Stratigraphy and Facies of Cretaceous Schrader Bluff and Prince Creek Formations in Colville River Bluffs, North Slope, Alaska

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By Romeo M. Flores, Mark D. Myers, David W. Houseknecht, Gary D. Stricker, Donald W. Brizzolara, Timothy J. Ryherd, and Kenneth I. Takahashi

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Stratigraphy and Facies of Cretaceous Schrader Bluff and Prince Creek Formations in Colville River Bluffs, North Slope, Alaska

By Romeo M. Flores,[1] Mark D. Myers,[1] David W. Houseknecht,[1] Gary D. Stricker,[1] Donald W. Brizzolara,[2] Timothy J. Ryherd,[2] and Kenneth I. Takahashi[1]

Abstract

Stratigraphic and sedimentologic studies of facies of the Upper Cretaceous rocks along the Colville River Bluffs in the west-central North Slope of Alaska identified barrier shoreface deposits consisting of vertically stacked, coarsening-upward parasequences in the Schrader Bluff Formation. This vertical stack of parasequence deposits represents progradational sequences that were affected by shoaling and deepening cycles caused by fluctuations of sea level. Further, the vertical stack may have served to stabilize accumulation of voluminous coal deposits in the Prince Creek Formation, which formed braided, high-sinuosity meandering, anastomosed, and low-sinuosity meandering fluvial channels and related flood plain deposits. The erosional contact at the top of the uppermost coarsening-upward sequence, however, suggests a significant drop of base level (relative sea level) that permitted a semiregional subaerial unconformity to develop at the contact between the Schrader Bluff and Prince Creek Formations. This drop of relative sea level may have been followed by a relative sea-level rise to accommodate coal deposition directly above the unconformity. This rise was followed by a second drop of relative sea level, with formation of incised valley topography as much as 75 ft deep and an equivalent surface of a major marine erosion or mass wasting, or both, either of which can be traced from the Colville River Bluffs basinward to the subsurface in the west-central North Slope. The Prince Creek fluvial deposits represent late Campanian to late Maastrichtian depositional environments that were affected by these base level changes influenced by tectonism, basin subsidence, and sea-level fluctuations.

Introduction

The Upper Cretaceous Schrader Bluff and Prince Creek Formations are spectacularly exposed in the bluffs along the west side of the Colville River between Umiat and Ocean Point, Alaska (figs. 1 and 2). Formerly assigned to the Colville Group (abandoned by Mull and others, 2003), these rock units in earlier investigations were given descriptions that consisted of composite-measured sections along the bluffs and of limited subsurface core and log data (Robinson and Collins, 1959; Detterman and others, 1963; Brosgé and Whittington, 1966). In order to better evaluate the relations of these strata to oil and gas reservoirs in nearby areas, however, we must supplement the information resulting from these rather widely spaced observation points with more closely spaced measured sections of the Schrader Bluff and Prince Creek Formations. This supplementation would (1) provide greater detail on facies relations and distribution; (2) subdivide rock units by using palynomorphs and sequence stratigraphic boundaries; and (3) correlate outcropping rocks with subsurface oil and gas reservoirs, also on the basis of sequence stratigraphy. For these purposes, several detailed measured sections were obtained during the present study and were combined with an examination and interpretation of the cored sequence in the Sentinel Hill Core Test 1 well (fig. 2).

This study is most applicable to the ongoing development of very large volumes of hydrocarbons in the region, including viscous oil from the Upper Cretaceous to Paleocene West Sak, Schrader Bluff, Orion, Polaris, and Ugnu fields; light oil from the Upper Cretaceous Tabasco field; and the likely future development of free gas and gas hydrate occurrences in the main producing area of the central North Slope. Reservoir rocks are mainly sandstones deposited in deltaic and fluvial settings that vary in size, distribution, compartmentalization by erosional surfaces, and internal sedimentary structures. These characteristics are particularly important because they form the basis for volumetric estimates of hydrocarbon reserves and for performance modeling that is critical to evaluation of economic development of oil and gas fields.

[1] U.S. Geological Survey.

[2] Alaska Division of Oil and Gas.

