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# RECONNAISSANCE INTERPRETATION OF 1978–1983 PERMAFROST, ALASKA HIGHWAY CORRIDOR, ROBERTSON RIVER TO TETLIN JUNCTION, ALASKA

by
Richard D. Reger and Trent D. Hubbard

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## (in envelope)

# RECONNAISSANCE INTERPRETATION OF 1978–1983 PERMAFROST, ALASKA HIGHWAY CORRIDOR, ROBERTSON RIVER TO TETLIN JUNCTION, ALASKA

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Richard D. Reger[1] and Trent D. Hubbard[2]

## INTRODUCTION

During 2008 the Alaska Division of Geological & Geophysical Surveys (DGGS) conducted reconnaissance interpretive mapping of permafrost in segment 2 of the Alaska Highway Corridor, a 12-mi-wide (19.3-km-wide) corridor that straddles the Alaska Highway through the upper Tanana River valley from the Robertson River eastward to near Tetlin Junction in the Tanacross Quadrangle (fig. 1). This work was an extension of geologic and permafrost mapping done in Alaska Highway Corridor Segment 1 from Delta Junction to Dot Lake during 2007 (Reger and others, 2008a and b; Reger and Solie, 2008a and b). Primarily, we inferred the extent of permafrost and ice content by interpreting ~1:65,000-scale, false-color infrared aerial photographs taken in July 1978, August 1980, and July 1983. We believe that, because of climatic warming, wildfires, and human alteration of the landscape since 1983, modern permafrost is warmer, thinner, less extensive, and deeper than our maps portray (Osterkamp and Romanovsky, 1999; Jorgenson and others, 2001). Interpreted proxy data include vegetation, slope and aspect, landforms, geology, local drainage, and terrain features. Landforms such as open-system pingos, polygonal ground, and thermokarst pits, gullies, and ponds are diagnostic of the presence or former presence of permafrost (Hopkins and others, 1955; Ferrians and others, 1969; Kreig and Reger, 1982). In conjunction with the interpretive mapping (sheets 1–4), we incorporated information available in the professional literature into preliminary maps. During summer fieldwork in 2008, we dug test pits to verify initial interpretations. In a supplemental study, Santosh Panda (Geophysical Institute, University of Alaska Fairbanks, Fairbanks, AK) installed Hobo temperature data loggers to evaluate shallow ground temperatures and temperature trends at nine scattered sites. Initial readings support our interpretation, but, because of the dearth of subsurface data in most of the map area, our permafrost designations should be considered tentative until validated by multi-year ground-temperature measurements below the level of annual temperature variation.

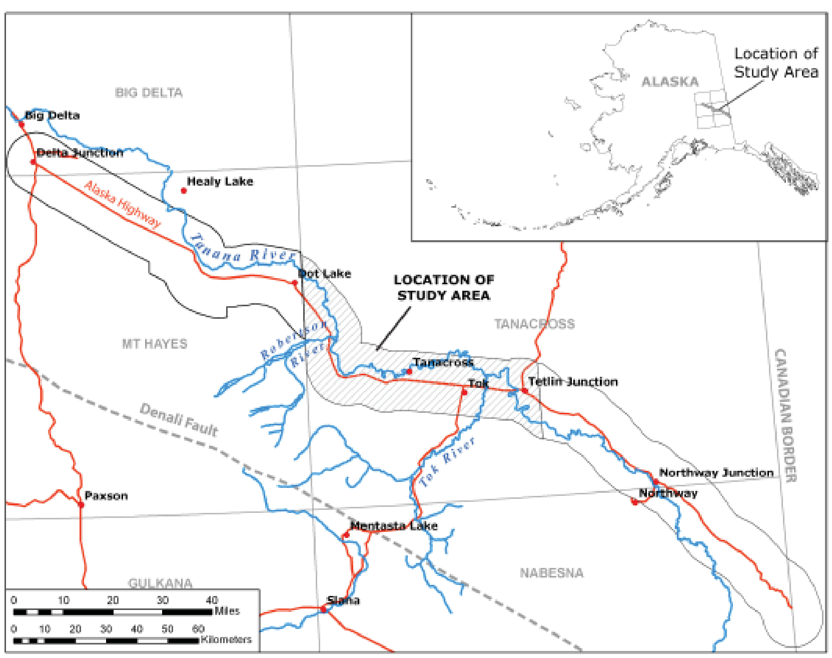


*Figure 1. Location of study area in Tanacross Quadrangle, Alaska.*

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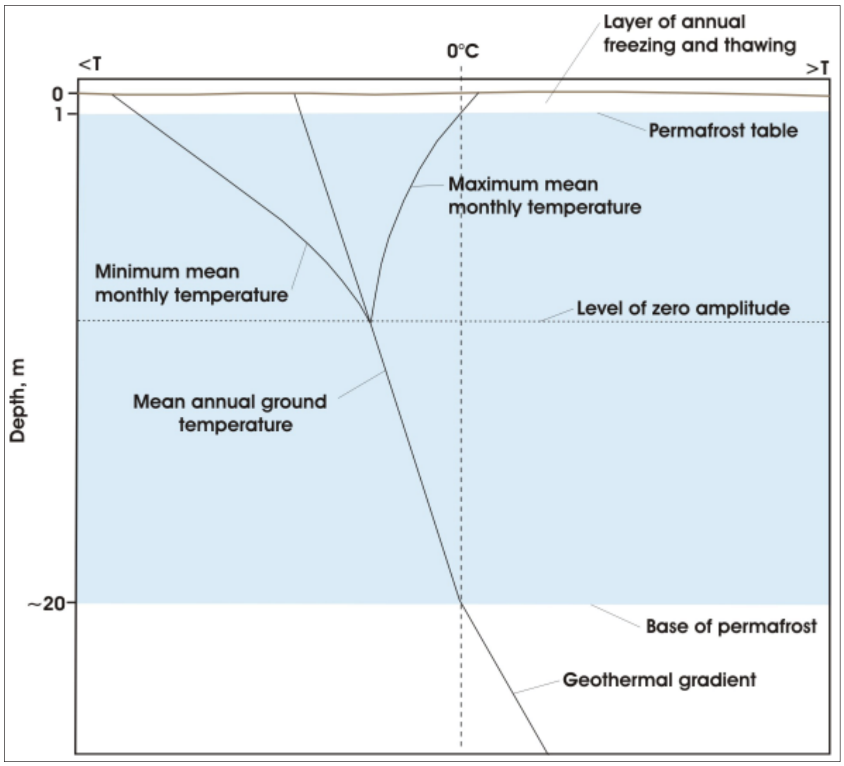
## FACTORS AFFECTING DISTRIBUTION AND DISTURBANCE OF CORRIDOR PERMAFROST

