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DEPOSITIONAL ENVIRONMENTS OF THE PRINCE CREEK FORMATION ALONG THE EAST SIDE OF THE TOOLIK RIVER, SAGAVANIRKTOK QUADRANGLE, NORTH SLOPE, ALASKA

by
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Cover caption: Outcrop of the Prince Creek Formation along the east side of the Toolik River. Image shows sand-rich meandering channel deposits overlain by mud-rich palustrine and lacustrine deposits. Geologist for scale. Image courtesy of Dolores van der Kolk.

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Peter P. Flaig[1] and Dolores A. van der Kolk[2]

Abstract

A 175-m-thick succession of nonmarine facies of the Prince Creek Formation along the east side of the Toolik River in the Sagavanirktok Quadrangle is interpreted as the deposits of meandering rivers and their associated floodplains. Facies consist of fine- to medium-grained sandstone, siltstone, mudstone, carbonaceous shale, and coal. Depositional environments of the Prince Creek Formation along the Toolik River include meandering river channels, levees, crevasse channels and crevasse splays, lakes, swamps, mires, and soil-forming environments. Sand bodies in the succession exhibit a low degree of interconnectedness and are encased in floodplain deposits. Floodplains were well preserved, extensively vegetated, and wet. Fine-grained successions containing abundant mud, silt, carbonaceous shale, and coal are up to 20 m thick in outcrops along the Toolik River and dominate the stratigraphy. This implies that lakes, marshes, mires, and swamps likely persisted for prolonged periods in this region. The abundance of water-dependent floodplain facies coupled with the presence of isolated sand bodies encased in these finer-grained deposits indicates that the region likely experienced an extended period of elevated base level, possibly as the result of sustained high subsidence rates related to lithospheric loading in the evolving Brooks Range orogenic belt to the south.

PRINCE CREEK FORMATION

The Colville Basin is an Early Cretaceous foreland basin filled during the Cretaceous and Tertiary by east- and northeast-prograding topset to deep-water clinoform systems sourced from the Chukchi Platform to the west and the Brooks Range orogenic belt of northern Alaska to the south. The nonmarine Prince Creek Formation (fig. 1), initially named by Gryc and others (1951), constitutes the most proximal part of a predominantly progradational, Late Cretaceous to Paleocene clinoform sequence that also includes shallow- to marginal-marine facies (Schrader Bluff Formation) and deep-water slope and basinal deposits (lower Canning Formation) (compare Mull and others, 2003; Decker, 2007). The Prince Creek Formation is an alluvial, coastal plain, and deltaic succession composed of conglomerate, sandstone, siltstone, mudstone, carbonaceous shale, coal, bentonite, and tuff (Roehler, 1987, Mull and others, 2003; Flaig and others, 2006, 2007, 2011). The Prince Creek Formation was initially considered to be entirely Cretaceous in age by Gryc and others (1951) who divided the formation into two distinct clastic tongues: the Turonian to Coniacian Tuluvak Tongue and the Campanian to Maastrichtian Kogosukruk Tongue. However, Mull and others (2003) revised the nomenclature of the Colville Basin and removed the lower, conglomeratic Tuluvak Tongue from the Prince Creek Formation by combining these nonmarine deposits with their Turonian to Coniacian shallow marine equivalents (formerly the Ayiyak Member of the Seabee Formation) and raising the Tuluvak to formation status. Mull and others (2003) also recognized that the bulk of the coal-bearing succession exposed at Sagwon Bluffs along the Sagavanirktok River, which was originally assigned to the Sagwon Member of the Sagavanirktok Formation (fig. 1), more closely resembles the coaly deposits of the Prince Creek Formation found elsewhere in the region than the overlying conglomeratic facies of the Sagwon Member of the Sagavanirktok. Recognizing the basal contact of the conglomerate as a probable sequence-bounding unconformity, they reassigned all of the strata below that unconformity at Sagwon Bluffs to the Prince Creek Formation. The Prince Creek Formation is now redefined to include strata of the Kogosukruk Tongue of the old nomenclature as well as the coal-bearing rocks originally assigned to the Sagavanirktok Formation at Sagwon Bluffs. This reorganization of nomenclature, along with recently published data from bluffs along the Colville River (Flores and others, 2007), indicates that deposition of the Prince Creek Formation in north-central Alaska began in the Campanian and continued into the Paleocene. A 175-m-thick composite section measured along the east side of the Toolik River for this study contains 19 varieties of palynomorphs that indicate that the succession is no older than Paleocene at that location (IRF Group Inc., 2008, unpublished report to the Alaska Department of Natural Resources; Gillis and others, 2014).