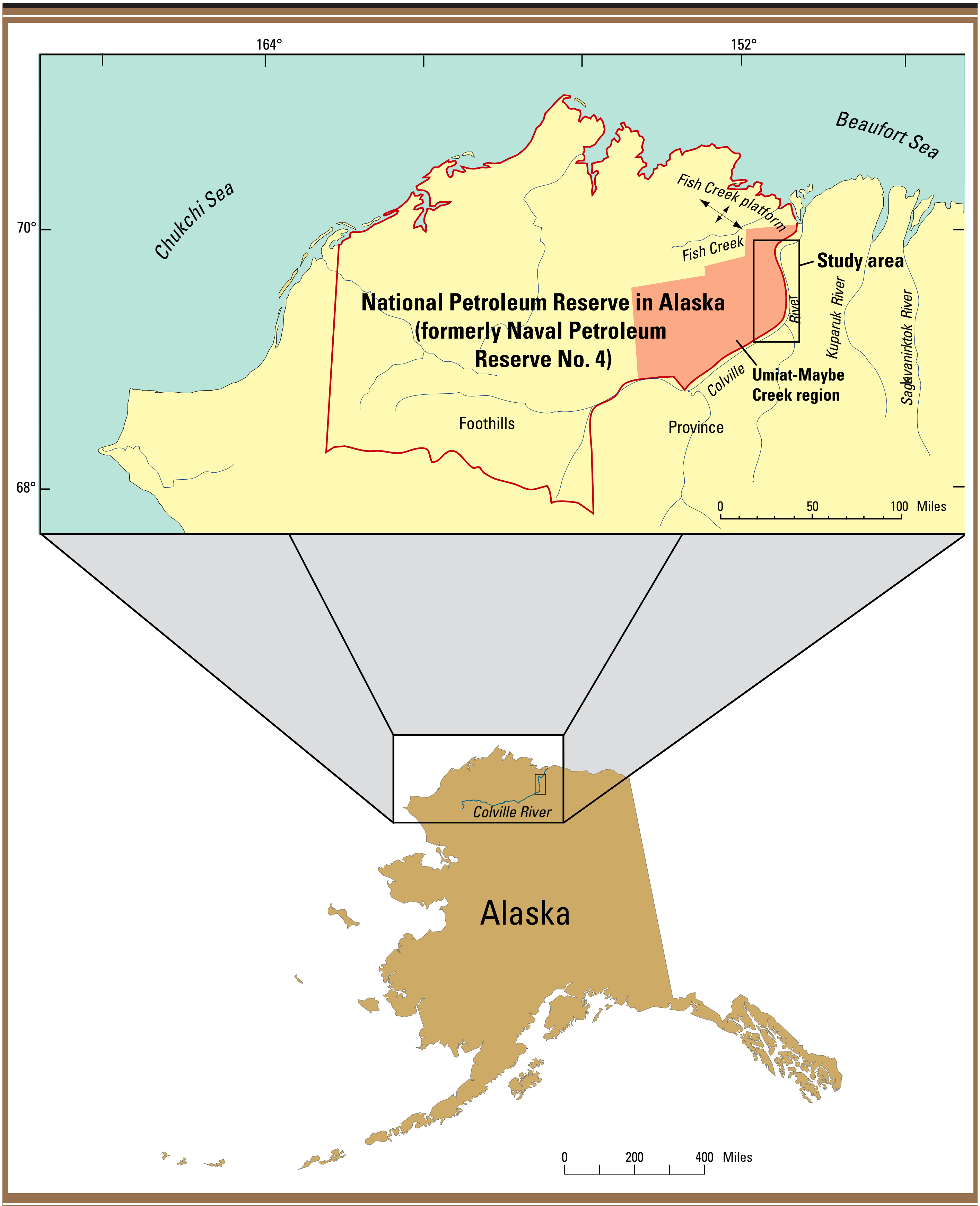

Figure 1. Map showing location of study area, the National Petroleum Reserve in Alaska, and the Colville River, North Slope of Alaska.