Permafrost distribution is a function of present and past climates (Hopkins and others, 1955). As a rough approximation, permafrost forms where the mean annual air temperature is <0°C (Péwé, 1982). To develop perennially frozen ground, the temperature of the ground surface must be <0°C (Muller, 1947; Ferrians and others, 1969). The most accurate relation between permafrost extent and ground temperatures is reflected by ground temperatures measured at a depth below the seasonal frost layer where there is no temperature variation (level of zero annual amplitude of Péwé, 1982) (fig. 2). In general, lowland permafrost is continuous (underlies >90 percent of the area) where the ground temperature at the depth of no temperature variation varies from -5°C to -11°C for >1 year; permafrost is discontinuous (underlies 50 to 90 percent of the area) where steady ground temperatures are -1°C to -5°C at the level of zero annual change; and permafrost is sporadic (underlies 10 to 50 percent of the area) or is composed of isolated small bodies (<10 percent of the area) where unvarying ground temperatures are 0° to -1°C (Ferrians, 1965). In complex mountainous terrains, permafrost temperatures are highly variable.

*Figure 2. Generalized ground-temperature profile in area of permafrost (from Péwé, 1982, fig. 20).*




Local variations in the volume, depth, thickness, ice content, and temperature of permafrost are the result of differences in heat flow into and out of the ground, which are functions of the local geothermal gradient and interactions of climate and local physiographic and geologic conditions (Williams, 1970). For example, because of low sun angles at the northern latitude of the proposed corridor, the amount of solar radiation reaching the ground surface significantly affects the amount of heat potentially entering the ground. A 10° south-facing slope receives ~33 percent more solar radiation than a 10° north-facing slope and ~14 percent more solar radiation than a flat surface (Hinzman and others, 2006). Although mean annual air temperatures are generally only ~3ºC colder in valley bottoms and on north-facing slopes compared to south-facing slopes due to convective atmospheric mixing, ground temperatures are significantly colder on north-facing slopes and valley bottoms because (1) steep winter temperature inversions draw heat out of the ground, and (2) during summers there is significant insulation by the surface cover of mosses and lichens, which is widespread on north-facing slopes and valley bottoms. In summer, the moist ground cover dries in the continental climate and insulates permafrost from atmospheric temperature fluctuations, reducing heat flow from the warmer atmosphere into the colder ground. In winter, when this ground cover is frozen, heat flows from the warmer ground into the colder atmosphere. In wet sphagnum bogs, this natural heat pump allows 2.5 to 4.5 times more heat flow out of the ground in winter than heat flow into the ground in summer, promoting the formation and preservation of permafrost in these wetland sites (Kreig and Reger, 1982, pl. 5). Thus, topography and aspect significantly affect the distribution of permafrost and vegetation, which is a sensitive indicator of ground temperature conditions, especially in the southern Yukon–Tanana Upland.

Near-surface permafrost thaws when ground temperatures rise above 0°C, as when the thermal properties of the ground surface are altered by human activities, geologic processes like slope failures, or wildfires so that heat flow into the ground exceeds winter heat loss. These changes lower the permafrost table and thicken the active layer of seasonal thawing (Ferrians and others, 1969). Responses to the thawing of perennially frozen ground are functions of the amount and type of ground ice present and the degree of disturbance. Permafrost contains several forms of ground ice, including buried snow, lake ice, aufeis, glacier ice, pingo-ice lenses, foliated ice wedges, regelation and injection ice masses, small segregations of clear ice, and pore ice (French, 2007). Melting of massive ground-ice bodies results in considerable differential settlement of the ground surface and the formation of large thaw ponds, thaw lakes, and thaw basins (alases) (Kreig and Reger, 1982). Melting of foliated ice wedges, which form polygonal cells in permafrost, produces mounds separated by differentially settled polygonal troughs (Péwé, 1954). Melting of permafrost rich in small, segregated ice lenses and thin ice seams produces general lowering of the ground surface without significant differential settling. Thawing of coarse sand and gravel with clear pore fillings may result in no settlement. Pre-burn vegetation typically returns a few years after a wildfire in an area, either directly or through a series of successional stages, depending on the type of vegetation formerly present and the severity of the burn (Chapin and others, 2006), and permafrost may become re-established in soils thawed as a result of the wildfire.

## LOWLAND PERMAFROST

In Corridor Segment 2 through the Tanana River valley from the Robertson River to Tetlin Junction, where average annual air temperatures vary from -4.5°C at Dot Lake to -4.7°C at Tok (http://www.wrcc.dri.edu/html-files/ak/ak.tmp.ext.html), permafrost is present as continuous, discontinuous, and isolated bodies.

### MORAINES AND OUTWASH DEPOSITS

High-relief glacial (Qgdy)[3] and glaciofluvial (Qgfy) deposits in lowlands are inferred to contain discontinuous permafrost with low ice content (Dl). Low-relief glacial deposits (Qgdo, Qgdy) in lowlands probably are discontinuously frozen with low to moderate ice content (Dm). North of the Robertson River, the deciduous tree cover indicates that the higher, outer zone of the Donnelly terminal moraine is discontinuously frozen with low ice content (Dl). A single, moderate-sized, simple ice wedge was observed in loess-covered till of Donnelly age 4.6 mi (7.4 km) west of the Alaska Highway along the southern limit of the Robertson River floodplain in the northwest Tanacross B-6 Quadrangle. This wedge, which is larger than ice wedges of Holocene age in pipeline trenches north of Delta Junction (Reger and Solie, 2008b), is probably late Donnelly in age. Widespread spruce cover and relatively low relief of the loess-blanketed, inner Donnelly terminal moraine indicate that permafrost is discontinuous with low to moderate ice content (Dm). Lowland loess and peat in local basins and drainageways are continuously frozen and ice rich (Fr). Sediments beneath larger lakes are unfrozen (U), but thick peat ringing larger lakes is thought to be frozen and ice rich (Fr).

A series of coalescing outwash fans of Delta and Donnelly ages that are discontinuously frozen with low to moderate ice (Dm) contents forms an apron along the lower slopes of the eastern Alaska Range between Robertson River and Moon Lake in the central Tanacross B-6 Quadrangle (Reger and others, 2010, sheet 2).