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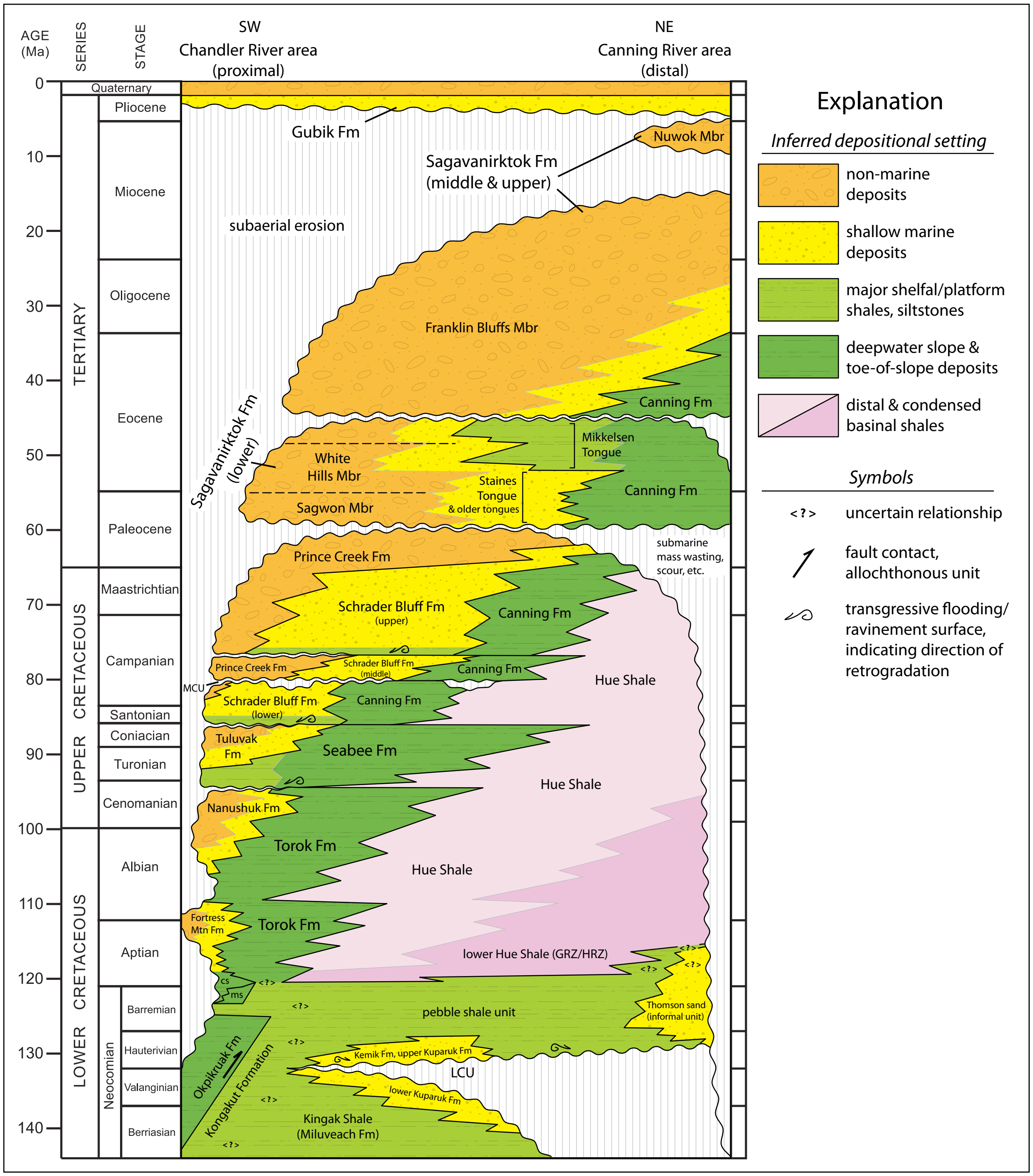

Figure 1. Chronostratigraphic column for the Colville basin, northern Alaska, revised from Mull and others (2003, USGS Professional Paper 1673) and Garrity and others (2005, USGS Open-file Report 2005-1182). Abbreviations as follows: Fm, Formation; Mbr, Member; Mtn, Mountain; LCU, Lower Cretaceous unconformity; MCU, mid-Campanian unconformity; cs, Cobblestone sandstone of Fortress Mountain Formation (informal); ms, manganiferous shale unit (informal). From Decker and others, this volume.

METHODS

Field reconnaissance during the early part of the Alaska Division of Geological & Geophysical Surveys' 2007 summer field season located a number of significant exposures assigned to the Prince Creek Formation along the east side of the Toolik River (Gillis and others, 2014). Four of these stratigraphic sections were measured, described, photographed, and interpreted using standard sedimentologic and stratigraphic techniques. This investigation yielded a relatively continuous composite measured section approximately 175 m thick (figs. 2, 3; sheet 1). Photographs were sutured into photomosaics to investigate facies changes and sedimentary architecture. Select samples were collected for analysis of biostratigraphy, petrography, reservoir quality, and thermal maturity.

FACIES

Based on grain size, thickness, physical sedimentary structures, the nature of upper and lower contacts, and inclusive flora, the Prince Creek Formation along the east side of the Toolik River was divided into seven facies. Table 1 summarizes and interprets these seven facies. Facies include fine- to medium-grained sandstone, very-fine- to fine-grained sandstone, siltstone, rippled/laminated mudstone, aggregated (blocky to platy) mudstone, carbonaceous shale, and coal. The succession is dominated by finer-grained facies (such as siltstone, mudstone, carbonaceous shale, and coal).

FACIES ASSOCIATIONS AND INTERPRETATIONS

The seven facies of the Prince Creek Formation found along the Toolik River can be grouped into five facies associations based on stacking pattern and genetic relationships: (1) meandering river channels and levees, (2) crevasse channels and crevasse splays, (3) lakes and marshes, (4) swamps and mires, and (5) soils.