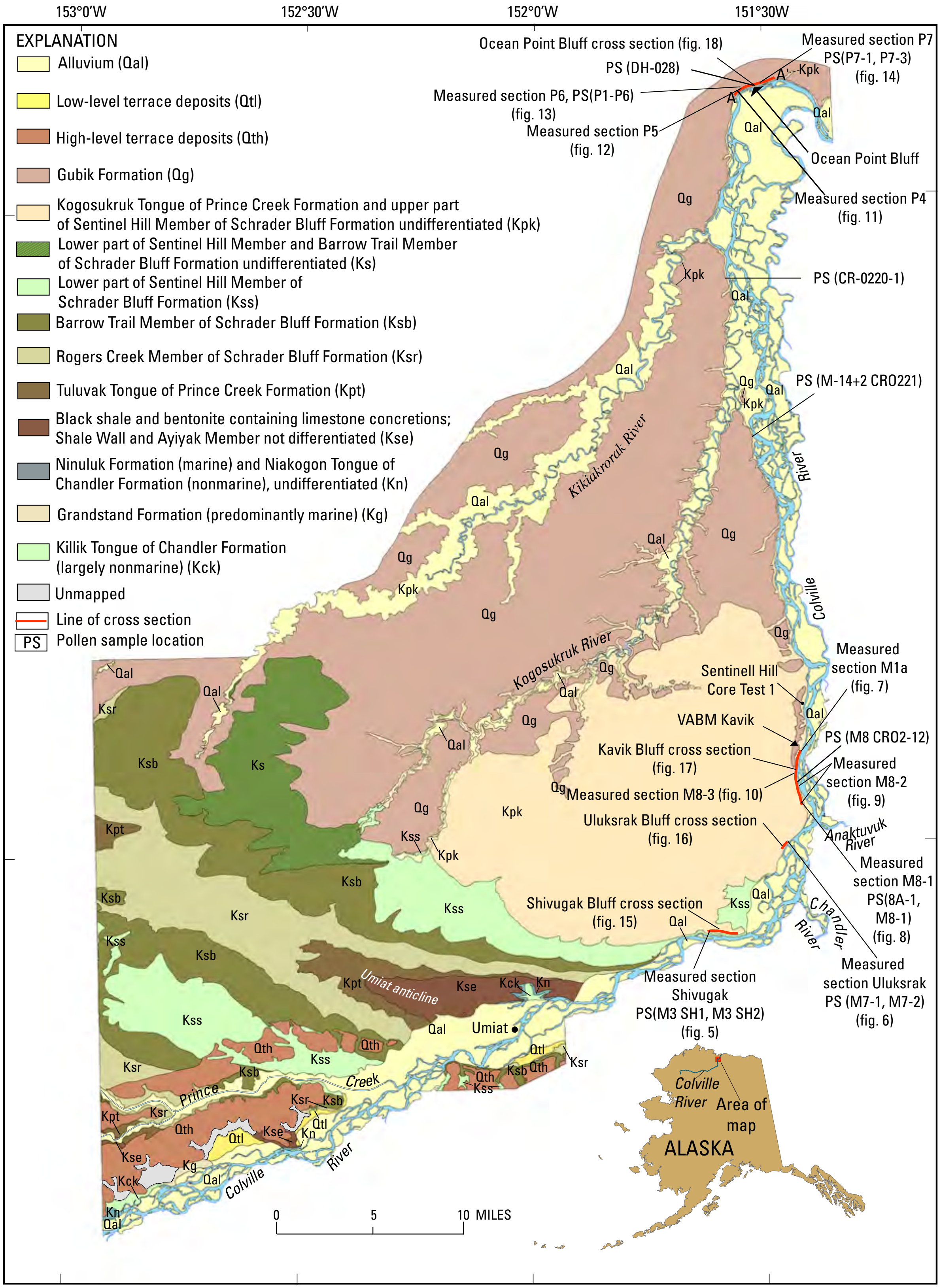

Figure 2. Geologic map of the study area from Umiat to Ocean Point, Alaska, showing place names as well as locations of palynological samples, measured sections, and stratigraphic cross sections along the Colville River Bluffs. Modified from Brosgé and Whittington (1966).

Stratigraphic Nomenclature and Methods

Outcrops of the Schrader Bluff and Prince Creek Formations in the Colville River bluffs area were studied by measuring and describing 13 stratigraphic sections along the 60-mi distance between Umiat and Ocean Point (fig. 2). These units include marine strata that were recognized as the Sentinel Hill Member of the Schrader Bluff Formation and as the mostly nonmarine Kogosukruk Tongue of the Prince Creek Formation prior to the major stratigraphic nomenclature revisions of Mull and others (2003) (fig. 3). Among other changes, that revision abandons the formal member designations within the Schrader Bluff Formation, so the lowermost units of this study are recognized informally as the upper part of the Schrader Bluff Formation (fig. 3). It should be emphasized, however, that this reference is strictly of local significance and that this part of the Schrader Bluff is probably older than much of the formation in the subsurface to the east. In addition, the Prince Creek Formation is now redefined to consist entirely of strata formerly assigned to the Kogosukruk Tongue of the Prince Creek Formation (fig. 3). Except for references to previous investigations that used the former stratigraphic names, this report adheres to the revised nomenclature of Mull and others (2003).