### EOLIAN DEPOSITS

Sand dunes in a small area on the abandoned Tanana River floodplain ~1.5 mi (~2.4 km) southeast of Moon Lake in the east-central Tanacross B-6 and west-central Tanacross B-5 quadrangles (Reger and others, 2010, sheets 2 and 3) are likely too thin and dispersed to influence the distribution and ice content of the near-surface permafrost, which is mapped as continuously frozen with moderate to high ice content (Fr) (sheets 2 and 3).

In a narrow band of thin sand dunes along the western margin of the abandoned floodplain of the Tanana River in the southeastern Tanacross B-4 Quadrangle, permafrost is probably discontinuous with low ice content (Dl) (sheet 4).

[3]Distribution of deposits and unit descriptions are provided in Reger and others (2010, sheets 1–4).

## FLOODPLAIN AND TERRACE DEPOSITS

Understanding plant succession on the floodplains of the Tanana River and its relation to developing permafrost conditions is fundamental to our mapping of permafrost in the floodplain and terraces, which is based in large measure on the character of the surface vegetation. Although the general succession has been known for many years (Viereck, 1970; Kreig and Reger, 1982), the significance of black spruce in the sequence remains uncertain (Mann and others, 1995). The succession begins with the emergence of bare channel bars and meander scrolls on the concave, inner sides of meanders. Scattered willows and horsetails opportunistically colonize the raw mineral soils, which freeze and thaw annually. Within ~5 years, horsetail meadows and open thickets primarily of willows develop on the inactive floodplain. These communities can accommodate periodic inundation and sediment accumulation by the growth of adventitious roots (Chapin and others, 2006). Then alders and balsam poplars invade older floodplain surfaces, the former adding important nitrogen to the soil through the action of nitrogen-fixing bacteria on their roots. In this phase, permafrost is sporadic and has low ice content. After ~50 years, fast-growing poplars rapidly rise above and replace the willows, which are not shade tolerant, forming poplar groves of generally uniform ages and allowing permafrost to spread and thicken. On older, higher surfaces of the inactive floodplain, white spruce, which has shade-tolerant seedlings that are unable to tolerate frequent burial and do not survive frequent flooding on younger surfaces, is able to survive. Spruce is slower growing than poplars but lives longer, so gradually the spruce mixes with the poplars and replaces them. During this shady phase, when the surface cover of mosses and lichens thickens enough to insulate the ground, permafrost becomes discontinuous and develops low to moderate ice contents. Gradually, forests of mixed white and black spruce develop on the abandoned floodplain, especially on natural levees and crevasse splays, which stand above the surrounding land surface and are better drained. These mixed conifer forests may persist for several millennia (Mann and others, 1995). In lowlands behind natural levees and crevasse splays on the abandoned floodplain, occasional flooding produces moist to wet soil conditions in which black spruce and eastern larch dominate (Viereck, 1970), and peat accumulates, promoting the development of continuous ice-rich permafrost.

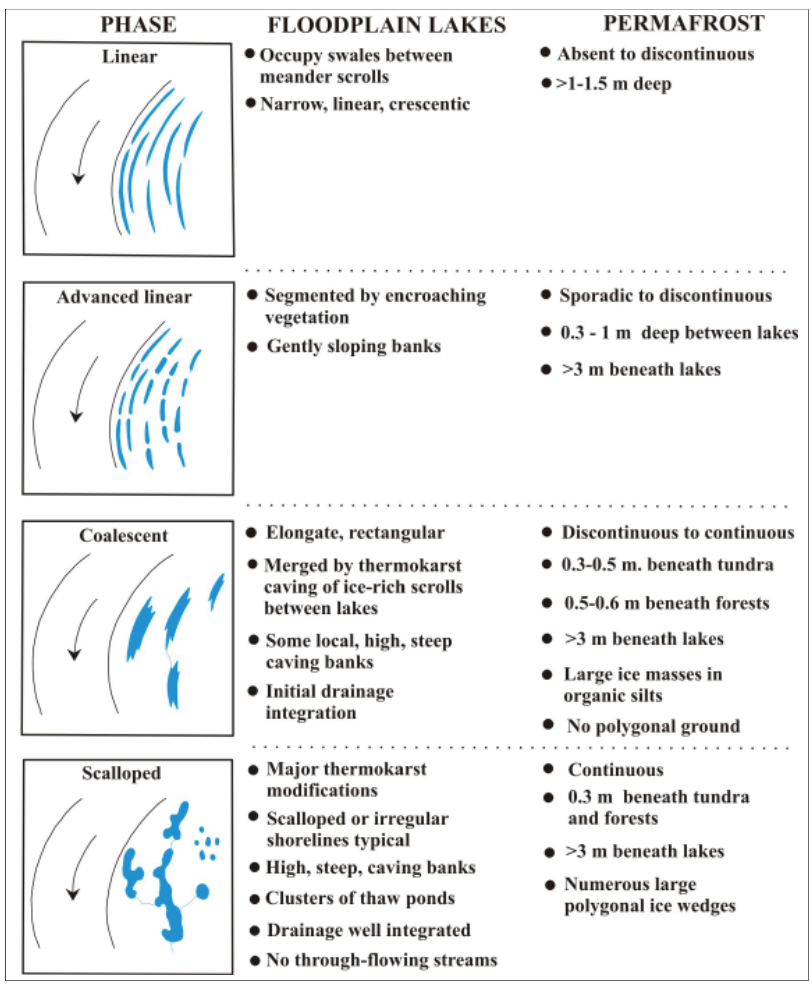



*Figure 3A. Evolution of shallow lakes on floodplains of meandering streams by thermokarst activity in a permafrost environment (Weber and Péwé, 1961, 1970; Péwé, 1970).*

Changes in the form of point-bar lakes that develop in swales between low scroll ridges on the floodplains of meandering streams document four successive phases in the development of permafrost (fig. 3A) These phases are distinguished on the basis of lake shapes, vegetation, orientation of lakes relative to the modern channel, character of the river banks, and distribution of driftwood (Weber and Péwé, 1961, 1970; Péwé, 1970, 1975a). Perennially frozen ground is absent in the linear phase of the inactive floodplain, but discontinuous masses begin forming in the advanced linear phase on older, higher surfaces of the inactive floodplain (fig. 3B). As permafrost spreads and thickens beneath the abandoned floodplain and low terraces, point-bar lakes expand and coalesce through the melting of ice-rich, near-surface frozen ground in response to attack by wind-driven waves and currents in sun-warmed, shallow floodplain lakes. In the coalescent and scalloped phases, permafrost becomes continuous, shallow, and ice rich.