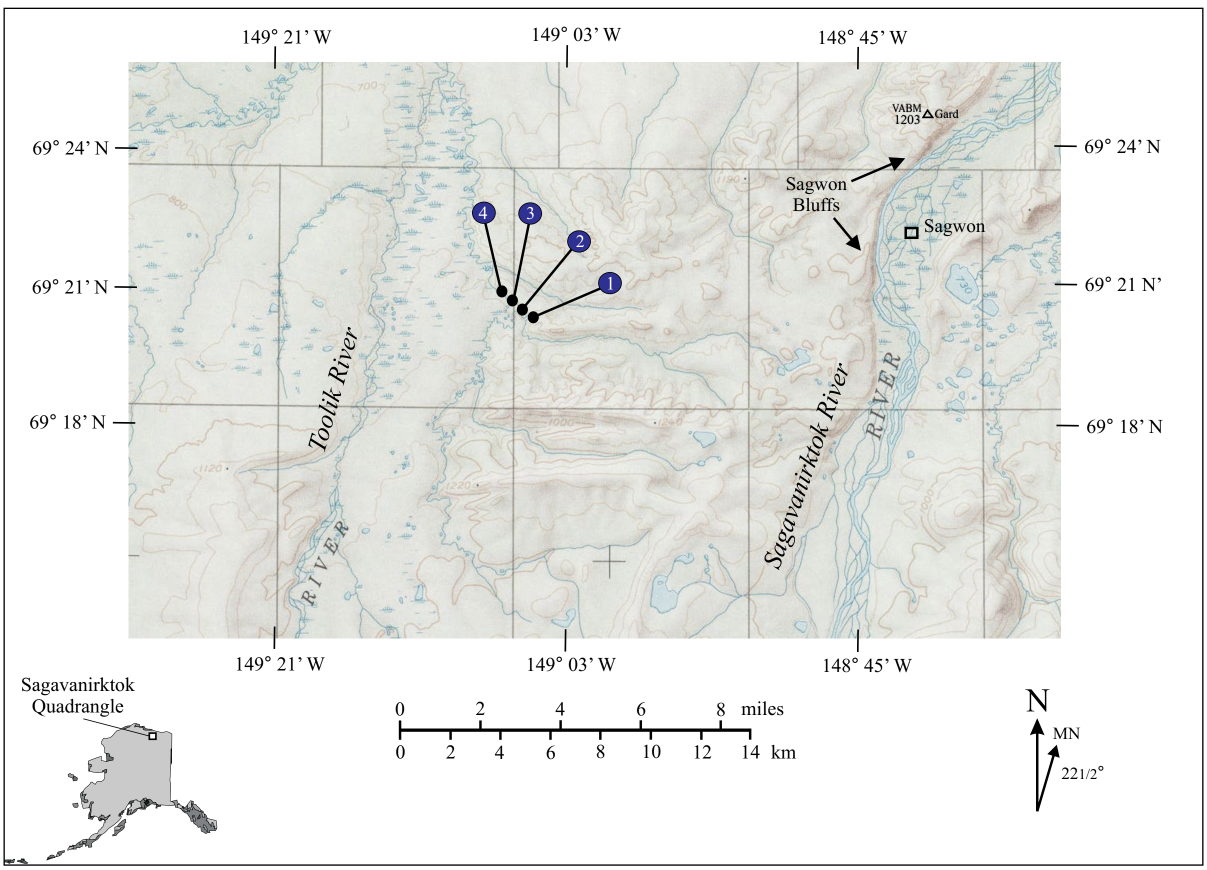

Figure 2. Location of measured stratigraphic sections 1–4 along the Toolik River in the Sagavanirktok Quadrangle, North Slope.

Figure 3. Images of the bluffs along the Toolik River where stratigraphic sections 1–4 were measured. Numbers on photographs correspond to measured sections on sheet 1 and map locations on figure 2. Bluffs are 20–30 m high.