The 13 measured sections include descriptions of the lithology, color, grain size, nature of contacts, trace and body fossil contents, and sedimentary structures. Lateral variations within the rock units were studied by using photographs of outcrops taken during helicopter flybys and while rafting the Colville River during fieldwork in the summer of 2002; photomosaics were also taken in earlier years. The photographs were then pieced together and used to trace the lateral continuity of rock units, especially sandstone and coal beds. The traced units were transferred to clear plastic overlays and digitized to generate interpretive cross sections. Nine of the measured stratigraphic sections were keyed to the cross sections to complement detailed lithology and thickness data of the rock units and to guide facies interpretations.

Twenty-eight coal and carbonaceous shale samples were collected from 12 measured sections of the Prince Creek Formation for determining the ages of their contained palynomorphs by the U.S. Geological Survey in Denver, Colo., and Irf Group, Inc., in Anchorage, Alaska. Nineteen samples yielded rich recovery with good preservation of spore and pollen that provided ages (table 1).

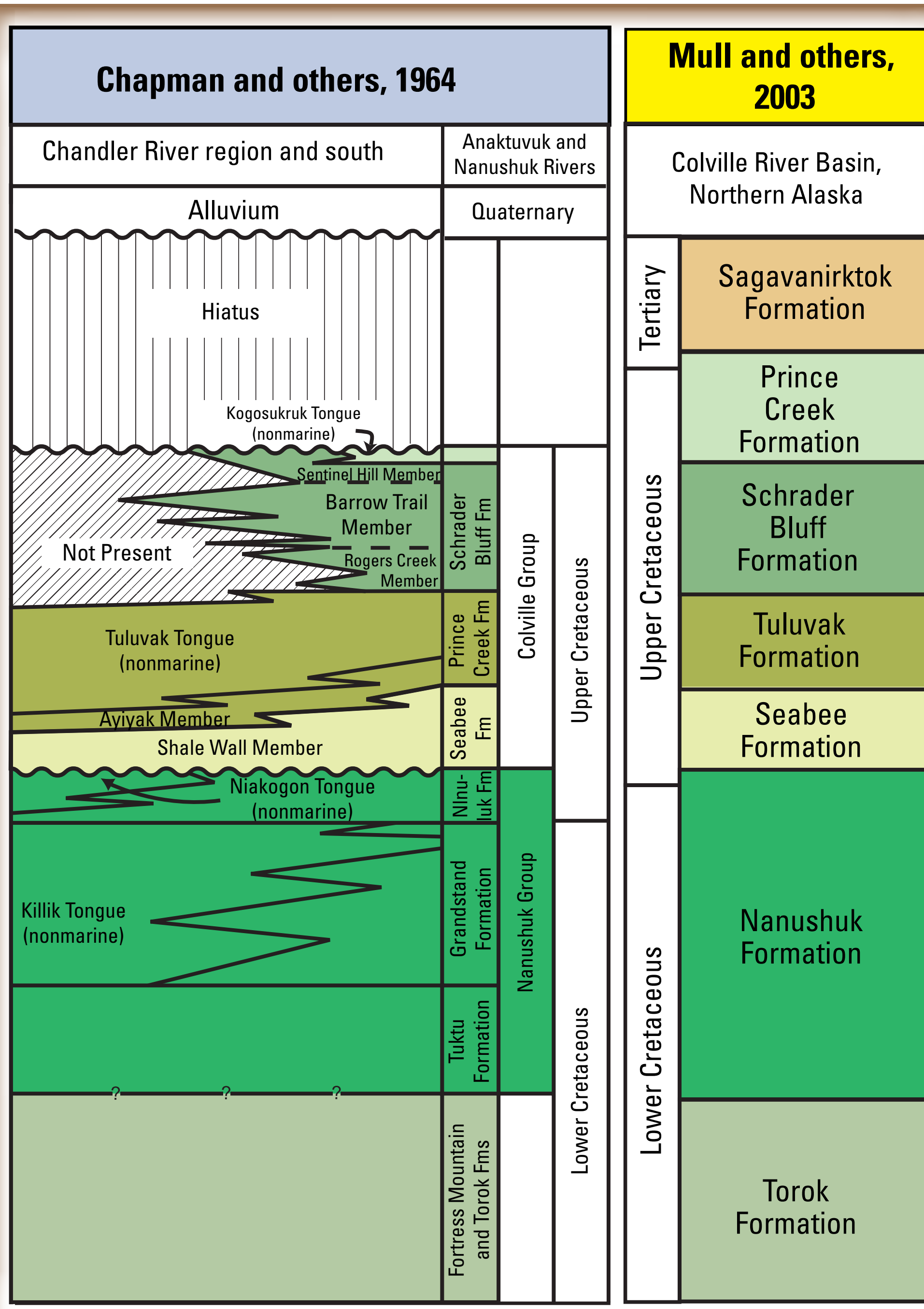

Figure 3. Generalized stratigraphic columns showing nomenclature of Cretaceous rocks by Chapman and others (1964) and as modified by Mull and others (2003). Fm, Formation.

Table 1. Palynological ages of samples collected from the Schrader Bluff and Prince Creek Formations along the Colville River Bluff from Umiat to Ocean Point.

[See fig. 2 for locations. Stratigraphic position of samples is shown in figs. 5–14. M/L, middle-late; indet., indeterminate; rew., reworked. A, abundant; C, common; N, numerous; R, rare; I, indeterminate]

Sample ID	Location	Formation	Age	TAXON																													
				Aequitriradite sp.	*Aequitriradites* cf. *spinulosus*	*Alete clavate* indet.	*Anacololsidites* sp.	*Anacolosidites* sp. *1*	*Annulispora* sp.	*Aquilapollenites amygdaloides*	*Aquilapollenites* cf. *dentatus*	*Aquilapollenites* sp.	*Aquilapollenites* spp.	*Aquilapollenites trialatus*	*Azonia* cf. *cribrata*	*Balmeisporites* sp.	Bisaccate gymnosperm pollen	*Botryococcus braunii*	*Camarozonosporites ambigens*	*Cibotiumspora* sp.	*Cicatricosisporites* cf. *dorogensis*	*Cicatricosisporites* sp. *1*	*Cicatricosisporites* spp.	*Cingulizonates bialatus*	*Cingutriletes* cf. *congruens*	*Circulodinium* sp.	*Clavatisporites* sp.	cf. *Converrucosisporites* sp.	*Crassispora?* cf. *apisulacea*	*Cycadopites fragilis*	*Deltoidospora* spp.	*Dictyophyllidites* sp.	*Erdtmannipollis procumbentformis*