Floodplain and low terrace deposits in the corridor consist of sand with beds and lenses of silt and gravel where channels are meandering and anastomosing and are composed of gravel and sand in reaches with braided channels (Reger and others, 2008a; Reger and others, 2010). The meandering–anastomosing channels of the Tanana River and the active braided floodplains with numerous unvegetated bars of its major tributaries are generally unfrozen, and permafrost does not develop until these surfaces become stabilized and plants become established (Viereck, 1970; Kreig and Reger, 1982). Large floodplain islands that support mature stands of white and black spruce have discontinuous permafrost (Mann and others, 1995), and perennially frozen ground generally has low ice content (Kreig and Reger, 1982). By analogy, post-Donnelly terraces along the Tanana River with extensive covers of mature white and black spruce also contain discontinuous permafrost with low ice content.

Permafrost beneath inactive and abandoned floodplain surfaces and low fluvial terraces in the meander belt north of the Tanana River is inferred to be discontinuous with low to moderate ice contents (Dm), based on the presence of mixed deciduous and coniferous forest, the presence of scattered, small thaw ponds, and the morphology of floodplain lakes (sheet 3). The younger three phases of the floodplain–lake sequence (Reger and Solie, 2008a, fig.1) are displayed on most of the Little Tanana Slough–Tanana River floodplain north of Tanacross; ice contents in these phases increase from youngest to oldest (figs. 3A and 3B). The limited presence of continuous, shallow, ice-rich permafrost (Fr) is indicated by the limited distribution of the scalloped-lake phase in the oldest parts of the floodplain.

A mixed deciduous–coniferous forest on the large expansion fan (Qfb) southwest of Wolf Lake in the northeastern Tanacross B-5 Quadrangle (Reger and others, 2010, fig. 2 and sheet 3) indicates that permafrost is discontinuous with low to moderate ice content (Dm). The expansion fan separates the meander belt of the Tanana River from a

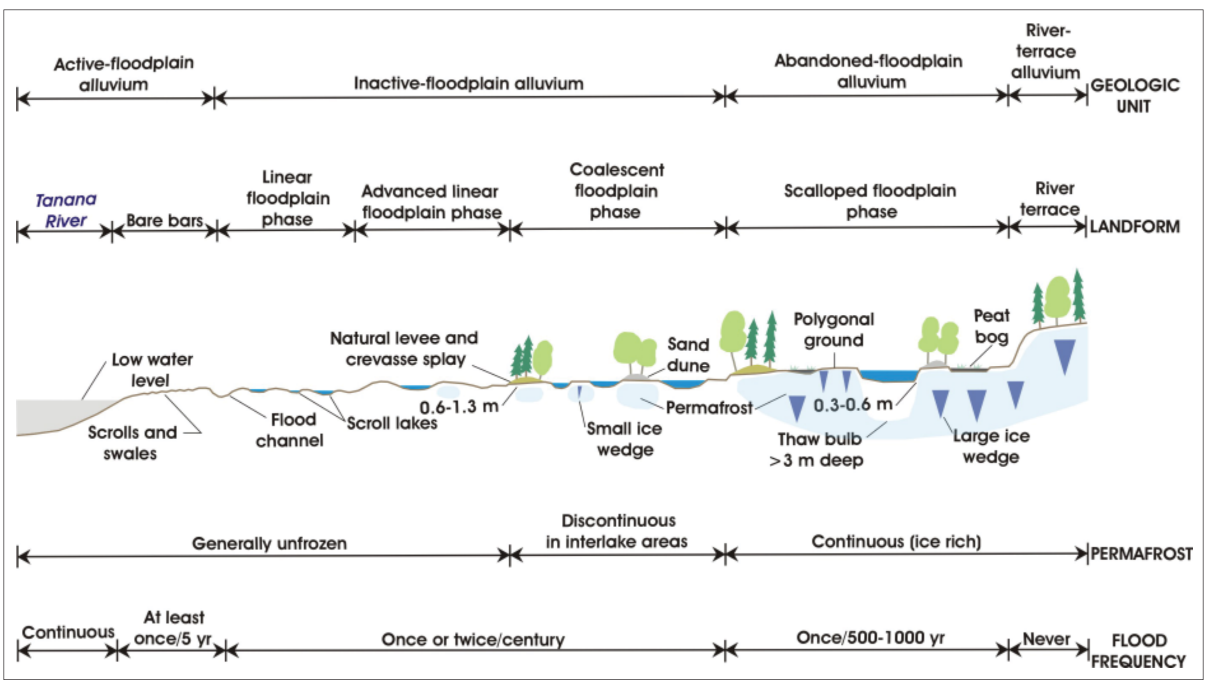



*Figure 3B. General relations of floodplain landforms, deposits, permafrost, and flood frequency in the meandering reach of the Tanana River in the Tanacross Quadrangle, based on model developed for Yukon–Koyukuk lowland by Weber and Péwé (1961, 1970) and Péwé (1970).*

narrow, swampy slackwater basin (Qfs) against bedrock of the southern Yukon–Tanana Upland. Shrubby vegetation and wet surface conditions in the slackwater lowland are evidence that surface drainage is widely restricted by continuous ice-rich permafrost (Fr). Lowland sediments are interpreted to be fine grained because tortuously winding channels of small streams, like Fish Creek, lack granular point-bar deposits. Interpretation of an unpublished airborne-resistivity profile (Burns and others, in prep.) across this feature (Reger and others, 2010, fig. 17) implies the water table is very shallow in contrast to the finer-grained lake and slackwater-basin deposits (Qfs), where permafrost is widespread and ice rich (Fr).

Abandoned floodplain sediments between the mouth of Porcupine Creek and the highway bridge over the Tanana River in the central Tanacross B-4 Quadrangle are Holocene in age, as demonstrated by a radiocarbon age of 1,610 ± 40 RC yr B.P. (WW-5158) (Reger and others, 2010, RC-10 in sheet 4 and table 1). Therefore, the discontinuous permafrost with low to moderate ice content in these fluvial sediments is also Holocene in age. Radiocarbon dating of a nearby high terrace above the dated floodplain surface demonstrates that this terrace is 11,715 ± 40 RC yr BP (WW-5139) (Reger and others, 2010, RC-9 in sheet 4 and table 1), implying that the discontinuous permafrost with low ice content in this feature is latest Pleistocene and Holocene in age.