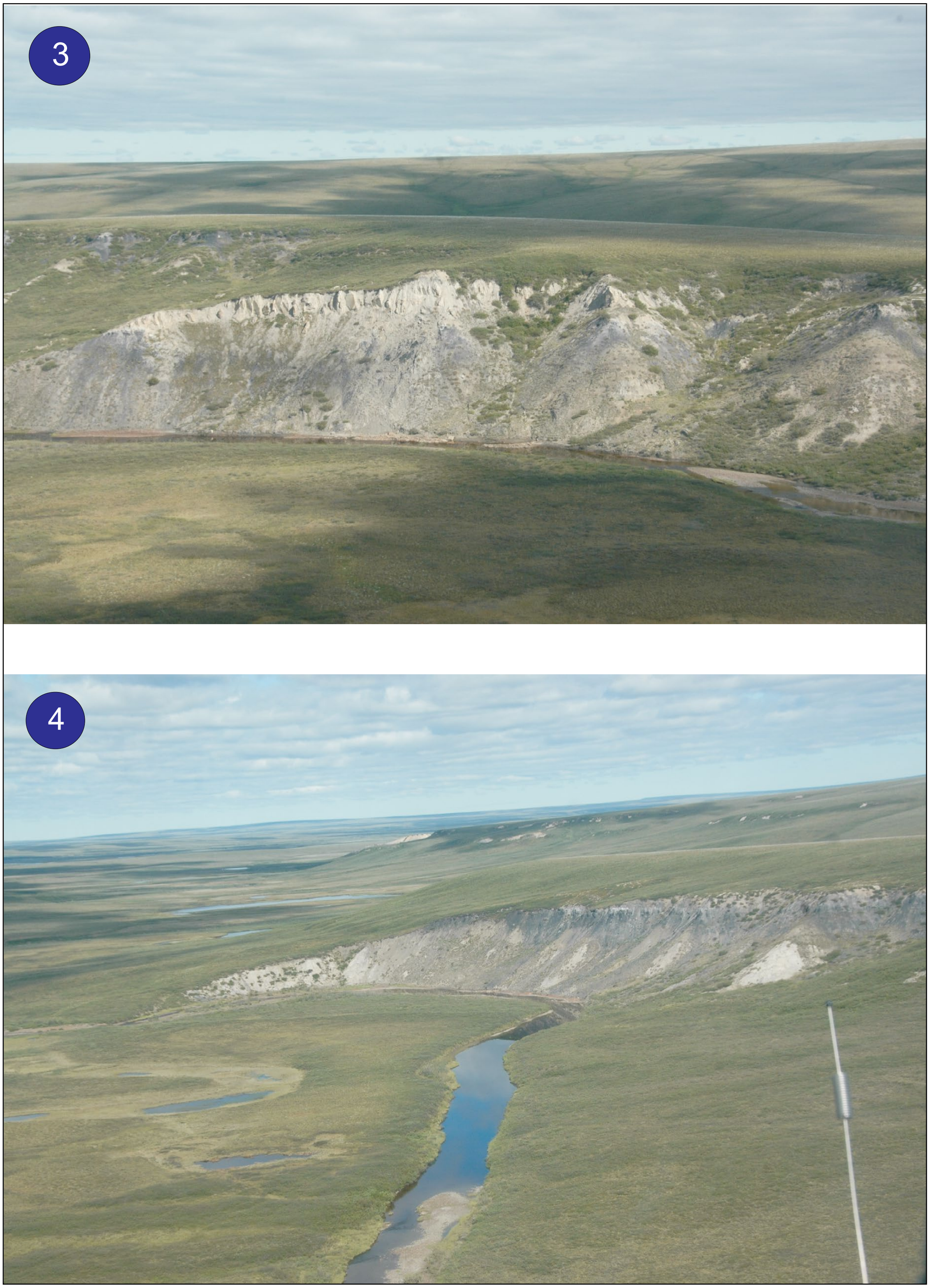

Figure 3 (continued). Images of the bluffs along the Toolik River where stratigraphic sections 1–4 were measured. Numbers on photographs correspond to measured sections on sheet 1 and map locations on figure 2. Bluffs are 20–30 m high.

Table 1. Description and interpretation of facies found within the Prince Creek Formation along the east side of the Toolik River, Sagavanirktok Quadrangle, North Slope, Alaska.

Facies	Thickness	Contacts	Sedimentary Structures	Flora	Diagnostic Features	Interpretation
F-1 Fine- to medium-grained sandstone	4.5–12(?) m (upper limit unknown)	Basal Erosional Upper Gradational	Common Trough cross-laminations, ripples, mud/coal rip-up clasts, quartz/chert pebbles Rare Planar-tabular laminations, lateral accretion surfaces	Common Wood impressions, carbonized or silicified wood fragments and plant fragments Rare Carbonized root traces, metasequoia	Thick, multi-story, erosionally-based sand body. Sandstone is the basal facies in an overall fining-upward succession. This is the only facies containing pebbles and trough cross-laminations	Meandering river channel-fill deposits
F-2 Very-fine- to fine-grained sandstone	0.25–1.0 m	Basal Erosional Upper Sharp to gradational	Common Ripples, siliceous or carbonaceous concretions Rare Coal rip-up clasts	Common Wood impressions, carbonized or silicified logs, carbonized or silicified wood fragments and plant fragments	Thin, erosionally based single-story sand body with sharp to gradational upper contact. Only facies containing silicified or carbonized logs	Crevasse channel and proximal crevasse splays
F-3 Siltstone	0.25–2.0 m	Basal Sharp to gradational Upper Sharp to gradational	Common Ripples Rare Mottles	Common Wood impressions, carbonized or silicified wood fragments and plant fragments Rare Carbonized root traces	Siltstone with sharp to gradational basal and upper contacts. Ripples are common. Often found in repeating couplets with F-4	Lakes, lake margins, levees and distal crevasse splays

Facies	Thickness	Contacts	Sedimentary Structures	Flora	Diagnostic Features	Interpretation
F-4 Parallel-laminated to rippled-mudstone	0.25–5.0 m	Basal Sharp Upper Sharp to gradational	Common Ripples, planar–tabular laminations, mottles, siliceous or carbonaceous concretions Rare Jarosite	Common Carbonized plant fragments Rare Carbonized root traces	Found in thick (up to 20 m) packages of rippled or laminated mud interbedded with rippled siltstone facies (F-3). Often gray in color and contains red or orange mottles	Lacustrine and palustrine deposits
F-5 Aggregated, blocky or platy rooted mudstone	0.25–1.5 m	Basal Sharp to gradational Upper Sharp to gradational	Common Aggregated, blocky or platy structure, mottles, siliceous or carbonaceous concretions Rare Jarosite	Common Carbonized roots, carbonized plant fragments	Carbonaceous roots throughout, blocky or platy structure	Paleosols
F-6 Carbonaceous shale	0.25–0.75 m	Basal Sharp to gradational Upper Sharp to gradational	Shale partings	Common Carbonized or silicified wood fragments and plant fragments, wood impressions	Highly organic black shale containing abundant carbonized plant material, shale partings	Distal floodplain and mires
F-7 Coal	0.1–5.25 m	Basal Sharp Upper Sharp	Conchoidal fracture, planar laminated plant material	Common Carbonized wood fragments and plant fragments, wood impressions	Composed entirely of carbonized plant and wood fragments	Swamps

Meandering River Channels and Levees

Meandering rivers and their associated levees are evidenced along the east side of the Toolik River by fining-upward successions (FUS) that range from 4.5 to at least 14 m thick and may be hundreds of meters in lateral extent (figs. 4, 6, sheet 1). Although not all FUS in the study area are exposed from the base to the top due to slump-covered or scree-covered slopes, those with visible basal contacts exhibit a multi-story, fine- to medium-grained sandbody with a basal erosion surface. Sandstones are quartzose, chert rich, and may contain minor amounts of metamorphic and sedimentary rock fragments, muscovite, and biotite. Quartz pebbles and cobbles as well as mud and coal rip-up clasts are often found immediately above the basal erosion surface. Sandbodies are primarily trough cross-laminated with rippled intervals, and contain abundant wood impressions and carbonized or silicified wood/plant fragments up to 5 cm in diameter and 20 cm in length. Carbonaceous root traces up to 15 cm long with diameters from 0.3 to 1.0 cm are found in some sandbodies, most commonly near the top. Lateral accretion surfaces are also developed within some of these sandbodies. The basal sandbody grades upward through a series of finer-grained facies that may include planar-laminated to massive fine-grained sandstone, rooted siltstone, and rooted mudstone. The FUS is commonly capped by a carbonaceous shale or coal. These fining-upward successions are interpreted to be the deposits of meandering streams, point/scroll bars, and levees (in the sense of Allen, 1965, 1970; Elliott, 1976; Nanson, 1980). Sand-dominated fining-upward successions of the Prince Creek Formation along the Toolik River appear to be laterally continuous for hundreds of meters; however their true width is obscured by tundra cover. The maximum thickness of these deposits is also unknown, as their basal surfaces are typically buried by slump and/or scree and their upper contacts are commonly truncated by Quaternary cover (fig. 3).