M8 CR02-12	lat 69.53104°N., long 151.48146°W.	Prince Creek	Indeterminate														I,A														I,A		
M8 CR013-1	lat 69.53495°N., long 151.48449°W.	Prince Creek	M/L Maastrichtian														I,A														I,R		
M8 CR013-3	lat 69.53495°N., long 151.48449°W.	Prince Creek	Maastrichtian														I,C														I,C		
CR-0220-1	lat 69.93679°N., long 151.59789°W.	Prince Creek	Early Maastrichtian														I,R														I,C		
M-14+2 CR0221	lat 69.81456°N., long 151.56445°W.	Prince Creek	Early Maastrichtian														I,A														I,C		
M7-1	lat 69.49430°N., long 151.50850°W.	Prince Creek	Indeterminate														I,A														I,C		
M7-2	lat 69.49430°N., long 151.50860°W.	Prince Creek	Early Maastrichtian														I,C														I,C		
M8-1	lat 69.52602°N., long 151.47640°W.	Prince Creek	Early Maastrichtian														I,C														I,C		
P5-1	lat 70.08283°N., long 151.56176°W.	Prince Creek	Early Maastrichtian							A							I,C																
M3 SH2	lat 69.42740°N., long 151.69018°W.	Prince Creek	Late Campanian							N							I,C																
M3 SH1	lat 69.42740°N., long 151.69018°W.	Schrader Bluff	Maastrichtian														I,C																
P7-1 (Phillips 12)	lat 70.08909°N., long 151.51025°W.	Prince Creek	Early Maastrichtian														I,C																
P7-3 (Colville River)	lat 70.08909°N., long 151.51025°W.	Prince Creek	Early Maastrichtian																														
02 DH-028	lat 70.08410°N., long 151.55301°W.	Prince Creek	Early Maastrichtian														I,R														I,A		
P-1-3	lat 70.08283°N., long 151.56176°W.	Prince Creek	Early Maastrichtian																														
Base P-2	lat 70.08283°N., long 151.56176°W.	Prince Creek	Early Maastrichtian														I,R														I,N		
P-3 Liscomb Bed	lat 70.08283°N., long 151.56176°W.	Prince Creek	Early Maastrichtian																														
8A-1	lat 69.52602°N., long 151.47640°W.	Prince Creek	Indeterminate														I,R														I,C		
02 P1-01	lat 70.08283°N., long 151.56176°W.	Prince Creek	Early Maastrichtian																														