Near the Tanacross Airfield in the northwestern corner of the broad, generally well-drained Tok fan is a conspicuously wet zone of groundwater emergence (Qfbe) that presents a potential impediment for a utility corridor through this area and may require rerouting or special design because of the shallow water table. The zone of groundwater emergence is indicated by swampy vegetation, the presence of water in shallow artificial trenches, a network of shallow natural drainage channels originating at clearwater springs, clearwater lakes, and clear streams from springs that drain into the silty Tanana River along the base of the fan scarp (Reger and others, 2010, fig. 28). Orientations of natural drainage channels and proximity to extensive swampy lowlands related to the nearby distal piedmont apron indicate that seepage there is apparently derived from the broad Tok fan to the southeast and from the toe of the piedmont apron to the southwest. Because heat is brought by groundwater flowing into this area, permafrost is tentatively inferred to be sporadic with low to moderate ice content (Sm?). Of seven water wells in the vicinity of the Tanacross Airfield, two penetrated permafrost and the maximum depth to water was only 35 ft (10.6 m), at least 18 ft (5.5 m) shallower than in water wells at Tok 10.5 mi (11 km) to the east (Williams, 1970, p. 43). Monitoring of water wells in the vicinity of the Tanana River demonstrates that water levels there mimic changes in river stage, indicating that river water is being contributed to the groundwater reservoir (Anderson, 1970).

Water is supplied to the groundwater reservoir at the apex of the broad Tok fan by the Tok River, which changes from year-round flow at the head of the fan to only summer flow in the distal part of the fan (Williams, 1970, p. 43). Interpretations of aerial photographs and unpublished airborne-resistivity data (Burns and others, in prep.) indicate that fine-grained sediments of the Tok River fan (Reger and others, 2010, sheet 4, Qft and Qab), which overlie the coarser deposits (Qfb) of the broader Tok fan[4], are ~92 ft (~28 m) thick near the head of the Tok River fan and thin to ~73 ft (~22 m) near the toe of the fan (fig. 4). In the proximal zone of the fan, frozen, fine-grained overbank deposits of the Tok River fan have low to moderate ice contents (Fm) and overlie sporadically to discontinuously frozen gravels of the Tok expansion fan, which probably have low to moderate ice contents (fig. 4). Peat-filled channels on the Tok River fan are frozen with moderate to high ice contents (Fr). Concentrations of shrubby vegetation and thaw ponds and thaw lakes on the surface of the Tok River fan indicate other areas of higher ice contents. Thaw bulbs with low to moderate moisture contents are present in granular channel deposits beneath active and former channels of the Tok River. In the distal half of the Tok fan and beneath the floodplain of the Tanana River, fine-grained sediments are generally unfrozen to discontinuously frozen with low to moderate moisture contents. In the Tanana River floodplain, thaw bulbs beneath active channels are fine grained and have moderate to high moisture contents. Small areas marginal to active channels of the Tanana River are underlain by expansion-fan sands of Holocene age. Areas marginal to the meander belt are interpreted to be high-resistivity, fine-grained, frozen and ice-rich slackwater-basin sediments.

Abandoned floodplain deposits of the Tok River fan are Holocene in age, as demonstrated by a radiocarbon age of 2,540 ± 40 RC yr B.P. (Beta-252318) (Reger and others, 2010, RC-8 in sheet 4 and table 1). Therefore, the permafrost in this younger part of the broad Tok fan is also Holocene in age. In the Tok fan east of the Tok River meander belt, sedge and willow lowlands and channels are interpreted to delineate a zone of groundwater emer-

[4]The large, gently sloping Tok fan is not a typical alluvial fan. Our investigations document evidence that the extensive, higher Tok fan surface west of the Tok River and the terrace remnant along the Alaska Highway east of the lower Tok River are part of an exceptionally broad expansion fan that was constructed by numerous massive outburst floods that surged down the Tok River during the last major glaciation (Reger and others, 2010, sheets 3 and 4; Reger and Hubbard, 2009). The eastern part of the Tok fan, which we designate the Tok River fan, was deposited by normal stream processes operating in the Tok River during the Holocene. The Tok River fan is inset into the broader Tok fan.

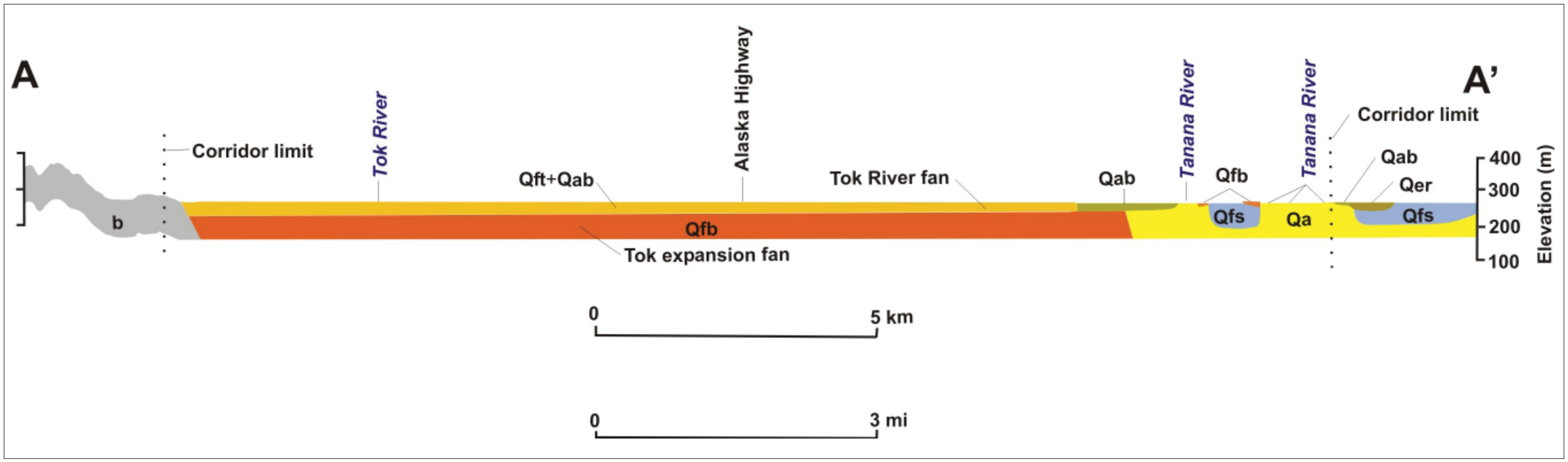



*Figure 4. Interpreted geologic cross-section (sheet 4, profile A–A') across Tok River fan, Tanacross A-4 and B-4 quadrangles. Vertical exaggeration = 6.1.*

gence (Qfte), and permafrost is inferred to be sporadic with low to moderate ice contents (Sm?). During winter months, the distal channel of the Tok River is dry. An extensive zone of the north-central distal Tok fan where groundwater is emerging (Reger and others, 2010, sheet 4, Qfbe and Qfte) is indicated by: numerous clearwater springs and channels; a network of anastomosing, natural drainage channels with water-tolerant shrubs and peat; and several clearwater lakes along the margin of the Tanana River floodplain in the east-central Tanacross B-5 Quadrangle northwest of Tok Junction (fig. 5). Permafrost is tentatively inferred to be sporadic with low to moderate ice contents (Sm?) in drainage channels and discontinuous with low to moderate ice contents (Dm) in low terraces in the channel network and in the margin of the Tok fan.