Crevasse Channels and Crevasse Splays

Crevasse channels and crevasse splays are recognized as thinner (0.25–1.0 m), single story, gradational to erosionally based, very-fine- to fine-grained rippled sandstones and siltstones that are laterally continuous for tens to hundreds of meters (compare Bridge, 1984; Mjøs and others, 1993) (fig. 5, sheet 1). These sandstones/siltstones often fine upward into rooted mudstone or are interbedded with them (see interval 25–27 m, sheet 1). Splay sands contain coal rip-up clasts, siliceous or ferruginous concretions, wood impressions, and carbonized or silicified wood/plant fragments. Crevasse splays are the only depositional environment along the Toolik River in which carbonized and silicified logs up to 15 cm in diameter and 30 cm long were found. This may be related to the reduction in flow velocity common in splay channels and on unconfined flows such as crevasse splays. Reduced flow velocities contribute to the settling of material from suspension and hence the deposition of allochthonous suspended material and vegetation on the floodplain (Smith and Pêrez-Arlucea, 1994; Martín-Closas and Galtier, 2005). Autochthonous floodplain species may also be preserved when covered with sediment during overbank flooding (Rust and others, 1984; Fielding, 1984; Elliott, 1985).

Lakes and Marshes

Lacustrine and palustrine (that is, pedogenically modified marginal-lacustrine and marsh) deposits along the Toolik River occur as thick (in excess of 20 m) successions of rippled- to planar-laminated gray mud containing abundant orange mottles, iron-rich concretions, and jarosite that alternate with rippled siltstone, which commonly includes leaf impressions and plant fragments (fig. 5, 6, sheet 1). Lacustrine intervals in alluvial sedimentary successions are typically composed of rhythmically laminated, finer-grained facies (Astin, 1990; Besly and Collinson, 1991; Smith and Pêrez-Arlucea, 1994; Bamberry and others, 1995; Tanner, 2000). Fossil leaves and plant fragments demonstrating exceptional preservation are found within the concretions and siltstones of these deposits and in scree below most outcrops (fig. 6). Lacustrine/palustrine successions are the thickest continuous deposits found within the Prince Creek Formation along the Toolik River.

Swamps and Mires

Organic-rich, peat-forming environments are preserved as layers of interbedded coal, carbonaceous shale, and black organic mud that range from 0.1 m to more than 5 m thick (fig. 7, sheet 1). The coal, carbonaceous shale, and mud all contain abundant carbonized wood and plant fragments. Coal beds are very common and relatively thick in the Prince Creek Formation along the Toolik River. This is in contrast to the organic facies of the older (early Maastrichtian) Prince Creek Formation located along the Colville River, which consist primarily of carbonaceous shale and highly organic mudstone (Flaig, 2010; Flaig and others 2011, 2013, 2014). Coals are rare along the Colville River, and when found have thicknesses that do not exceed 1 m (Flaig and others, 2011, 2013). Coals of similar thickness to those in outcrops along the east side of the Toolik River are found in the Prince Creek Formation at Sagwon Bluffs, approximately 15 km to the northeast of the study area.

Figure 4. Medium-grained sandstone in fining-upward succession. Basal surface of the sandbody erosionally truncates a coal. Sandbody is 4.5 m thick, representing the interval from 114.5–119 m in measured section #3 (sheet 1).