Table 1. Palynological ages of samples collected from the Schrader Bluff and Prince Creek Formations along the Colville River Bluff from Umiat to Ocean Point.—Continued

[See fig. 2 for locations. Stratigraphic position of samples is shown in figs. 5–14. M/L, middle-late; indet., indeterminate; rew., reworked. A, abundant; C, common; N, numerous; R, rare; I, indeterminate]

Sample ID	Location	Formation	Age	*Expressipollis* cf. *accuratus*	*Fibulapollis scabratus*	*Foraminisporis undulosus*	*Foveosporites* sp.	*Gleicheniidites senonicus*	*Hannisporis amplus*	*Hannisporis scollardensis*	*Impardecispora marylandensis*	*Inundatisporis tappaniae*	*Ischyosporites* sp.	*Integricorpus* sp.	*Kurtzipites trispissatus*	*Laevigatosporites* sp.	*Laevigatosporites* spp.	*Laricoidities magnus*	*Leiosphaeridia "stellata"*	Linear septate fungal hypha	*Lunatadinium dissolutum*	*Lycopodiacidites* sp.	*Mancicorpus pseudosenonicus*	*Matonisporites* sp. indet	*Osmundacidites wellmanii*	*Ovoidites arcticus*	*Ovoidites parvus*	*Ovoidites* sp.	*Ovoidites?* sp.	*Podocarpidites* sp.	cf. *Polycingulatisporites reduncus*	cf. *Proteacidites* sp.	*Pulcheripollenites krempii*
M8 CR02-12	lat 69.53104°N., long 151.48146°W.	Prince Creek	Indeterminate																														
M8 CR013-1	lat 69.53495°N., long 151.48449°W.	Prince Creek	M/L Maastrichtian														I,N																
M8 CR013-3	lat 69.53495°N., long 151.48449°W.	Prince Creek	Maastrichtian														I,C																
CR-0220-1	lat 69.93679°N., long 151.59789°W.	Prince Creek	Early Maastrichtian														I,A								C								
M-14+2 CR0221	lat 69.81456°N., long 151.56445°W.	Prince Creek	Early Maastrichtian														I,C								C								
M7-1	lat 69.49430°N., long 151.50850°W.	Prince Creek	Indeterminate														I,C								C								
M7-2	lat 69.49430°N., long 151.50860°W.	Prince Creek	Early Maastrichtian														I,A								C								
M8-1	lat 69.52602°N., long 151.47640°W.	Prince Creek	Early Maastrichtian														I,A								C								
P5-1	lat 70.08283°N., long 151.56176°W.	Prince Creek	Early Maastrichtian																														
M3 SH2	lat 69.42740°N., long 151.69018°W.	Prince Creek	Late Campanian	C																													
M3 SH1	lat 69.42740°N., long 151.69018°W.	Schrader Bluff	Maastrichtian																														
P7-1 (Phillips 12)	lat 70.08909°N., long 151.51025°W.	Prince Creek	Early Maastrichtian																														
P7-3 (Colville River)	lat 70.08909°N., long 151.51025°W.	Prince Creek	Early Maastrichtian																C														
02 DH-028	lat 70.08410°N., long 151.55301°W.	Prince Creek	Early Maastrichtian														I,C								C								
P-1-3	lat 70.08283°N., long 151.56176°W.	Prince Creek	Early Maastrichtian																N														
Base P-2	lat 70.08283°N., long 151.56176°W.	Prince Creek	Early Maastrichtian																														
P-3 Liscomb Bed	lat 70.08283°N., long 151.56176°W.	Prince Creek	Early Maastrichtian																														
8A-1	lat 69.52602°N., long 151.47640°W.	Prince Creek	Indeterminate														I,C																
02 P1-01	lat 70.08283°N., long 151.56176°W.	Prince Creek	Early Maastrichtian																						N								

TAXON

Table 1. Palynological ages of samples collected from the Schrader Bluff and Prince Creek Formations along the Colville River Bluff from Umiat to Ocean Point.—Continued

[See fig. 2 for locations. Stratigraphic position of samples is shown in figs. 5–14. M/L, middle-late; indet., indeterminate; rew., reworked. A, abundant; C, common; N, numerous; R, rare; I, indeterminate]

