley have a different morphology

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[3]Tempelman-Kluit (1980) summarized physiographic and geologic evidence for the Yukon Plateau, a dissected erosion surface of low relief and regional dimensions east of the Yukon–Tanana Upland in northwestern Canada. He noted the presence of coarse fluvial gravels and volcanics along the transcurrent Tintina and Shakwak–Denali faults and proposed that the Yukon Plateau developed during the early Tertiary when transcurrent faulting occurred. According to Tempelman-Kluit, the Yukon Plateau was uplifted during normal faulting when the Tintina and Shakwak trenches developed in post-Miocene time. Lacking a regional seismic-monitoring network, he suggested that the Tintina and Shakwak–Denali faults have long been inactive. However, seismic monitoring in interior Alaska has demonstrated that significant earthquakes occurred in 1972 along the Tintina fault and in 2002 and 2004 along the Denali fault (Ruppert and others, 2008).
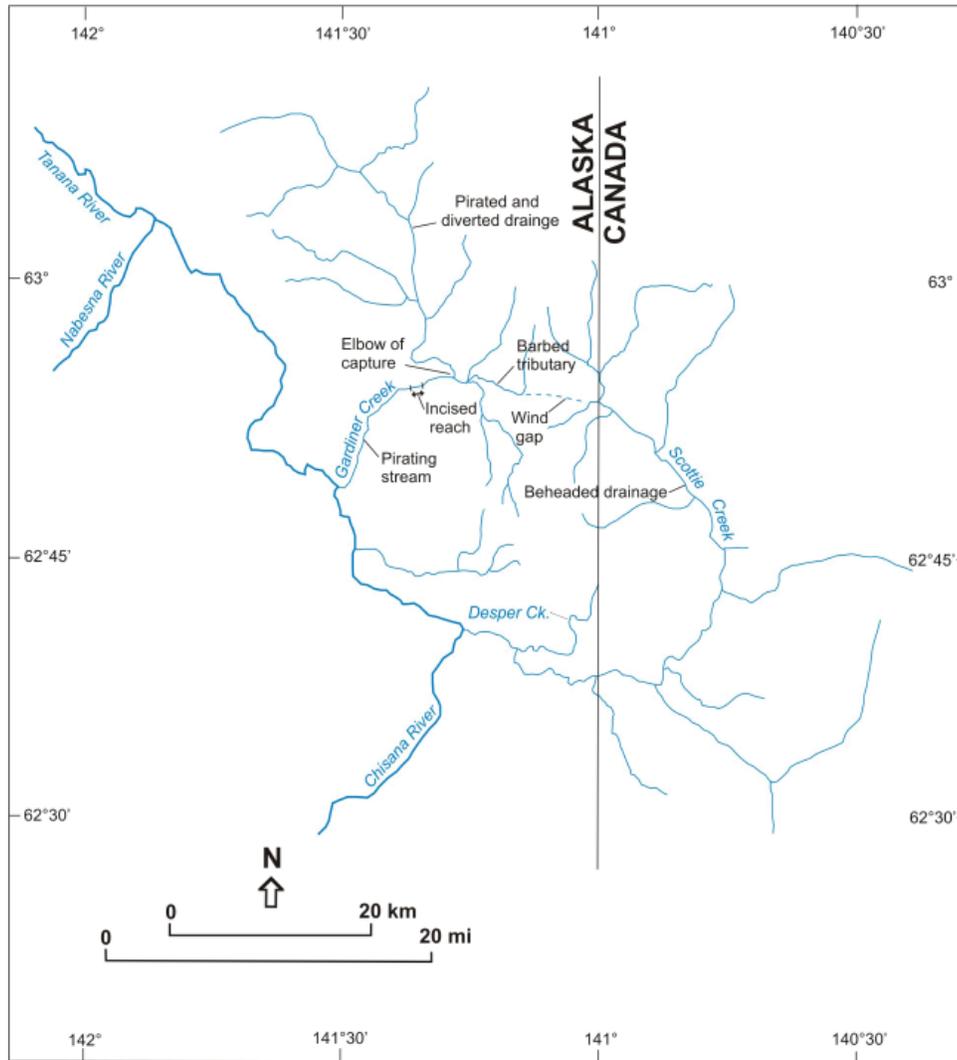
Figure 2. Features demonstrating piracy by Gardiner Creek of headwaters of much longer former course of Scottie Creek.

than similarly located lakes in reaches of the Tanana River that were subject to former outburst floods. In the upper Tanana River valley, floodplain-marginal lakes are generally very shallow (~3–4 m deep) and contain extensive complexes of lake deltas and natural levees, indicating that they were impounded by gradual alluviation of the valley floor, rather than the sudden growth of massive expansion fans. Complexes of thaw lakes on abandoned-floodplain surfaces are present primarily upstream of the Tok fan.

In contrast to the meander belt of the Tanana River downstream from the junction with the Tok River, meander-scroll topography in the Northway Lowland is preserved only locally on inactive floodplains. On older surfaces, these small relief features are buried beneath fluvial sediments, lowland loess, eolian sand, and vegetation. Instead of lateral migration within a well-defined meander belt, most channel changes in the lowland apparently occurred suddenly by avulsion during seasonal floods. On terraces, thaw lakes are large and typically have scalloped shorelines resulting from thermokarst modification of perennially frozen, ice-rich silts and sands (Wallace, 1948). Muddy lakes with actively sloughing steep banks not connected to active drainage channels and large lakes in inactive and abandoned flood channels are evidence that thermokarst modification is a very active process in the lowland.

In inactive and abandoned floodplains dominated by intricately mixed fluvial and lacustrine deposits, seasonal floods bring turbid river waters into lake basins through connecting narrow stream channels, causing lake areas to expand. In larger lakes, natural levee–lake delta complexes are deposited near active channels during flooding

(fig. 3). During low-water intervals, lakes drain into the rivers through these same channels and lakes shrink in size, leaving wet lowlands in areas formerly inundated. Large lakes on terraces isolated from active channels generally do not contain flood deltas.

Maximum relief of ~3 m in the lowland is provided by stabilized sand dunes that are typically surrounded by wet marshlands. Aggradation of major streams, like the Nabesna and Chisana rivers, appears to be promoting a corresponding rise in water table in the lowland, at least close to active stream channels.