## OUTBURST FLOOD DEPOSITS

Logs of water wells in the Tok area indicate that the large fan consists of >120 ft (>36 m) of sandy gravel with minor beds and lenses of silt and sand (Williams, 1970). At the time of observation, water levels in the wells varied from 53 to 70 ft (16.1 to 21.2 m) below ground surface and permafrost was present in 4 of 16 water wells in the Tok area, indicating that small bodies of frozen ground with low ice contents are present (Sl). However, during September 1974, 17 soil borings drilled to a depth of 50 ft (16.7 m) in a ~2,900- by ~4,300-ft (~879- by ~1303-m) area near Tok penetrated up to 5 ft (1.5 m) of sand and silt underlain by sandy gravel with scattered cobbles, and all encountered the permafrost table at depths of 2 to 15 ft (0.6 to 4.6 m) (Kreig and Reger, 1982, pl. 7). No groundwater was encountered in any of the boreholes. These observations indicate that permafrost is

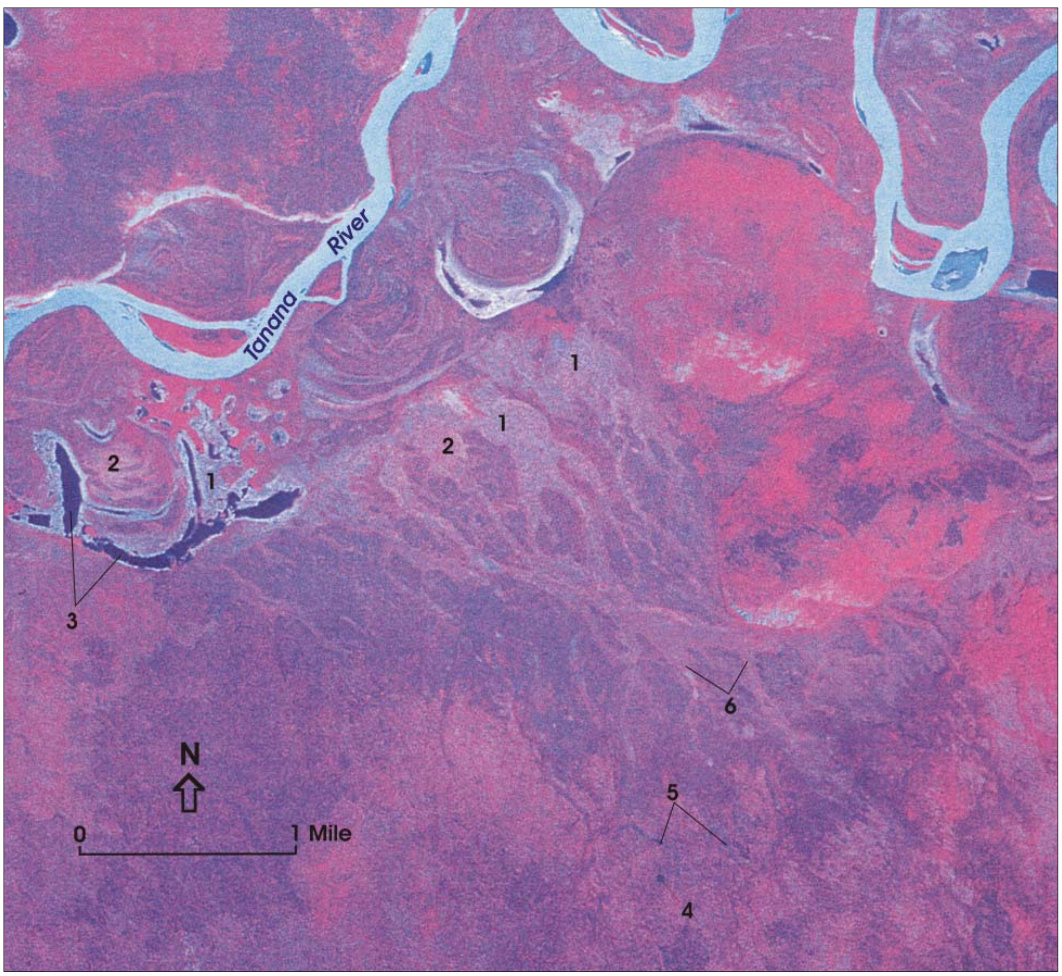



*Figure 5. Features indicating groundwater emergence along margin of Tok fan, central Tanacross B-4 Quadrangle. Symbols: 1 = swampy vegetation, 2 = peat bog, 3 = Clearwater floodplain lake with rims of partially floating peat, 4 = large clearwater spring, 5 = clearwater stream, 6 = network of shallow drainageways (Alaska High Altitude Photograph 21-266 taken July 1978).*

at least locally continuous in the Tok fan. Because surface vegetation on the Tok fan does not apparently reflect permafrost deeper than 6 ft (1.8 m) (Kreig and Reger, 1982, pl. 7), determination of the distribution of permafrost in the fan is not feasible without subsurface data, but we tentatively classify permafrost in the Tok fan as sporadic with low ice content (Sl). Because at least the shallower part of the broad Tok fan (Qfb) was built by outburst floods during the last major (Donnelly) glaciation (Reger and Hubbard, 2009), permafrost in these deposits must be late Donnelly to Holocene in age. Bodies of perennially frozen sediments deeper in the fan may be relict.

## UPLAND PERMAFROST NORTH OF THE TANANA RIVER

In contrast to broad outwash fans and moraines south of the Tanana River in this second segment of the proposed pipeline corridor, where permafrost map units are typically large, permafrost in the southern Yukon–Tanana Upland is complexly distributed because of local differences in topographic relief and aspect and the presence of shallow bedrock beneath a fairly thin loess cover. North of the Tanana River, southern slopes are generally unfrozen (G) where bedrock is steep and exposed and sporadically frozen with low ice content (Sl) where less steep and composed of tree-covered, silty and sandy colluvium. Ridge crests and upper eastern and western slopes that are covered with deciduous trees are typically discontinuously frozen with low ice contents (Dl). Northern and lower eastern and western slopes and valley bottoms with mixed deciduous and coniferous trees are discontinuously frozen with low to moderate ice contents (Dm). Where vegetated with black spruce, shrubs, and peat bogs, lowermost northern slopes and valley bottoms typically are continuously frozen and ice rich (Fr). Open-system pingos are restricted to these deposits in tributary valleys of the southern Yukon–Tanana Upland (Holmes and others, 1968).