Sample ID	Location	Formation	Age	cf. *Verrucosisporites* sp.	*Undulatisporites* sp.	*Tsugaepollenites* sp.	*Trilites* sp.	*Trilete zonate*	*Tricolporopollenites* sp.	*Tricolpites* sp.	*Tricolpate*	*Triatriate pollen*	*Tetracolpites* sp.	*Taxodiaceaepollenites hiatus*	*Syncolporites* sp.	*Stereisporites* sp.	*Stereigranisporis regius*	*Spelaeotriletes* cf. *triangulus*	*Spelaeotriletes* cf. *pretiosus*	*Skochorate?*	*Sigmopollis* sp.	*Selagosporis* sp. 1	*Scabratricolpites* sp.	*Scabratricolpites* sp.	*Scabratricolp(or)ites?* sp.	cf. *Santalacites* sp.	*Retitriletes* spp.	*Retitriletes* sp.	*Retispora lepidophyta*	*Reticuloidosporites* sp.	*Reticulatisporites labiatus* rew.	*reticulate alete ? algal*	*Pulcheripollenites?* sp.
M8 CR02-12	lat 69.53104°N., long 151.48146°W.	Prince Creek	Indeterminate																														
M8 CR013-1	lat 69.53495°N., long 151.48449°W.	Prince Creek	M/L Maastrichtian													I,N																	
M8 CR013-3	lat 69.53495°N., long 151.48449°W.	Prince Creek	Maastrichtian											C																			
CR-0220-1	lat 69.93679°N., long 151.59789°W.	Prince Creek	Early Maastrichtian					I,N																									
M-14+2 CR0221	lat 69.81456°N., long 151.56445°W.	Prince Creek	Early Maastrichtian																														
M7-1	lat 69.49430°N., long 151.50850°W.	Prince Creek	Indeterminate													I,N																	
M7-2	lat 69.49430°N., long 151.50860°W.	Prince Creek	Early Maastrichtian																														
M8-1	lat 69.52602°N., long 151.47640°W.	Prince Creek	Early Maastrichtian																														
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M3 SH1	lat 69.42740°N., long 151.69018°W.	Schrader Bluff	Maastrichtian																														
P7-1 (Phillips 12)	lat 70.08909°N., long 151.51025°W.	Prince Creek	Early Maastrichtian																														
P7-3 (Colville River)	lat 70.08909°N., long 151.51025°W.	Prince Creek	Early Maastrichtian															C															
02 DH-028	lat 70.08410°N., long 151.55301°W.	Prince Creek	Early Maastrichtian											C																			
P-1-3	lat 70.08283°N., long 151.56176°W.	Prince Creek	Early Maastrichtian															N															
Base P-2	lat 70.08283°N., long 151.56176°W.	Prince Creek	Early Maastrichtian																				I,N										
P-3 Liscomb Bed	lat 70.08283°N., long 151.56176°W.	Prince Creek	Early Maastrichtian										N										I,N										
8A-1	lat 69.52602°N., long 151.47640°W.	Prince Creek	Indeterminate					I,N																									
02 P1-01	lat 70.08283°N., long 151.56176°W.	Prince Creek	Early Maastrichtian																														

General Stratigraphy

In addition to hosting several large accumulations of predominantly heavy oil in the Kuparuk River Unit, Milne Point Unit, and Prudhoe Bay Unit areas, sandstones of the Schrader Bluff and Prince Creek Formations serve as potential shallow gas reservoirs in the National Petroleum Reserve in Alaska (NPRA), which is bounded on the east and south by the Colville River (fig. 1). Early geologic investigations by Brosgé and Whittington (1966) from 1944 to 1953 in the Umiat-Maybe Creek region in southeastern NPRA, adjacent to the Colville River (fig. 1), reported the presence of gas reserves in the lower part of the Colville Group. There, the Upper Cretaceous section is more than 5,000 ft thick and consists (in ascending order) of the Seabee Formation, Tuluvak Tongue of the Prince Creek Formation, Schrader Bluff Formation, and Kogosukruk Tongue of the Prince Creek Formation (fig. 3). According to Mull and others (2003), these formations are generally regressive marine and coastal facies broken up by minor retrogradational successions. The focuses of this study—the Schrader Bluff and Prince Creek Formations—constitute a large-scale prograding complex of shallow marine to marginal marine facies and coastal plain facies (Mull and others, 2003).