Radiocarbon ages indicate that deposits initially described as alluvial and eolian by Fernald (1965a) in Riverside Bluff southeast of Tetlin Junction are Donnelly and Holocene in age (table 1, sheet 1). Laminated sand and silt exposed near the middle of the Riverside Bluff section, which date 25,800 ± 800 RC yr B.P. (W-1174)
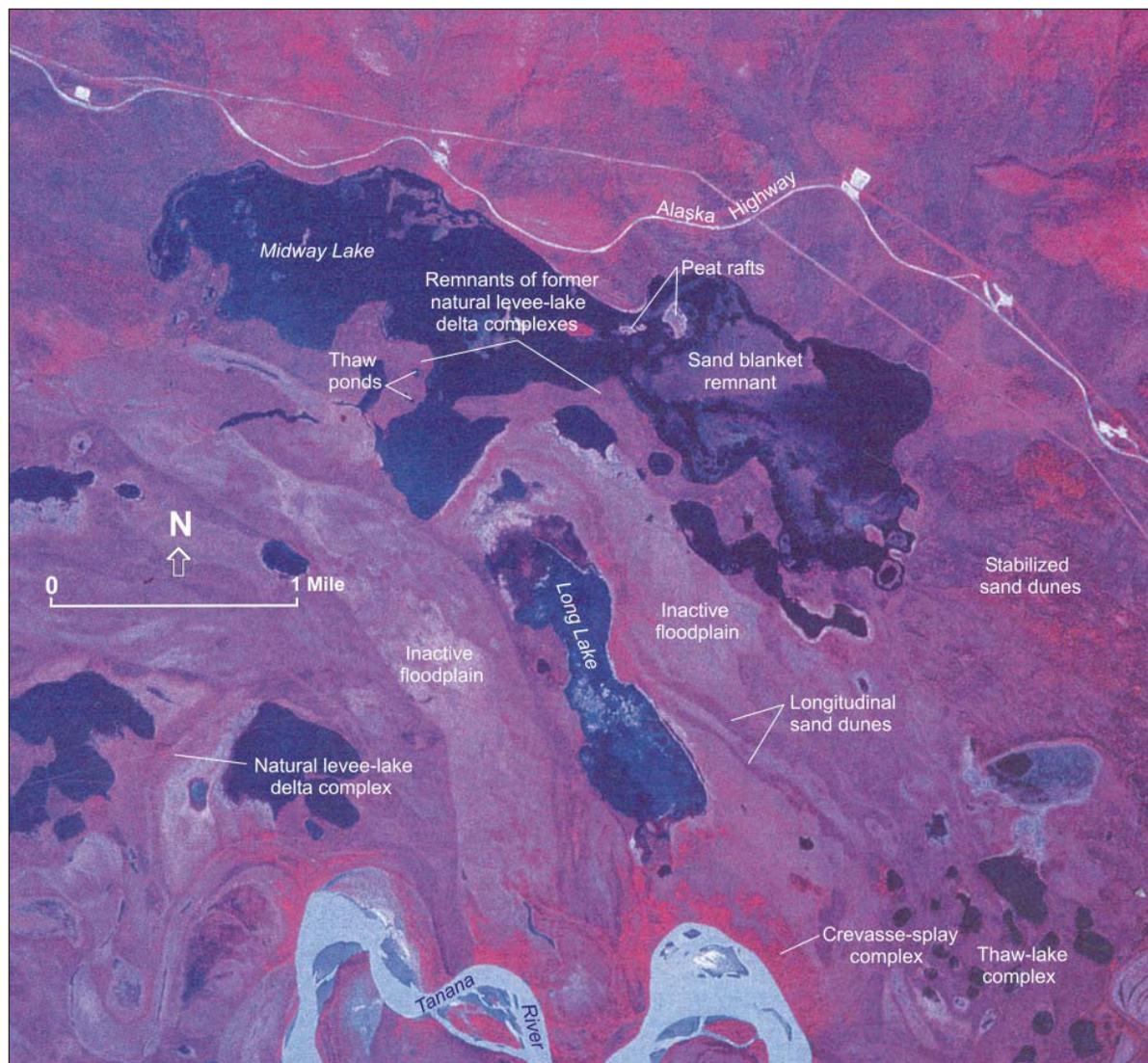
Figure 3. Fluvial, eolian, and thermokarst features near Midway Lake, north-central Tanacross A-3 Quadrangle. Thaw ponds and lakes indicate remnants of natural levee–lake delta complexes are fine grained and ice rich. A natural levee–lake delta complex divides lake west of Long Lake. Scalloped southeastern shoreline of Midway Lake is evidence that stabilized and frozen sand dunes are locally ice rich or overlie fine-grained, ice-rich, frozen sediments. Orientations of longitudinal sand dunes on inactive floodplain of Tanana River indicate depositing winds consistently blew from the northwest in this part of the upper Tanana River valley. Thaw lake complex in southeastern corner of figure developed on fluvial terrace that predates inactive floodplain (Alaska High Altitude Photograph ALK 60 CIR 21-341, taken July 1978).

Table 1. Summary of radiocarbon dates associated with late Quaternary deposits in Alaska Highway corridor, Tanacross and Nabesna quadrangles.

Map locality[a]	Material dated and stratigraphic context	Chronological significance	Laboratory number	Radiocarbon age (RC yr B.P.)	Source
RC-11	Thin organic layer 18.5 m above base of 25-m-thick sand and silt unit (fig. 4)	Age of sand and silt unit in Riverside Bluff section	W-1174	25,800 ± 800	Fernald (1965a)
RC-12	Wood, peat, and organic silt and sand from 1 m above base of 4.6-m-thick layer (fig. 4)	Minimum age of nonglacial interval prior to last major glaciation. Near base of Riverside Bluff section	W-976	>42,000	Fernald (1965a)
RC-13	Black peat from 1 m above base of 6-m-thick fluvial–colluvial section above thick eolian sand (fig. 4)	Minimum age of eolian sand in Riverside Bluff section	W-1167	6,200 ± 300	Fernald (1965a,b)
RC-14	Aquatic plant debris from 0.6-m-thick organic layer between 3.7- and 5.1-m-thick eolian sand layers (fig. 5)	Dates period of local eolian sand deposition in Riverside Bluff section	I-11,704	11,880 ± 180	Carter and Galloway (1984)
RC-15	Aquatic plant debris from 0.6-m-thick organic layer at base of eolian sand unit (fig. 5)	Dates beginning of local eolian sand deposition in Riverside Bluff section	USGS-1037	12,230 ± 120	Carter and Galloway (1984)
RC-16	*Equus* astragalus bone in retransported loess (fig. 16)	Dates age of retransported horse bone and maximum age of enclosing sediments	Beta-252319 (AMS)	40,590 ± 600	Identified by R. Dale Guthrie (oral commun., 09/18/08)

[a]Numbers for sample localities in sheet 1 continue from designations for radiocarbon-sample localities initiated in Reger and others (2008, table 1) and continued in Reger and others (2011, table 1).

(RC-11, fig. 4, table 1), were initially interpreted to be fluvial by Fernald (1965a, fig. 3), but were later interpreted to be lake sediments by Carter and Galloway (1984) (fig. 5). We suggest that the section beneath the eolian sands in Riverside Bluff could represent an expansion-fan and slackwater-basin complex deposited on a floodplain and in adjoining shallow floodplain-marginal lakes during early Donnelly floods. Fernald (1965a) dated woody peat beneath the unconformity at the base of the thick sand section in lower Riverside Bluff at >42,000 RC yr B.P. (W-976) (RC-12, fig. 4, table 1), indicating MIS stage 3 or 4 deposition.

EOLIAN AND RELATED DEPOSITS

EOLIAN SAND

Deposition of eolian sand was widespread from the Tetlin Junction dune field southeastward through the Alaska Highway corridor, where gray eolian sand beneath a thin loess cover discontinuously blankets and laps against bedrock ridges and hills of the southern Yukon–Tanana Upland (fig. 6A). These deposits form a discontinuous
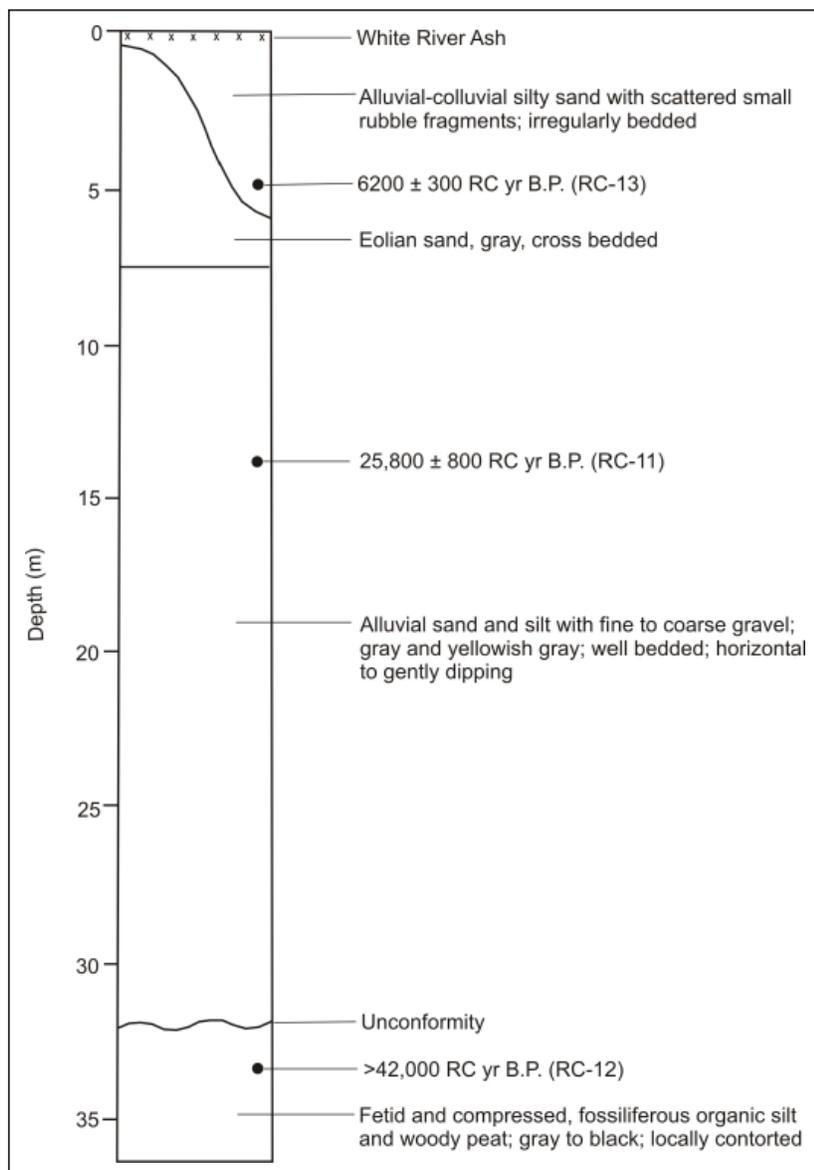
Figure 4. Composite stratigraphic section exposed in Riverside Bluff upstream from mouth of Bitters Creek as described by Fernald (1965a, fig. 3), including radiocarbon samples RC-11 through 13 (sheet 1, table 1).

belt of stabilized dunes with up to 19 m of relief along the Alaska Highway (fig. 6B), and discontinuously cover the lowland (sheets 1 and 2). A fairly thick blanket of stratigraphically complex, undifferentiated eolian deposits blankets rounded ridges and hills as well as lowlands of the southern Yukon–Tanana Upland. Steep first-order tributaries have cut deep gullies by headward erosion into the thick eolian blanket. After periodic wildfires destroyed or disrupted surface vegetation, freshly exposed eolian sediments were at least locally swept into dunes where winds had adequate velocities and duration.