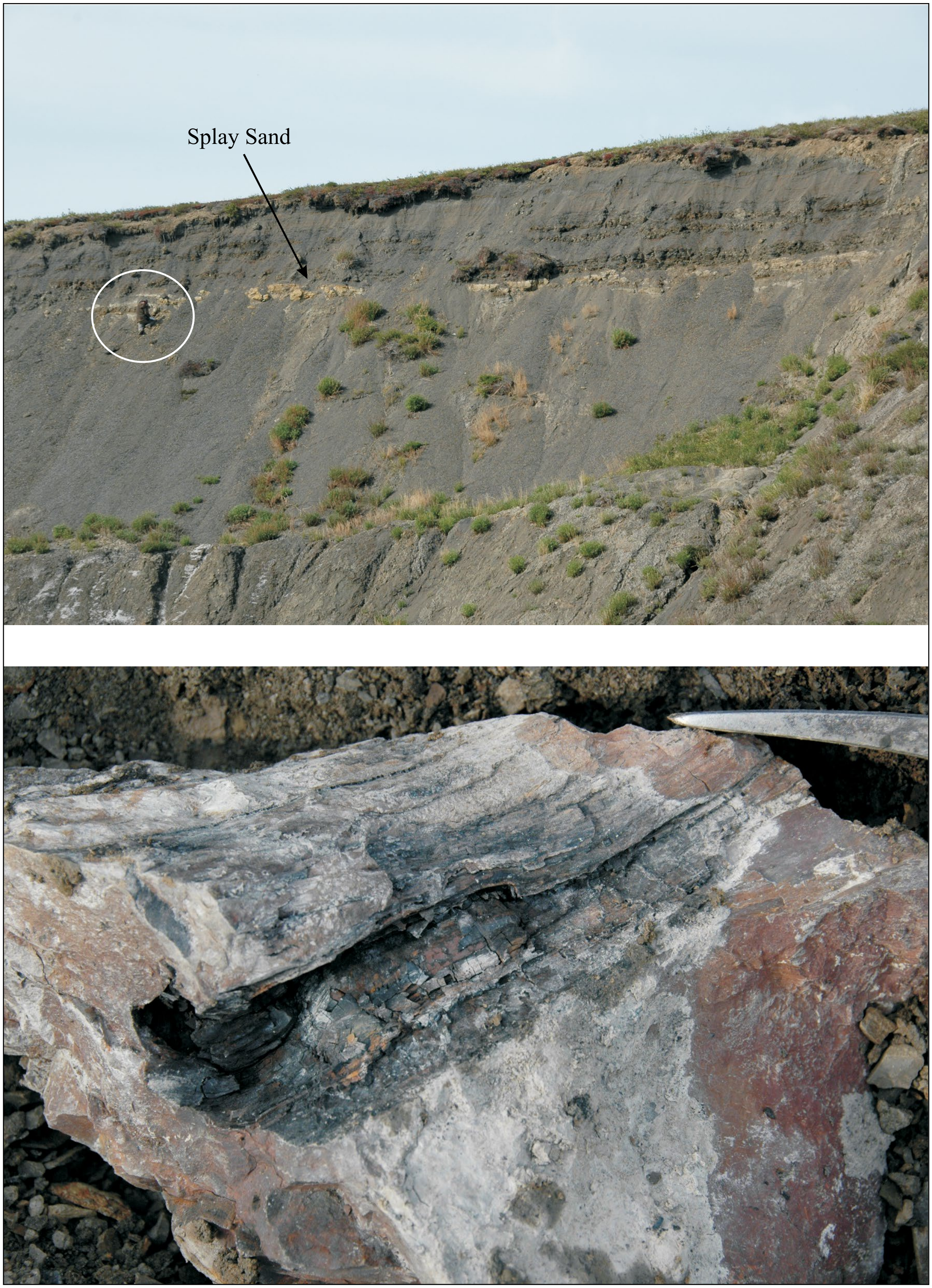

Figure 5. Thin (0.5 m) crevasse splay sand containing carbonized logs interbedded with finer-grained floodplain facies representing 25–26.5 m in measured section #1 (sheet 1). Geologist (upper photo) and hammer pick (lower photo) for scale.