Permafrost in the eolian sand blanket and dune field north of the Tanana River in the southern Yukon–Tanana Upland is generally discontinuous with low ice content (Dl), except on northern and eastern aspects, where ice contents may reach moderate percentages (Dm) (fig. 6). Where eolian sand is retransported and incorporates lowland loess and organic materials, surface vegetation indicates that permafrost is continuous and ice contents are moderate to high (Fr). Beneath the lake impounded against the bedrock hills by the Tetlin Junction dune field, the sediments probably lack permafrost. Radiocarbon dating indicates that the Tetlin Junction dune field accumulated during the last major (Donnelly) glaciation and continues to be locally reactivated in response to destruction of the stabilizing vegetation by periodic wildfires (Reger and others, 2010, RC-6 and RC-7 in sheet 4 and table 1). Therefore, permafrost in the dune field must be late Donnelly to Holocene in age.

## UPLAND PERMAFROST SOUTH OF TANANA RIVER

Widespread discontinuous alpine permafrost is inferred at higher elevations in the eastern Alaska Range because of colder air temperatures at higher elevations. Discontinuous permafrost probably has low ice content (Dl) because slopes are generally moderate to steep and well drained and bedrock is shallow (sheets 2 and 3). No attempt was made to separate possible sporadic permafrost with low ice content (Sl), which may be present in very steep south-facing rock walls, from discontinuous permafrost. However, in active rock glaciers (Qcg), massive talus cones and protalus lobes (Qct), and ice-cored Holocene moraines (Qgdh) in topographic settings at least partly protected from direct solar radiation (Reger and others, 2010, sheet 2), continuous permafrost is inferred to have

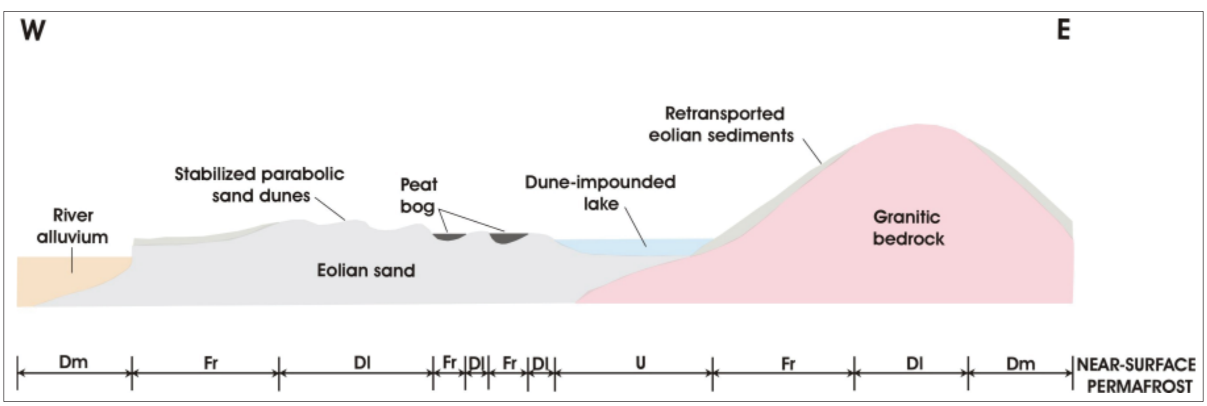



*Figure 6. Generalized relations of landforms and geology to near-surface permafrost in the Tetlin Junction dune field. Symbols: Dl = discontinuous permafrost with low ice content; Dm = discontinuous permafrost with low to moderate ice content; Fr = continuous permafrost with moderate to high ice content; U = no permafrost.*

low to moderate ice content (Fm). Coarse glacial drift in mountain valleys is inferred to contain discontinuous permafrost with low ice content (Dl).

In the stream-dissected northern plateau of the eastern Alaska Range southeast of Tok River, mixed deciduous–coniferous woodlands on ridge flanks and shrub- and tundra-covered ridge crests indicate the presence of discontinuous permafrost with low ice content (Dl) (sheet 4). The loess cover is thin on ridge crests and thickens down ridge flanks. Valley bottoms, which are vegetated with low shrubs, are discontinuously frozen with low to moderate ice contents (Dm).

## EVIDENCE OF FORMER PERMAFROST

At locality A (sheet 4) in a former roadcut of the Alaska Highway just east of the MP 1303 crossing of the Tanana River in the southeast Tanacross B-4 Quadrangle, we found 13 sand wedges in groups or as single wedges in grüssified granitic bedrock (fig. 7)[5]. Fillings of some of these wedges include angular, pebble-sized fragments of weathered granitic bedrock that are distributed in clusters near the wedge axis or near the sidewalls, and several of the sand wedges include former tension cracks up to ~0.2 in. (~5 mm) wide in massive sand that are filled with silty sand (fig. 8). The largest sand wedge measures 1.3 ft (0.4 m) wide and extends into the weathered bedrock ~5.3 ft (~1.6 m). In these wedges, the sand fill is continuous with the overlying retransported eolian sand with rock fragments. This section is overlain by an unweathered loess of variable thickness that contains a prominent Cca horizon. Capping the exposure is a ~3.3-ft-thick (~1-m-thick) loess bearing a post-Donnelly weathering profile


*Figure 7. View north of sand wedges in weathered granitic bedrock exposed in former roadcut near MP 1303 Alaska Highway, southeast Tanacross B-4 Quadrangle. Photo taken 08/01/08 by R.D. Reger.*

[5]Unfortunately, this outstanding exposure was buried in 2009 beneath waste material excavated from the nearby large roadcut for the highway realignment related to the new Tanana River bridge and is no longer available for study.

that is equivalent to a profile measured near the Tanana River bridge (Reger and others, 2010, fig. 27). The sand wedges occupy modified, near-orthogonal joints striking 108° and 205° azimuth. Sand wedges in bedrock have been documented in the Tanana River valley on the campus of the University of Alaska Fairbanks (Péwé, 1975a and b), in the roadcut at MP 292.6 Richardson Highway (Péwé and Reger, 1983, p. 29), and in a borrow pit at mi 0.6 (km 1) of Shaw Creek Road, a side road intersecting the Richardson Highway near the mouth of Shaw Creek (Péwé and Reger, 1983, p. 38).