Moderately indurated Bt horizons in soil profiles on steep, permafrost-free, south-facing slopes indicate that some of the eolian sand may date back to the penultimate glaciation (fig. 7). At and near the base of the gray eolian sand overlying schist bedrock in Material Site 62-1-020-5 in the east-central Tanacross A-3 Quadrangle (sheet 1, locality V-1), ventifacts of slightly modified, angular vein-quartz fragments up to 8 cm across exhibit surface polish, shallow surface etchings and pits, and sharp edges. The sharp edges are probably retouched edges of fracture fragments and not converging facets carved on well-developed ventifacts by windblown sand. These quartz ventifacts are distinctively stained pinkish gray (5YR7/2) to pink (5YR7/3 and 5YR7/4). At a second ventifact locality on
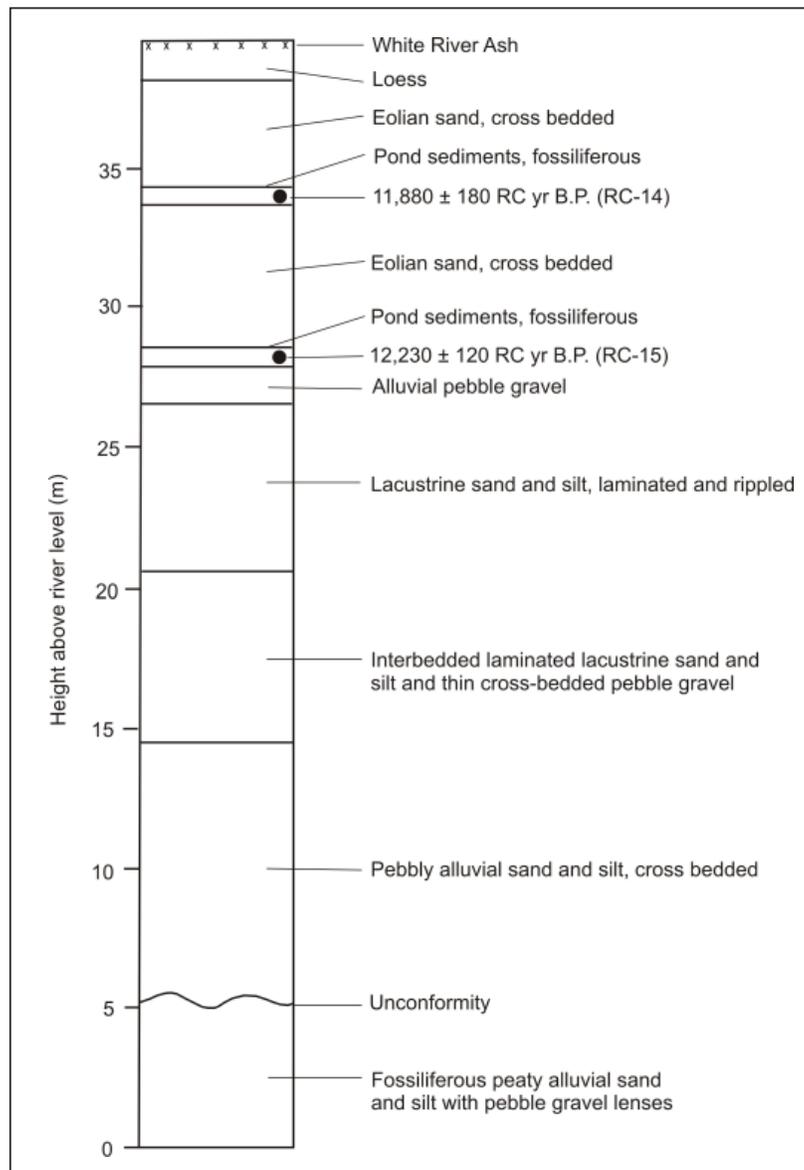
Figure 5. Stratigraphic section in Riverside Bluff downstream from mouth of Bitters Creek as described by Carter and Galloway (1984, fig. 41), including radiocarbon samples RC-14 and 15 (sheet 1, table 1).

Figure 6A. Rounded, weathered granitic tor rises above eolian sand blanket in Material Site 62-1-019-5 north of Alaska Highway milepost 1280.4 in the northeastern Tanacross A-3 Quadrangle. Aplite dikes and mafic inclusions stand up to 10 cm in relief. Scattered white spruce and quaking aspen trees and kinnikinnick-grass mat indicate this south-facing slope is xeric. Yellow shovel handle is 1 m long (photograph taken 8-11-08 by R.D. Reger).

Figure 6B. View south–southwest of roadcut through large sand dune near Alaska Highway milepost 1246, west-central Nabesna D-1 Quadrangle. Balsam poplar, white birch, and robust black spruce trees are typical of well-drained sand-dune crests in this area (photograph taken 8-14-09 by R.D. Reger).

Paradise Hill in the south-central Nabesna D-1 Quadrangle (sheet 2, locality V-2), the eolian sand cover is ~1 m thick, and angular, frost-rived fragments of quartzose gneiss and mafic schist have been polished by wind-blown sand.

On the floor of the lowland near Northway along the southwestern margin of the corridor, eolian sand blankets feature stabilized longitudinal dunes between Nuziamundcho and Big John lakes southeast of the Tanana River (sheet 1) and southeast of the Nabesna River (sheet 2). Orientations of longitudinal dunes and associated hairpin dunes indicate that the floodplains of both the Tanana and Nabesna rivers were sources of abundant sand entrained by winds consistently blowing parallel to the corridor axis from the northwest. The age of these longitudinal dunes is not known. Scalloped margins of these sand blankets in the vicinity of Northway, document encroachment of laterally migrating streams into dune areas.

During the penultimate and last major glaciations, strong katabatic winds swept downslope across outwash fans and aprons at the mouths of major tributary valleys all across the northern flank of the eastern Alaska Range, entraining and transporting sand and silt into nearby lowlands and into the southern Yukon–Tanana Upland (Thorson and Bender, 1985; Lea and Waythomas, 1990; Muhs and others, 2003; Muhs and Budahn, 2006). We suggest that north-blowing katabatic winds entrained large volumes of sand and silt from the outwash complex in the Chisana River–Stuver Creek drainages and the adjacent riverine lowlands and deposited a massive amount of sand against bedrock hills and in the lowlands of the adjacent Yukon–Tanana Upland (fig. 8). The north–northeast orientations of transverse dunes in the Gardiner Creek dune field are evidence that summer winds blowing from the northwest and west subsequently reworked the abundant eolian sand to form parabolic dunes that are now stabilized (fig. 9). Tributaries of Gardiner Creek and other local drainages appear to be clogged by dune sand, lowland loess, and retransported eolian sediments, forming dune-dammed ponds and lakes, and numerous small thaw lakes are present in ice-rich silts (sheet 2). However, not all small lakes in the Gardiner Creek lowland and adjacent areas are dune impounded or thaw lakes; several are impounded behind large beaver dams in deeply incised drainages (fig. 10).