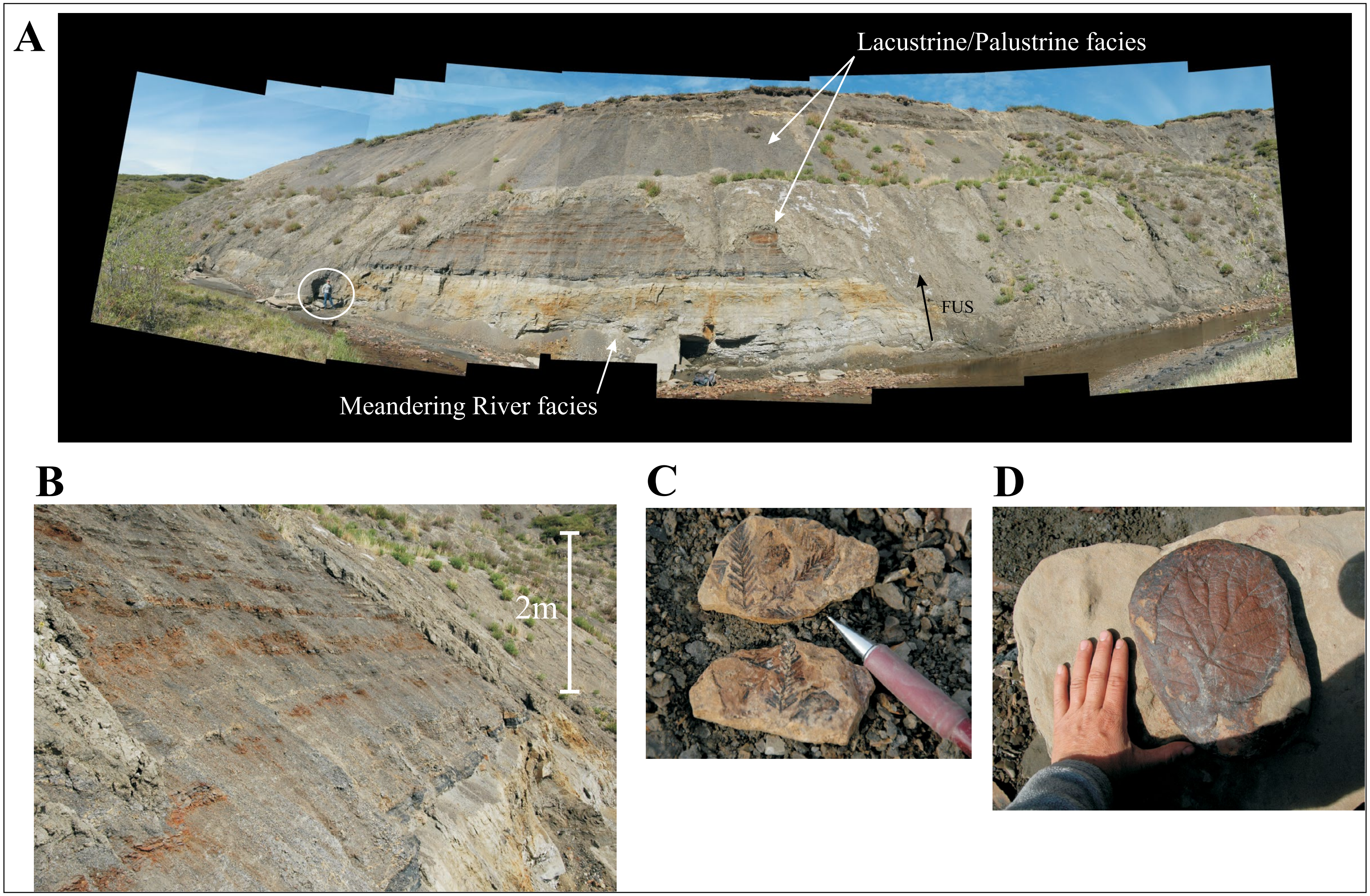

Figure 6. Lacustrine interval in measured section 1 (sheet 1). Images show: (A) Transition from meandering channel facies (FUS) upward into a 20-m-thick lacustrine/palustrine interval, (B) close-up of interbedded gray mud and red silt of lacustrine interval, (C) metasequoia leaves found in red siltstone, and (D) leaf fossil, identified by Tomsich and others (2014) as *Pseudoprotophyllum,* found in scree below lacustrine interval. Geologist and pencil for scale.

Figure 7. Coal seam, 5.25 m thick, in the Prince Creek Formation. Coal seam represents ~170.1–175.35 m in measured section 4 (sheet 1). Geologist and pencil for scale.

Soils

Soils in the Prince Creek Formation are evidenced by the presence of vertically stacked mudstones containing aggregates with a blocky or platy structure and abundant carbonized root traces 0.25–1.5 m thick (fig. 8). Mudstones are predominantly olive-gray, gray, or black and contain reddish-orange mottled soil aggregates, iron concretions, and rare jarosite. Soils along the Toolik River are gleyed (drab-colored from saturation in water), indicating wet, saturated conditions, but are also mottled, suggesting intermittent periods of drying (compare Fanning and Fanning, 1989; McCarthy and others, 1997, Flaig and others, 2013).

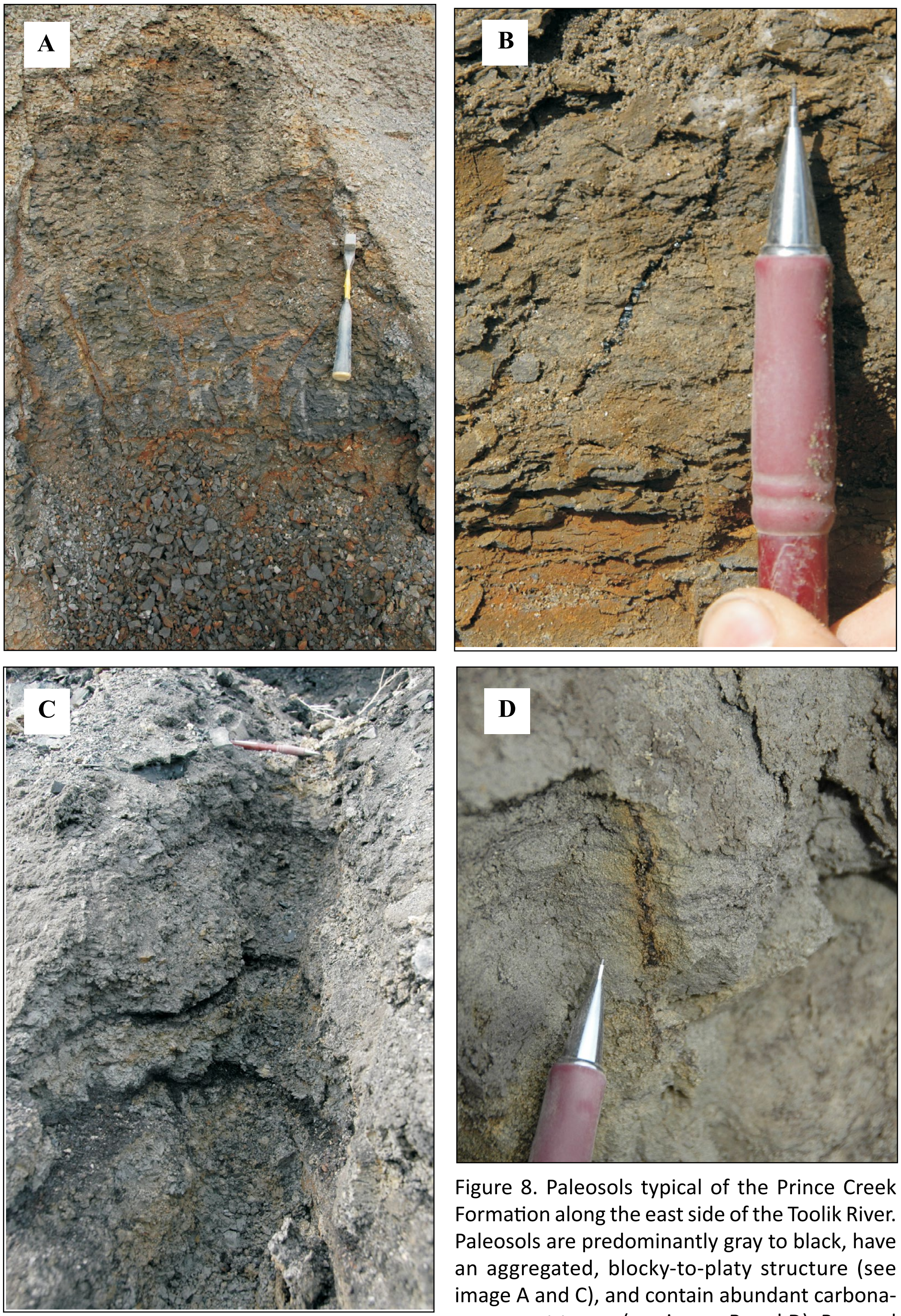

Figure 8. Paleosols typical of the Prince Creek Formation along the east side of the Toolik River. Paleosols are predominantly gray to black, have an aggregated, blocky-to-platy structure (see image A and C), and contain abundant carbonaceous root traces (see image B and D). Pen and hammer for scale.