The presence of these sand wedges along altered bedrock joints and their compositions indicate that these features have a complex history. They clearly predate the loess that caps the exposure, so they are probably pre-Donnelly in age. There is no evidence for erosion of the wedges by meltwater runoff or outburst floods. Instead, wedge fillings of retransported eolian sand that contains fragments of weathered bedrock are evidence that former ice wedges melted and the overlying sandy colluvium accumulated in the resulting cavities, similar to polygonal sediment wedges of Donnelly age in the Donnelly Dome area south of Delta Junction (Péwé and others, 1969). Wedge fillings containing both sand mixed with angular grüs fragments and thin tension cracks filled with silty sand in massive sand are evidence that some wedges were formerly composed of ice mixed with sand. Sand wedges in permafrost areas like Alaska's Interior likely formed by contraction of permafrost in response to rapid and deep chilling of the ground, so that thermal contraction exceeded the tensile strength of the ground (French, 2007). Cracking of the ground begins at the top of permafrost when the ground temperature there chills to between -20º and -30°C, and cracking propagates from the top of permafrost (permafrost table) upward to the ground surface and from the permafrost table downward (Lachenbruch, 1962). In homogeneous material, thermal-contraction cracks typically have a polygonal surface pattern, but in bedrock with pre-existing near-orthogonal joints, winter contraction would widen the joints, expanding cracks into which overlying material could sift, provided that material (like thin eolian sand) was not bonded by ice. With varying amounts of joint widening through time, sediment

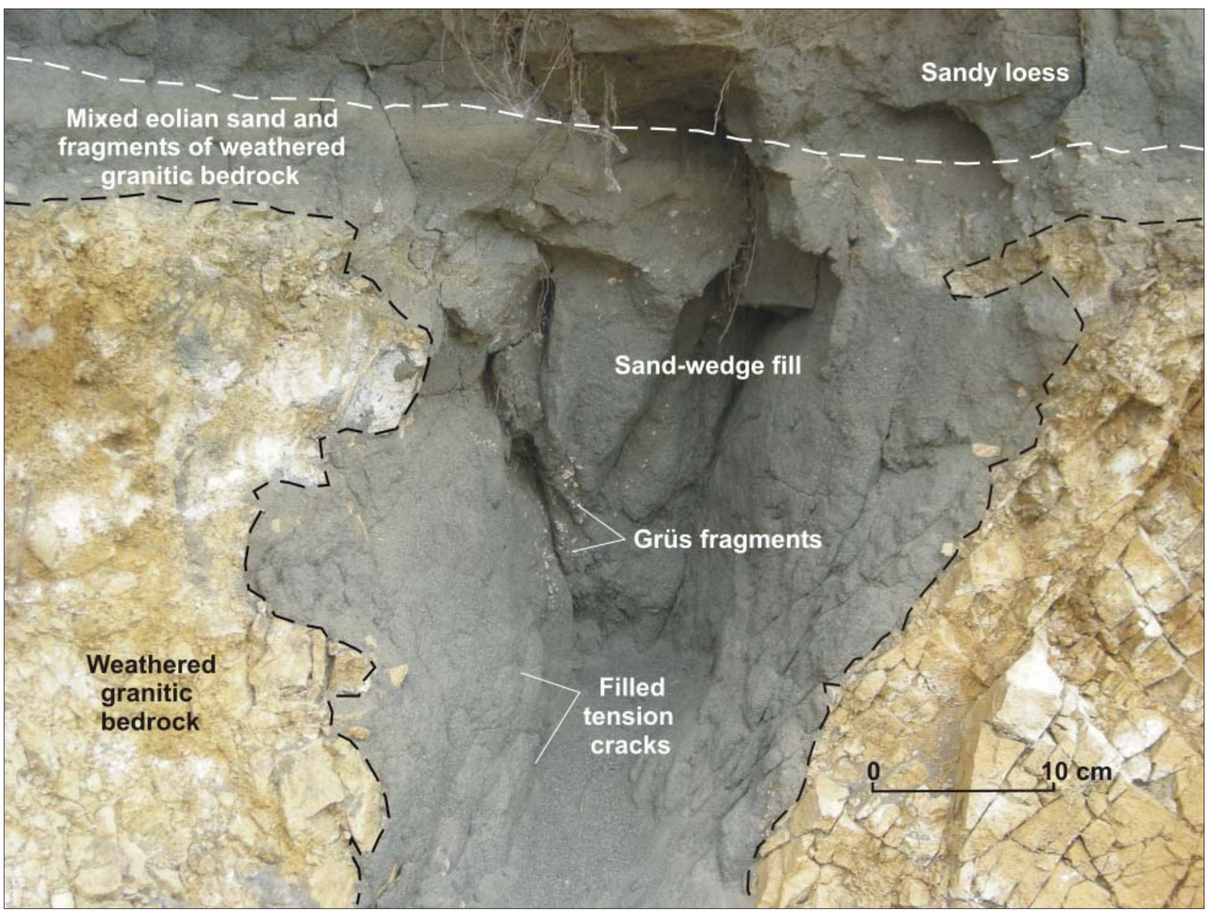



*Figure 8. Details of sand-wedge filling with mixed eolian sand and angular fragments of weathered granitic bedrock in former roadcut near MP 1303 Alaska Highway. Photo taken 08/03/08 by R.D. Reger.*

wedges would form in bedrock, similar to the formation of ice wedges in sediments. Primary sand wedges form in arid polar deserts of continuous permafrost, like the dry valleys of Antarctica (Péwé, 1959) and in northern Alaska and arctic Canada (Murton and others, 2000). We assume that a sparse steppe vegetation probably existed in this rigorous climate at this wind-swept upland site, where a thin eolian-sand blanket accumulated and primary sand wedges formed, as a steppe flora apparently existed here during the last major glaciation (Young, 1982). When local conditions were less arid but still very cold and windy, wedges of mixed ice and sand likely formed, and tundra vegetation was probably present (Black, 1976). Secondary sand wedges formed when local conditions changed so that permafrost and ice wedges thawed and wedge-shaped fillings accumulated in the resulting cavities (French, 2007). Thawing of permafrost may have occurred as a result of climatic warming or in response to a wildfire that destroyed the local shrubland or woodland vegetation (Chapin and others, 2006). Today, this upland site is generally unfrozen (sheet 2).

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