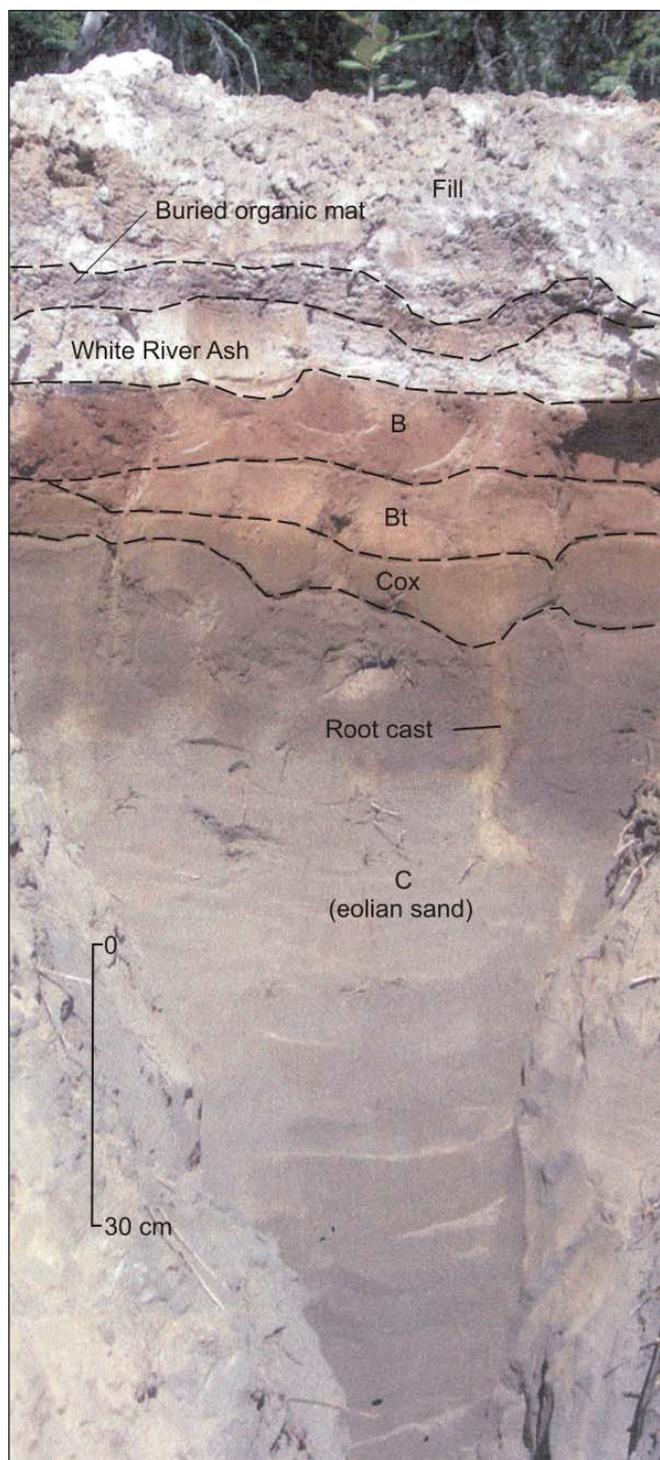Figure 7. Soil profile (SP-14) in eolian sand blanket exposed in Material Site 62-1-020-5 on ridge crest north of Alaska Highway milepost 1276.9 in northeastern Tanacross A-3 Quadrangle (sheet 1). Removal of 0.9- to 1.8-m-thick sand blanket overlying frost-rived schist bedrock exposed scattered quartz ventifacts at and near base of eolian sand. Moderately indurated **Bt** horizon indicates profile could be of penultimate glacial age.
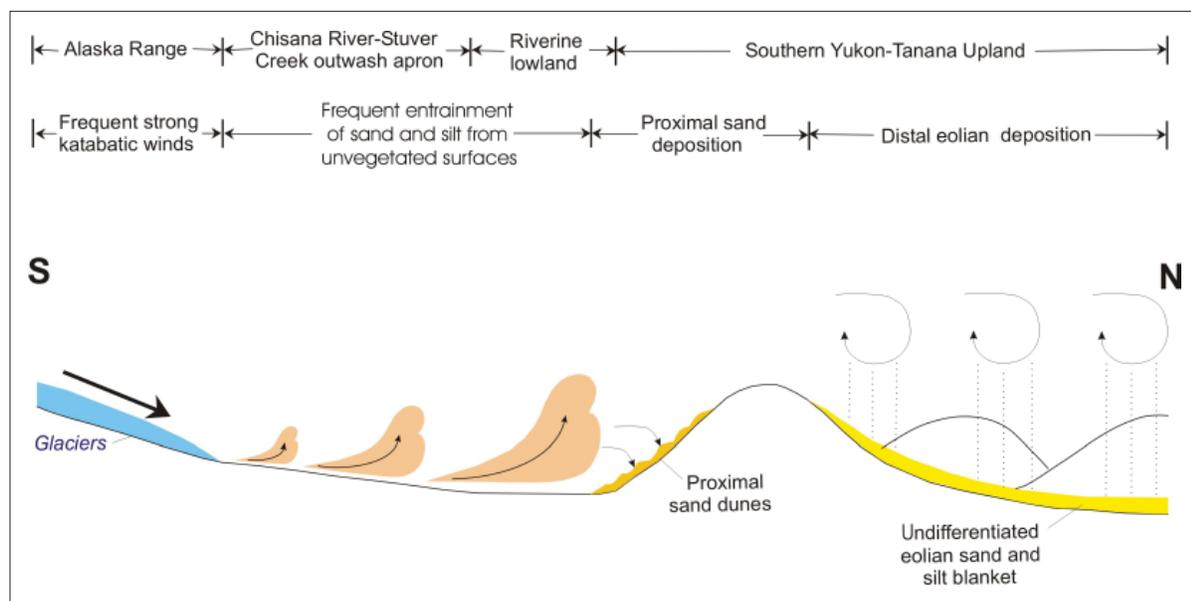
Figure 8. Model of eolian processes and deposits during penultimate and last major glaciations in southeastern Northway–Tanacross Lowland, Nabesna Quadrangle.

Several test pits excavated into frozen sand dunes encountered fine to medium sand with up to a trace of silt beneath 15 to 30 cm of silty loess. Depths to permafrost ranged from 45 to 68 cm, and little visible ice was observed. Analyses of moisture samples indicate that soil moisture in eolian sand ranges from 17 to 45 percent (table 2, sheets 1 and 2). Thawed samples were thixotropic where silty.

Typical vegetation on stabilized dunes with good near-surface drainage includes mixed robust black spruce, paper birch, and balsam poplar trees with scattered willow shrubs and moss mats up to 15 cm thick (fig. 11). In this well-drained setting, sola are as deep as 0.6 m and provide evidence of at least local dune reactivation after deposition of the White River Ash 1.89 RC ka ago (Schaefer, 2002) (fig. 12). Aspen trees typically grow on well-drained, south-facing slopes. In moist interdune areas, where near-surface drainage is impeded by shallow permafrost, the dominant vegetation is scattered to dense stands of stunted black spruce trees and willow shrubs with moss mats 23 to 28 cm thick; in wetter areas, sedge tussocks are typically present.

Thin loess covers bear Holocene to probable penultimate weathering profiles, indicating that near-surface eolian sand was deposited over a long time interval. Based on radiocarbon dating, we suggest that dune sands were deposited primarily during glacial stades when katabatic winds were more frequent and powerful and sand sources were generally unvegetated (Thorson and Bender, 1985). Fernald (1965a, b) dated black peat overlying eolian sand exposed in upper Riverside Bluff at 6,200 ± 300 RC yr B.P. (W-1167) (RC-13, fig. 4 and table 1, sheet 1), providing a minimum age for the main period of dune activity there. Carter and Galloway (1978, fig. 41) interpreted sands with large-scale cross bedding in the upper section at Riverside Bluff as eolian, and their published radiocarbon ages of 11,880 ± 180 RC yr B.P. (I-11,704) (RC-14, fig. 5 and table 1, sheet 1) and 12,230 ± 120 RC yr B.P. (USGS-1037) (RC-15, fig. 5 and table 1, sheet 1) demonstrate that the main episode of eolian deposition there occurred during the latter part of the last major glaciation. During Holocene climate amelioration and expansion of the boreal forest, periodic wildfires destroyed vegetation, locally reactivating the eolian sand blanket.