DISCUSSION

Tectonic, eustatic, climatic, and autocyclic processes are commonly invoked as the major factors controlling sedimentation and stacking patterns in basins (for example, Schumm, 1977; Bridge and Leeder, 1979; Miall, 1988; Flemings and Jordan, 1990; Vail and others, 1991; Schumm, 1993; Cant, 1998; Catuneanu, 2004). Active tectonism is considered to be a major factor driving recurring episodes of subsidence and uplift in basins (Bridge and Leeder, 1979; Heller and others, 1988; Flemings and Jordan, 1990; Heller and Paola, 1996). Low subsidence rates in foreland basins, frequently driven by orogenic unroofing and isostatic unloading in the adjacent orogenic belt, are associated with decreased accommodation, high channel densities, increased interconnectedness of fluvial sandbodies, and low preservation potential for floodplain deposits. Conversely, high subsidence rates, commonly associated with increased orogenic activity and lithospheric loading, are thought to produce high-accommodation, low channel interconnectedness, and an increased potential for the preservation of floodplain deposits (Bridge and Leeder, 1979; Flemings and Jordan, 1990; Heller and Paola, 1996, Catuneanu and others, 2009). As orogenic loading increases, subsidence rates increase in areas proximal to the orogenic belt. The basin is typically underfilled (Catuneanu, 2004), and with an increase in subsidence, fine-grained, low-energy facies with low channel densities (Heller and Paola, 1996) and reduced sandbody interconnectedness (Bridge and Leeder, 1979) are deposited in proximal areas just beyond the coarsest-grained wedges (Flemings and Jordan, 1990).

Meandering channel deposits of the Prince Creek Formation along the east side of the Toolik River exhibit poor sandbody/channel interconnectedness, with individual sandbodies typically found to be encased in finer-grained floodplain deposits (see sheet 1). In fact, fine-grained floodplain deposits (such as lakes, swamps, marshes, and mires) are the dominant facies in the study area. This suggests that the region likely experienced an extended period of high subsidence, possibly driven by orogenic loading.

Coals are historically understood to be the products of peat-forming environments (Stopes, 1922; White, 1925; Tatsch, 1980). A wet climate is essential for peat production (Thiessen, 1925; Fern, 1988), as is a high water table, substantial growth of vegetation, and a lack of clastic influx (Flores, 1984, Fielding, 1987). Coals are produced in anoxic/reducing environments such as low lying wetlands, mires, backswamps, and lake marginal or river marginal environments (Tatsch, 1980; Flores, 1984; Fielding, 1987). For coal formation to occur, these environments must be starved of clastics and unable to drain under the existing conditions (Stopes, 1922; White, 1925; Francis, 1961; Fielding, 1987). During periods of high subsidence, base level increases, accommodation increases, channels become more stable on their floodplains, and a greater percentage of the fine-grained material in the basin is preserved (Bridge and Leeder, 1979; Alexander and Leeder, 1987; Flemings and Jordan, 1990). The amount of subsidence within a basin can control peat production, peat distribution, and coal preservation (Fielding, 1987) by controlling the water table (Flores, 1984). Coals are relatively thick (up to 5 m; see fig. 7) and very common in the Prince Creek Formation along the Toolik River (and along the Sagavanirktok River) as are other facies formed in environments with poor drainage (such as lakes, marshes, and mires).

Structural lows related to tectonic subsidence within basins can help trap floodwaters of fluvial systems and generate ideal environments for the formation of long-lived alluvial plain lakes (Bridge and Leeder, 1979; Alexander and Leeder, 1987). Thick packages (>20 m) of fine-grained facies interpreted as alluvial plain lakes dominate deposition in the Prince Creek Formation along the east side of the Toolik River (see sheet 1, fig. 3).

These observations: (i) poor sandbody/channel interconnectedness, (ii) individual sandbodies encased in finer-grained floodplain deposits, (iii) thick coals, and (iv) abundant lacustrine as well as other water-dependent floodplain facies, are all consistent with deposition in a poorly drained, actively subsiding, high-accommodation environment. Deposition of the Prince Creek Formation along the east side of the Toolik River may have been controlled by subsidence related to active tectonism and lithospheric loading in the Brooks Range to the south. This interpretation suggests that the orogenic belt was actively loading the lithosphere during the Paleocene prior to the episode of uplift and unroofing at ~60 Ma, indicated by apatite-fission track data (O'Sullivan, 1996; O'Sullivan and others, 1997; Gillis and others, 2014). It also implies that the depositional systems of the Prince Creek Formation along the Toolik River occupied a position somewhat proximal to the orogenic belt in the Paleocene.

CONCLUSIONS

Strata of the Prince Creek Formation along the east side of the Toolik River in the Sagavanirktok Quadrangle are the deposits of an ancient meandering river system. Depositional environments associated with this river system include levees, crevasse channels, crevasse splays, lakes, marshes, swamps, mires, and soil-forming environments. Floodplains were extensive, predominantly wet, and supported abundant vegetation. Lakes, marshes, swamps, and mires were the most common depositional environments in the region, and their deposits constitute the bulk of the sedimentation. Conditions suitable to support water-dependent environments persisted for extended periods of time in the region. Sustained subsidence and ample accommodation during deposition of the Prince Creek Formation may have been driven by lithospheric loading in the evolving Brooks Range orogenic belt. The deposits of the Prince Creek Formation exposed to the northeast in the Sagwon Bluffs along the Sagavanirktok River are thought to have been deposited contemporaneously with those along the Toolik River. Preliminary investigations of the Prince Creek Formation at Sagwon bluffs indicate that facies trends, alluvial architecture, and interpreted paleoenvironments are remarkably consistent between the two outcrop belts.

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