EOLIAN AND RETRANSPORTED SILT, INCLUDING TEPHRAS

Bedrock hills and ridges along the southern Yukon–Tanana Upland are thinly to thickly covered by loess that caps the eolian sand blanket. Loess blankets range in thickness from ~10 to 25 cm, with a measured maximum of ~97 cm. In samples of frozen inorganic silt (loess) recovered from two test pits, gravimetric soil moisture[4] was 21 to 39 percent (table 2; sheets 1 and 2). Depths to permafrost ranged from 25 to 55 cm. Although no visible ice was observed in frozen loess, thawed silty loess was thixotropic. In frozen organic silty loess and retransported

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[4]Percent soil moisture = [weight frozen or moist soil sample minus weight dry soil sample divided by weight dry soil sample] multiplied by 100.
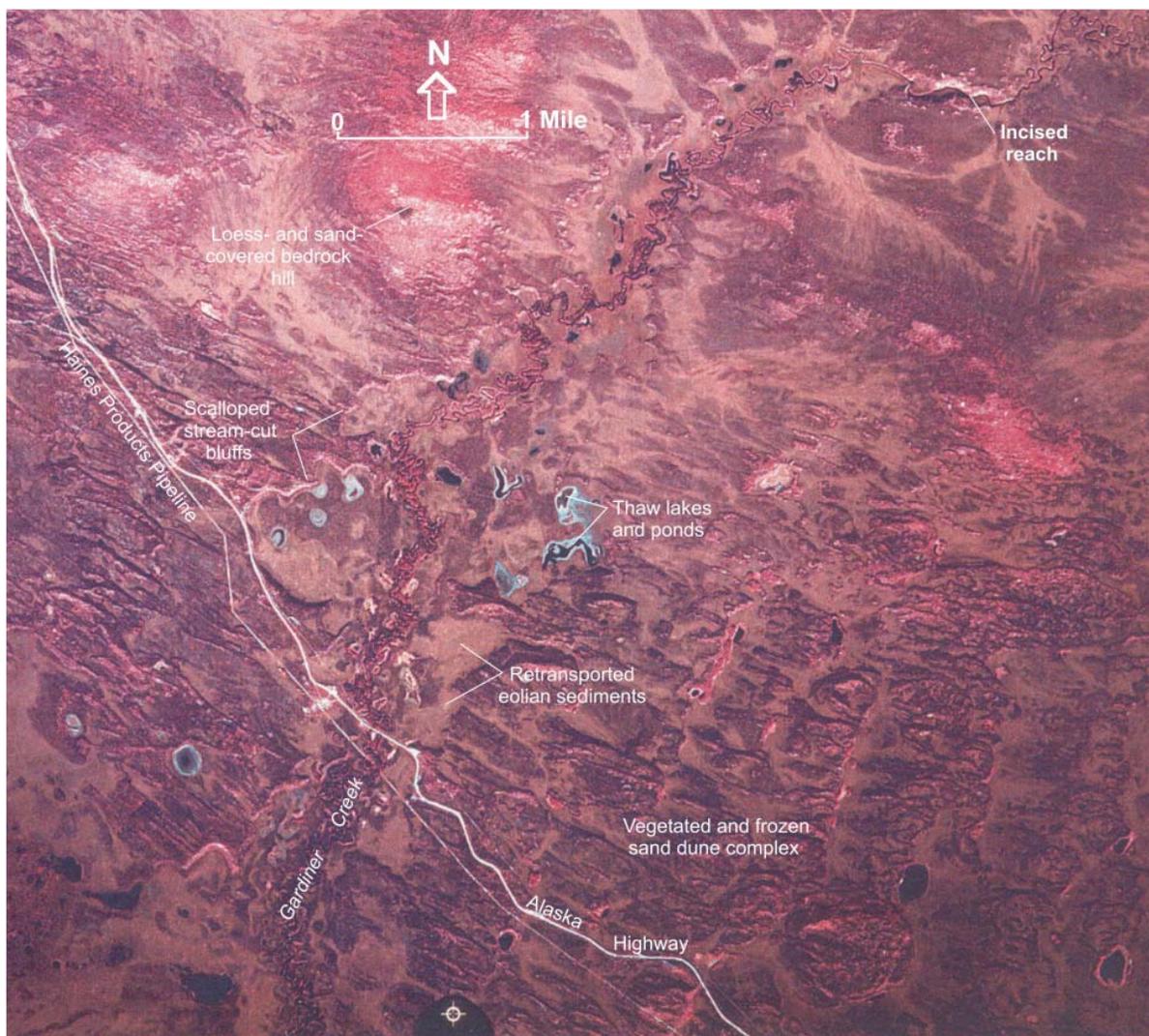
Figure 9. Stabilized, frozen sand dunes and retransported eolian sediments in Gardiner Creek lowland, west-central Nabesna D-1 Quadrangle. Waves of parabolic transverse sand dunes, now vegetated by black spruce and broadleaf trees, were deposited by strong, consistent winds from the northwest in this section of upper Tanana River valley. Thaw ponds and thaw lakes are evidence that eolian sediments are frozen and locally ice rich. Sedge wetlands on frozen, ice-rich, retransported eolian sediments demonstrate that subsurface drainage is widely impeded. Comparison of radii of scalloped bluffs and former stream channels along base of stream-cut bluffs with radii of tortuously winding Gardiner Creek reveals that modern stream is underfit for valley it occupies (Alaska High Altitude Photograph ALK 60 CIR 3944, taken August 1981).

organic silt, depths to permafrost ranged from 34 to 60 cm. Analyses of four gravimetric soil moisture samples indicate that 33 to 345 percent soil water is present in lowland and reworked loess (table 2). Ground ice was not visible in most reworked silt samples, but scattered clear crystals ≤3 mm across were visible in the sample with the highest moisture content. These sediments are typically thixotropic when thawed.

Schaefer (2002) investigated a 10-m-thick eolian section southeast of Tetlin Junction near Alaska Highway milepost 1284 in the Tanacross A-3 Quadrangle (fig. 13, locality T-1, sheet 1), and identified several Quaternary tephras (fig. 14). The youngest volcanic-ash layer, the White River Ash, crops out just beneath the surface organic mat. This bilobate plinian tephra is widespread in east-central Alaska and the west-central Yukon Territory (Robinson, 2001; Lerbekmo, 2008). Along the Alaska Highway in the southeastern corridor, the northern lobe varies in thickness from 10 to 16.5 cm (Hanson, 1965, fig. 1, table 2, samples 48–51). The northern lobe was apparently ejected ~1.9 RC ka from a vent near the summit of glacier-covered Mt. Churchill, a 15,535 ft (4,735 m) peak in

Figure 10. Aerial view of small lake impounded behind large beaver dam in incised drainage in Gardiner Creek dune field. Prostrate paper birch trees around margins of lake and on upper walls of stream valley were cut down by beavers (photograph taken 07-31-09 by R.A. Combellick).

the western St. Elias Mountains (Lerbekmo and Campbell, 1969; Winkler, 2000). Clague and others (1995) dated the outer growth rings of standing trees entombed by White River Ash of the eastern lobe and obtained a weighted mean age of 1,147 cal. yr B.P. (n=4). Based on microprobe analysis of proximal pumice glass and distal tephra glass, which is supported by isopach maps of the northern and eastern lobes, Richter and others (1995) suggested that plinian eruptions from the Mt. Churchill vent distributed both the northern and eastern lobes. That source was later questioned by Mashiotta and others (2004), who found no White River Ash in a 460-m-long ice core collected between Mts. Mitchell and Bona.

The Old Crow tephra is a regionally important stratigraphic marker. For several years, based on isothermal-plateau fission-track analyses of glass shards, the age of the Old Crow tephra was considered to be 140 ± 10 ka (Preece and others, 1999). However, the age was recently recalculated to be 131 ± 11 ka by Péwé and others (2009)[5]. Similarly, uncertainty exists about the age of the Sheep Creek tephra. Thermoluminescence dating of loess above and below the Sheep Creek tephra in the Fairbanks area by Berger and others (1996) indicates that the age of the Sheep Creek-F tephra there is 190 ± 20 ka, but optical (OSL) dating of this multi-layered volcanic ash in the Yukon forced reassessment of this age (Westgate and others, 2008). Today, Sheep Creek tephra layers C, K, and A, which are present at several localities from Canyon Creek between Delta Junction and Fairbanks in the west (fig. 1) (Weber and others, 1981; Hamilton and Bischoff, 1984) to the Yukon Territory in the east, are thought to have been ejected from Mt. Drum in the Wrangell Mountains ~80 ka ago (Westgate and others, 2008). Schaefer (2002) first identified the Tetlin tephra in her section 96TOK1 (fig. 14). Her geochemical and $^{40}Ar/^{39}Ar$ analyses indicate that the Tetlin tephra was erupted from Mt. Drum 627 ± 47.7 ka ago. Thus, these tephras in the upper Tanana River valley demonstrate periodic explosive activity by volcanoes in the Wrangell and St. Elias mountains through the Quaternary.

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[5]Subsequently, comparison of the Old Crow tephra with the newly redated glass fission-track standard indicates that the Old Crow tephra could have a mean age of 124 ± 10 ka (November 2009 Westgate personal communication cited in Reyes and others, 2010). Analysis of plant and insect remains on the surface preserved beneath the Old Crow tephra at The Palisades along the Yukon River and fossil remains in associated sediments indicate that the Old Crow tephra was deposited late in MIS 6 time, as interpreted by Péwé and others (1997).

Table 2. Gravimetric soil moisture in samples of eolian sand, silty loess, and retransported loess in Alaska Highway corridor, Tanacross and Nabesna quadrangles.

Sample number[a]	Composition	Moisture content (percent dry weight)	
		Eolian sand	Lowland and retransported loess
M-1a M-1b	Frozen eolian sand, well bonded, no visible ice Unfrozen, wet, silty retransported loess, thixotropic	45	21
M-2	Frozen, well-bonded, black peaty and woody retransported organic silt, scattered clear ice crystals ≤3 mm across	—	345
M-3	Frozen, well-bonded silty loess, no visible ice, thixotropic when thawed	—	39
M-4	Frozen, well-bonded, fine to medium eolian sand with trace silt, thixotropic when thawed	28	—
M-5	Frozen, well-bonded, fine to medium eolian sand, no visible ice	19	—
M-6	Frozen, moderately bonded, medium eolian sand with trace silt, no visible ice	19	—
M-7	Frozen, well-bonded, retransported organic silt, no visible ice	—	76
M-8	Frozen, moderately bonded, clean, fine to medium eolian sand, no visible ice	17	—
M-9	Frozen, well-bonded, medium eolian sand, no visible ice, thixotropic when thawed	25	—
M-10	Frozen, well-bonded, retransported organic fine sand with some silt, no visible ice	—	60
M-11	Frozen, well-bonded retransported silt, no visible ice	—	33

[a]Sample locations shown in sheets 1 and 2. Samples M-through M-9 collected 07-20-09. Samples M-10 and M-11 collected 08-01-09.

Figure 11. Aerial view southwest of stabilized sand dunes in Gardiner Creek lowland, west-central Nabesna D-1 Quadrangle. Well-drained crests of sand dunes, where permafrost is ≥2 ft (≥0.6 m) deep, support mixed forest of robust black spruce, balsam poplar, and paper birch with scattered willow shrubs. In moist interdune areas, dominant vegetation is scattered to dense black spruce and willow shrubs with moss ground cover (photograph taken 07-23-09 by R.D. Reger).

Retransported loess and sand range from massive to thinly bedded, are generally planar, and are organic rich[6]. Where fine-grained upland sediments were available to be entrained by flowing water, silt- and sand-charged hyperconcentrated flows retransported these sediments to lower slopes and valley floors and buried surface organic materials, including plants, bones, and carcasses (Guthrie, 1990) (see sidebar). Local tilting, faulting, and overturning of bedding in retransported silt and sand are generally associated with mass movements related to the thawing of ground-ice masses (Péwé and others, 1997, 2009; Muhs and others, 2001).

A single small astragalus bone from the left rear foot of a prehistoric horse, identified by R.D. Guthrie (9-18-09 oral commun.), was discovered in a thawed 4-year-old highway cut through perennially frozen, retransported dark brown (10YR3/3) organic silt with a trace of very fine sand near Alaska Highway milepost 1276 in the south-central Tanacross A-2 Quadrangle (locality F-1, sheet 1). The bleached fossil bone was recovered 70 cm below the 1.9 RC ka White River Ash (fig. 16). The *Equus* bone was subsequently dated at 40,590 ± 600 RC yr B.P. (Beta-252319) (RC-16, table 2), demonstrating that this prehistoric horse, one of the important elements of a diverse Pleistocene megafauna in eastern Beringia (Guthrie; 1968, 1982, 1990; Clague and others, 2004), lived during the stage 3 interstade[7], and establishing a maximum time limit for deposition of the enclosing reworked loess. No other bones were recovered at the site despite careful examination of the roadcut faces. The bleached nature of the bone indicates that, after the animal died, the body was probably scavenged and its bones scattered. The remains were exposed to surface weathering conditions long enough that surviving bones became bleached before they were transported downslope and buried. However, weathering of the fossil bone did not totally destroy its collagen, an adequate amount of which remained to provide a reliable AMS radiocarbon age. Lack of bone staining indicates

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[6]Because of their distinctive fetid odor produced by decaying organic matter, these deposits were called 'muck' by early miners (Tuck, 1940).
[7]According to Anderson and Lozhkin (2001), the stage 3 interstade occurred between ~25–30 and ~43 RC ka in interior Alaska. Clague and others (2004) date this nonglacial interval between 25 and 60 RC ka.

that the enclosing silt was frozen soon after burial of the bone and remained frozen until 2004, when this roadcut was excavated and the retransported loess started thawing.

A fossil tooth, identified as *Equus lambei*[8], was picked up on a gravel bar in Gardiner Creek at locality F-2 (sheet 2). Although the tooth was out of stratigraphic context when found, it most likely came from the dune sands that are widespread in that area.

COLLUVIUM

Crudely bedded to massive lenses, layers, and wedges of angular fragments of frost-rived, weathered local bedrock are present beneath eolian cover deposits on bedrock slopes throughout the southern Yukon–Tanana Upland. These diamictons, termed the Tanana Formation by Péwé (1975), predate overlying eolian deposits and are the sources of locally auriferous fluvial gravels in valley bottoms. The coarse colluvial diamictons beneath eolian cover deposits in the corridor are at least locally older than the Tetlin tephra, dated 627 ± 47.7 ka by Schaefer (2002), although they may be much younger elsewhere in the corridor.

Between Scottie Creek and Mirror Creek in the southeastern corner of the map area (sheet 2), a mantle of undifferentiated, frost-rived colluvium forms blankets and aprons on lower slopes of hills and ridges of schist bedrock (Richter, 1976). Slope diamictons have a silty sand matrix, likely because of an influx of eolian deposits. Clasts are composed of angular fragments of the local bedrock. Reworking of these deposits by debris flows left tongues and fans of relatively coarse, mixed colluvium–alluvium in valley bottoms and on proximal fan surfaces in valleys. Fine-grained components of slope colluvium and retransported eolian sediments were washed onto distal valley bottoms, where they were likely mixed with lowland loess and frozen.

Landslides developed in three geologic settings in the corridor: (1) in frozen retransported loess and eolian sand, (2) in weathered granitic bedrock, and (3) in schist bedrock. Three large retrogressive landslides are expanding headward toward and across the Alaska Highway from southwest-facing

[8]Identified on 12-16-2009 by Patrick Druckenmiller of the University of Alaska Museum of the North.

RETRANSPORTATION OF LOESS AND EOLIAN SAND

Parallel to subparallel rills and gullies are widespread on loess and eolian sand deposits on slopes in the southern Yukon–Tanana Upland (Péwé, 1955), reflecting the ready erosion of these fine-grained sediments by running water. Typically, loess is massive and contains conformable tephra layers where undisturbed and is thinly bedded where retransported. It is composed mostly of silt-sized particles that sifted out of suspension in the atmosphere and settled on surface vegetation and on ground surfaces. Closer to sediment sources, loess deposits are sandier and apparently contain significant saltation contribution (Nickling, 1978). Grains are derived from weathering of pre-existing rocks and are invariably angular in morphology. Uncemented loess is unconsolidated, and porosity typically ranges from 40 to 55 percent, providing an open sediment structure (Pye, 1987). Loess is a quasi-stable foundation material in which the open structure collapses at higher moisture contents, causing loess to suddenly settle when wetted and probably promoting its erodibility. Loess also has high vertical permeability, probably because of high porosity and the presence of vertical root casts and joints. Consequently, in thick loess deposits, drainage is typically subsurface through tunnels and cavities cut by flowing water and enlarged by stoping of tunnel walls and ceilings, a process known as piping (fig. 15).

In the past in interior Alaska, loess and eolian sand were retransported from upland depositional sites mainly by stream flow, subterranean piping, and hyperconcentrated flow to lower slopes and valley bottoms, where they were typically mixed with airfall silt (lowland loess) and became perennially frozen and ice rich (Tuck, 1940; Péwé, 1975, 1982; Kreig and Reger, 1982). Gullies and rills initially developed on unprotected upper and middle slopes where surface runoff became concentrated. Drainageways were also initiated on middle and lower slopes by the thawing of shallow ice-rich permafrost, which opened up underground cavities and released considerable subsurface water through the melting of ground ice, enlarging subsurface cavities and tunnels by hydraulic erosion and piping (Péwé, 1954, 1982). Coincidently, surface runoff from torrential rainfall and snowmelt entered the subterranean passages through thermokarst pits and readily eroded the fine-grained walls and floors, further expanding the network of subterranean passages (Péwé, 1954). Eventually the upward stoping roofs of the underground passages broke through to the surface and formed deep, steep-sided trenches and gullies in association with piping tunnels on middle and lower slopes. Then headward gully erosion extended the gullies and rills upslope.

The silt-rich alluvial fans and aprons that ultimately formed complex, wedge-shaped fills in upland valleys spread downslope from the rills and gullies on upper and middle slopes and received material flushed from subsurface pipes. Much reworking of eolian deposits and even removal of valley fills occurred during past interstadial and interglacial warm periods when melting of permafrost was widespread (Péwé and others, 1997, 2009; Anderson and Lozhkin, 2001). Later, slope creep, solifluction, and deposition of upland loess rounded and partially masked upland gullies and rills (Péwé, 1955).
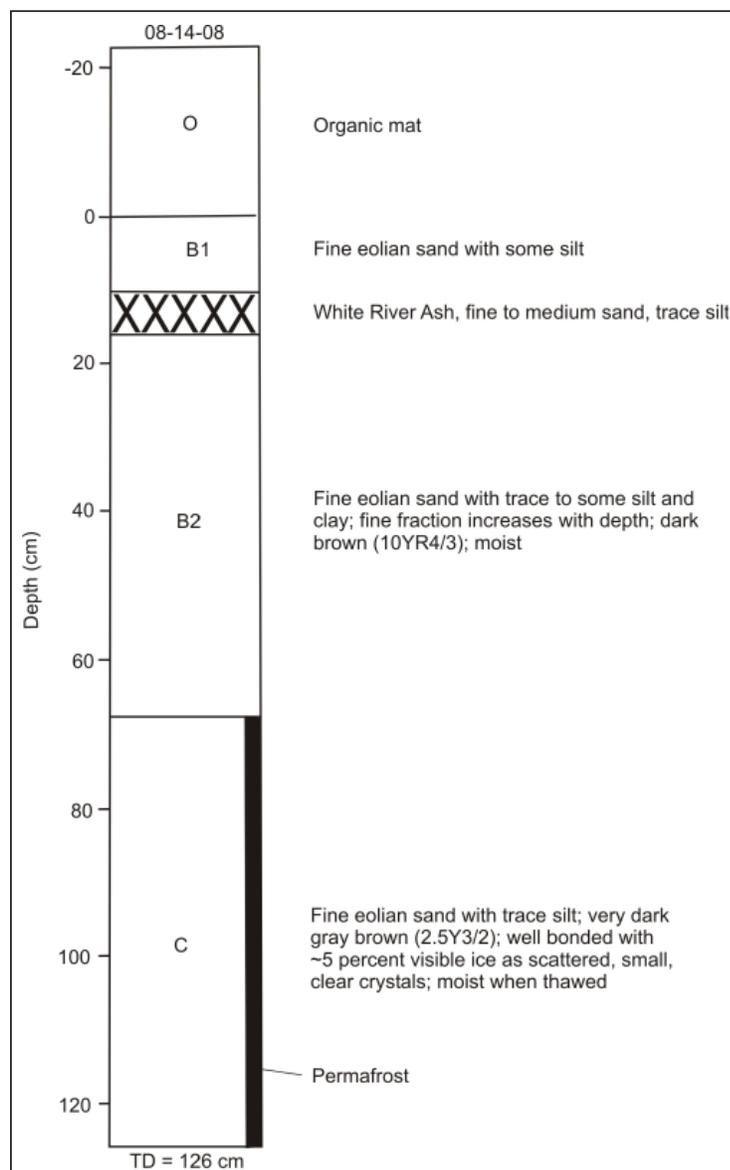
Figure 12. Section exposed in test pit (SP-15) on crest of frozen sand dune with robust mixed forest of black spruce and paper birch trees, west-central Nabesna D-1 Quadrangle (sheet 2).

bluffs of the Chisana River by the thawing of frozen retransported loess and eolian sand near Alaska Highway mileposts 1265 and 1267 in the southwestern Tanacross A-2 Quadrangle (sheet 1) (Reger and others, 2012). A much smaller slope failure of this type is located 1.5 km southeast of Steve Lake along the margin of the Chisana River floodplain in the north-central Nabesna D-2 Quadrangle (sheet 2).

An active, moderate-sized failure in weathered granitic bedrock is present on the 40-m-high north wall of Gardiner Creek canyon in the west-central Nabesna D-1 Quadrangle (fig. 17, sheet 2). The surface of the slide body is laced with numerous fresh, arcuate scarps, indicating that internal displacements are by complex rotational slumping. An unvegetated fluvial bar of lag boulders in a sandy matrix at the toe of the slide is evidence of scouring by recent flooding. A fresh, large ice-impact scar on the trunk of a nearby large spruce tree demonstrates that breakup flooding reached a height of 3 m above the level of Gardiner Creek prior to July 23, 2009, when we visited the site. At the top of a fresh, 1.3-m-high scarp at the head of the landslide, a 1- to 2-cm-thick layer of White River Ash crops out beneath a 12-cm-thick vegetation mat. Beneath this Holocene tephra is a 30-cm-thick layer of very fine to fine, dark grayish brown (2.5Y4/2) eolian sand, which overlies massive to crudely bedded, granular, weathered granitic bedrock (grus). The grus is crosscut by 10- to 12-cm-wide, irregular, massive, sandy crack fillings (fig. 18) that probably formed when tension cracks opened up beneath the eolian surface sand. Although the permafrost table is 90 cm deep in the scattered open woodland of quaking aspen behind the crown of

Figure 13. View north–northeast of roadcut exposure of tephra section 96TOK1 evaluated by Schaefer (2002) near Alaska Highway milepost 1284, northeastern Tanacross A-3 Quadrangle (locality T-1, sheet 1) (photograph taken 08-10-08 by R.D. Reger).

the landslide and 36 cm deep ~50 m behind the crown of the slide in dense black spruce forest, we recognized no diagnostic evidence of the former ice wedges in the scarp face, like slumping of marginal sediments into cavities as ice wedges thawed (Péwé and others, 1969).

Along the Canada border east of upper Desper Creek in the southeastern Nabesna D-1 and northeastern Nabesna C-1 quadrangles (sheet 2), two small slides occurred between 2,500 and 3,500 ft (760 and 1,070 m) elevation on steep east- and west-facing slopes in schist bedrock (Richter, 1976). These features were not investigated in the course of our fieldwork.

GLACIAL HISTORY

Paleomagnetic evaluations of stream gravels in the vicinity of Dawson City, Yukon Territory, provide convincing evidence for the initial expansion of the Cordilleran ice sheet in the late Pliocene (Froese and others, 2000). The Klondike Gravel represents a pulse of outwash from the expanding Cordilleran ice sheet north of the Tintina trench down the Klondike River valley >2.58 m.y. ago and <3.04 m.y. ago. At least four younger cycles of glaciation separated by three interglaciations are recorded by loess–retransported-loess couplets in the Midnight Dome Loess, which is paleomagnetically dated from ~1.5 Ma to <0.78 Ma (Froese and others, 2000).

Evidence for maximum (late Pliocene–early Pleistocene) glacial extents and ice-marginal lakes mapped by Duk-Rodkin and others (2002, 2004) in the upper Tanana River valley was not recognized during our field investigations. However we identified drift of the penultimate glaciation in roadcuts 4.3 km east of the Canada border near the Little John archaeological site in the Mirror Creek drainage along the Alaska Highway (Easton and others, 2009), close to the middle Pleistocene ice limit mapped by Duk-Rodkin and others (2002). West of the Canada border, Duk-Rodkin and others (2002) placed the middle Pleistocene ice limit in the Chisana River drainage just inside

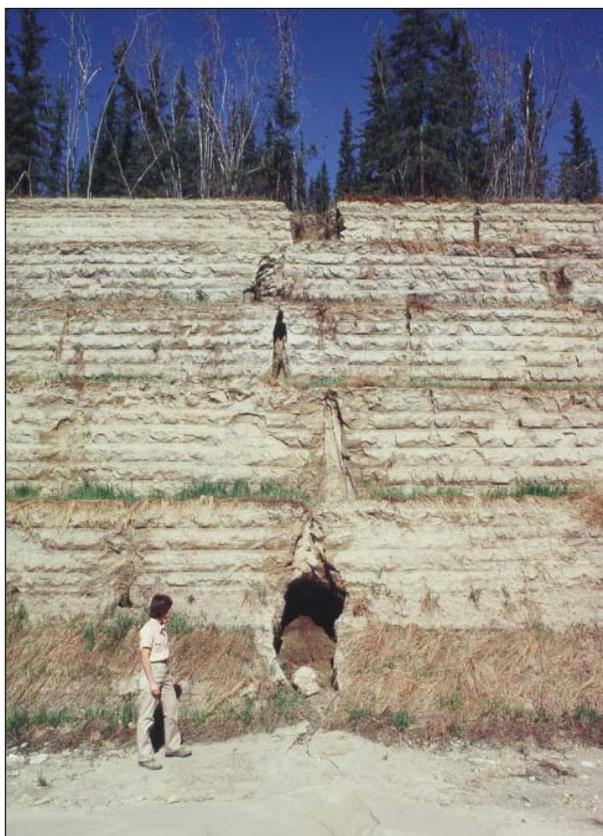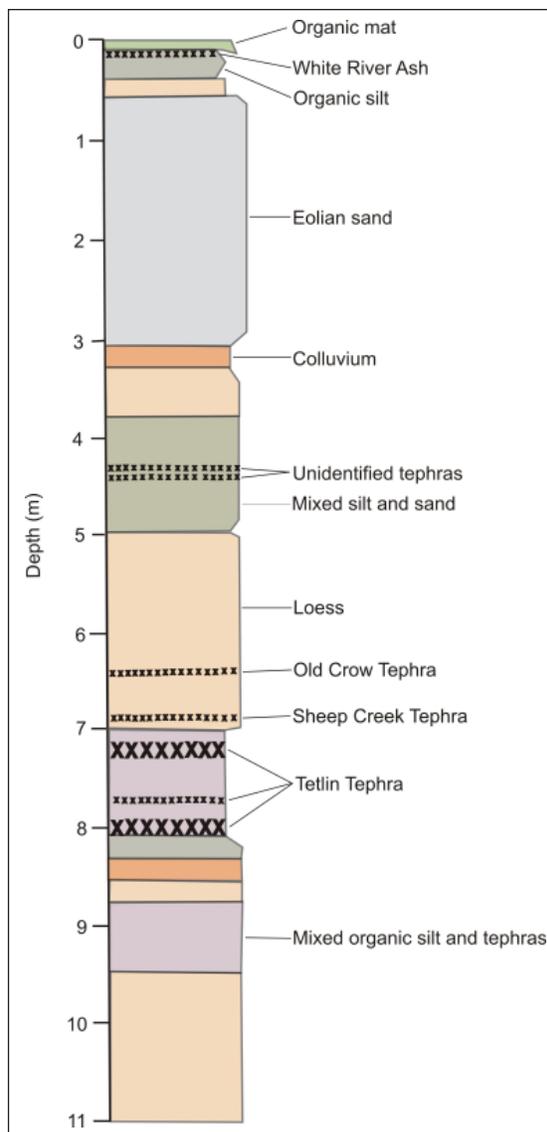*Figure 14. Generalized section 96TOK1 (after Schaefer, 2002, fig. 3).*

Figure 15. Cross section of subsurface pipe associated with vertical joints in massive silty loess exposed in terraced Gold Hill roadcut west of Fairbanks along Parks Highway. Note small fan of retransported silt at mouth of pipe in foreground (photograph taken 05-12-81 by R.D. Reger).

Figure 16. Fossil astragalus bone of Equus, *dated 40,590 ± 600 RC yr B.P. (Beta-252319) (RC-16, table 1), in retransported organic silt with trace fine sand exposed in roadcut near Alaska Highway milepost 1267 (locality F-1, sheet 1). White bone color indicates prolonged exposure to surface conditions before retransportation and burial. Lack of bone staining indicates enclosing sediments became perennially frozen soon after burial and remained frozen until 2004, when this roadcut was excavated and retransported loess started thawing (photograph taken 08-16-08 by R.D. Reger).*

Figure 17. Aerial view of moderate-sized, active failure in weathered granitic bedrock on north wall of Gardiner Creek canyon, central Nabesna D-1 Quadrangle (photograph taken 07-23-09 by T.D. Hubbard).

Figure 18. Irregular sand-filled cracks in grus exposed in scarp of active slope failure in Gardiner Creek canyon. Location shown in figure 17. Scale in inches and centimeters (photograph taken 07-23-09 by R.D. Reger).

the southeastern corner of the corridor, ~8 km downvalley from the limit of the last major (Jatahmund Lake = Donnelly) glaciation mapped by Richter (1976), who recognized only a small patch of penultimate (Black Hills = Delta) drift in that drainage. According to Duk-Rodkin and others (2002), ice of the penultimate glaciation blocked the lower Scottie Creek drainage and impounded a moderate-sized meltwater lake in that lowland, which today contains numerous thaw lakes. They also show ice of the penultimate glaciation against the bedrock ridge north of the Chisana River to the west of the Scottie Creek lowland. During our investigations, we found no evidence of glaciation north of the Chisana or Tanana rivers. From their penultimate ice limit in the Chisana River drainage, Duk-Rodkin and others (2002) mapped an extensive meltwater lake in the Northway lowland that extended westward 87 km to near Tetlin Junction. In this reach, the lowland is characterized by numerous floodplain and thaw lakes. Although we saw no surface evidence for such a large body of water, such as lake-bottom deposits, beaches, wavecut shorelines, or hanging deltas, we lack subsurface data with which to evaluate the presence or absence of meltwater-lake sediments at depth in that lowland.

Fernald (1965a) and Richter (1976) mapped the limit of the Jatahmund Lake glaciation in the drainages of the Nabesna and Chisana rivers ~38 km and ~29 km, respectively, south of the Alaska Highway, outside the limits of this corridor. From these ice limits, extensive granular outwash fans and aprons extended northward to the southern limit of the Yukon–Tanana Upland and down the Tanana River. Rigorous periglacial conditions during the penultimate and last major glaciations produced widespread permafrost and eolian deposits in the map area.

MODERN GEOLOGIC HAZARDS

On November 3, 2002, the eastern Alaska Range was severely shaken by a M7.9 earthquake along the Denali–Totschunda fault system, which passes as close as ~56 km southwest of Northway. During that event, unfrozen, saturated, fine-grained alluvium and artificial fills beneath the Northway airport became unstable and liquefied (Harp and others, 2003). Loss of foundation support and severe ground shaking caused asphalt-paved airport runways, taxiways, and parking areas to break apart and damaged structures (fig. 19). Future strong earthquakes have the potential for destabilizing liquefaction-prone floodplain sediments and artificial fills in the corridor (Hubbard and Reger, in press).

Figure 19. Asphalt pavement of parking area at Northway airport broken apart by loss of support and severe shaking during major earthquake of 11-03-02 along Denali–Totschunda fault system in eastern Alaska Range (photograph taken 08-19-08 by R.D. Reger).

The summer of 2009 was particularly warm and sunny, which accelerated melting of alpine snow and ice fields and released enough meltwater to cause widespread flooding of major streams draining the eastern Alaska Range (fig. 20). Facilities located along these streams, such as Native subsistence fish camps, were inundated by floodwaters and were temporarily abandoned.

Widespread shallow and locally ice-rich permafrost is present in abandoned floodplains and low terraces of the Tanana, Nabesna, and Chisana rivers and in lowlands and lower slopes of the southern Yukon–Tanana Upland (Reger and others, 2012). Destruction of surface vegetation and stream erosion promote thawing of the perennially frozen ground and locally produce landslides and thermokarst gullies. Gully development has the potential to destabilize slopes, especially where melting permafrost increases erosion rates. Gullies developing downslope from culverts along the Alaska Highway can pose significant hazards to infrastructure (fig. 21). In stabilized dune sands and eolian sand blankets, permafrost is continuous to discontinuous and ice contents are moderate, except on middle to upper south-facing slopes where permafrost is absent. Permafrost is discontinuous to sporadic beneath inactive floodplains. Thaw bulbs underlie lakes and streams of moderate to large size in the Northway lowland.

ACKNOWLEDGMENTS

Figure 20. Aerial view northwest of natural levee and slackwater basin inundated by flooding Chisana River in northwestern Nabesna D-2 Quadrangle (photograph taken 07-31-09 by R.D. Reger).

Figure 21. Chaotic vegetation due to thawing permafrost in intermittent drainage from highway culverts east of Alaska Highway near milepost 1233, northeastern Nabesna C-1 Quadrangle. Figure provides scale (photograph taken 08-16-09 by T.D. Hubbard).

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