Schrader Bluff Formation

The Schrader Bluff Formation was originally defined by Gryc and others (1951) to include all marine rocks of the Upper Cretaceous Colville Group. At the type section in Schrader Bluff (fig. 2), it was redefined by Whittington (1956) to consist of the predominantly marine interval of the Colville Group overlying the nonmarine Tuluvak Tongue of the Prince Creek Formation (fig. 3), which now constitutes the upper portion of the shallow marine to nonmarine Tuluvak Formation of Mull and others (2003).

In the study area along the bluffs west of the Colville River between Umiat and Ocean Point (figs. 1 and 2), the upper part of the Schrader Bluff Formation consists of shallow marine sandstones, which are locally incised by nonmarine channel deposits overlain by nonmarine sandstone, conglomerate, and carbonaceous mudstone and coal beds of the Prince Creek Formation (fig. 3). Examination of the Sentinel Hill Core Test 1 well (which is located about 6.5 mi north of the Anaktuvuk River [fig. 2]) by Robinson and Collins (1959) combined with measured stratigraphic sections along the lower Colville River by Stefansson and others (1947), Stefansson and Whittington (1946), and Brosgé and Whittington (1966) indicated that the Schrader Bluff Formation contains marine fossiliferous fauna (for example, *Mytilus* sp., *Tellina* sp., *Gyrodes* sp., *Pecten* sp., *Protocardia* cf., *Panope* sp., and a variety of foraminifera (fig. 4).

The Schrader Bluff Formation is mainly composed of marine bentonitic shale and claystone with interbedded bentonite, ash, tuff, sandstone, and siltstone (Brosgé and Whittington, 1966). Calcareous and arenaceous foraminifera (for example, *Eoeponidella strombodes*) and pelecypods (for example, *Protocardia*, *Tellina*, *Panope*, and *Gyrodes*) are abundant throughout the formation; they are of Late Cretaceous age, with the microfossils indicating a more specific range in age from post-Turonian to Maastrichtian (Brosgé and Whittington, 1966). Coal beds in the upper Schrader Bluff Formation (formerly the Sentinel Hill Member, fig. 3) at different localities were used by Brosgé and Whittington (1966) to document the northward to northeastward trend of the shoreline in Campanian and Maastrichtian time.

Prince Creek Formation

The Prince Creek Formation was first defined by Gryc and others (1951) as being located 9 mi upstream from Umiat on Prince Creek, a tributary of the Colville River. They, as well as others (including Detterman and others [1963] and Brosgé and Whittington [1966]), described the formation as containing predominantly nonmarine strata of the Tuluvak Tongue in the lower part and of the Kogosukruk Tongue in the upper part, separated by marine sandstone and shale of the Schrader Bluff Formation (fig. 3). More recently, the Tuluvak Tongue was interpreted to be much more closely linked genetically to the shallow marine sandstones formerly designated as the Ayiyak Member of the Seabee Formation than to the Kogosukruk Tongue (fig. 3). Consequently, Mull and others (2003) (1) removed the Tuluvak strata from the Prince Creek Formation, removed the Ayiyak strata from the Seabee Formation, and combined them to form the Tuluvak Formation of current usage; and (2) designated strata formerly assigned to Kogosukruk Tongue as constituting the entire Prince Creek Formation. In our study area north of the Umiat anticline, most of the nonmarine rocks exposed in the bluffs along the west side of the Colville River from Shivugak Bluff to Ocean Point (fig. 2) are now considered to be in the Prince Creek Formation. The contact between the Prince Creek Formation and the underlying Schrader Bluff Formation is exposed in the Shivugak Bluff (fig. 2). The sharp (probably erosional) contact between the Prince Creek Formation and the overlying Sagavanirktok Formation crops out “only in the vicinity of the Sagavanirktok River” (Mull and others, 2003, p. 17), well to the east of our study area (fig. 1).

Stefansson and others (1947) measured nearly complete sections of the stratigraphic sequence formerly assigned to the Kogosukruk Tongue (now the Prince Creek Formation) exposed along the Kogosukruk and Colville Rivers. Later, Brosgé and Whittington (1966) designated exposures in the Colville River Bluffs near the mouth of the Anaktuvuk River to Ocean Point as the type section of the Kogosukruk Tongue because of the continuously well-exposed sequence of mudstone, claystone, siltstone, sandstone, conglomerate, tuff, bentonite, coal, and carbonaceous shale. The coal and carbonaceous shale distinguish these strata (now the Prince

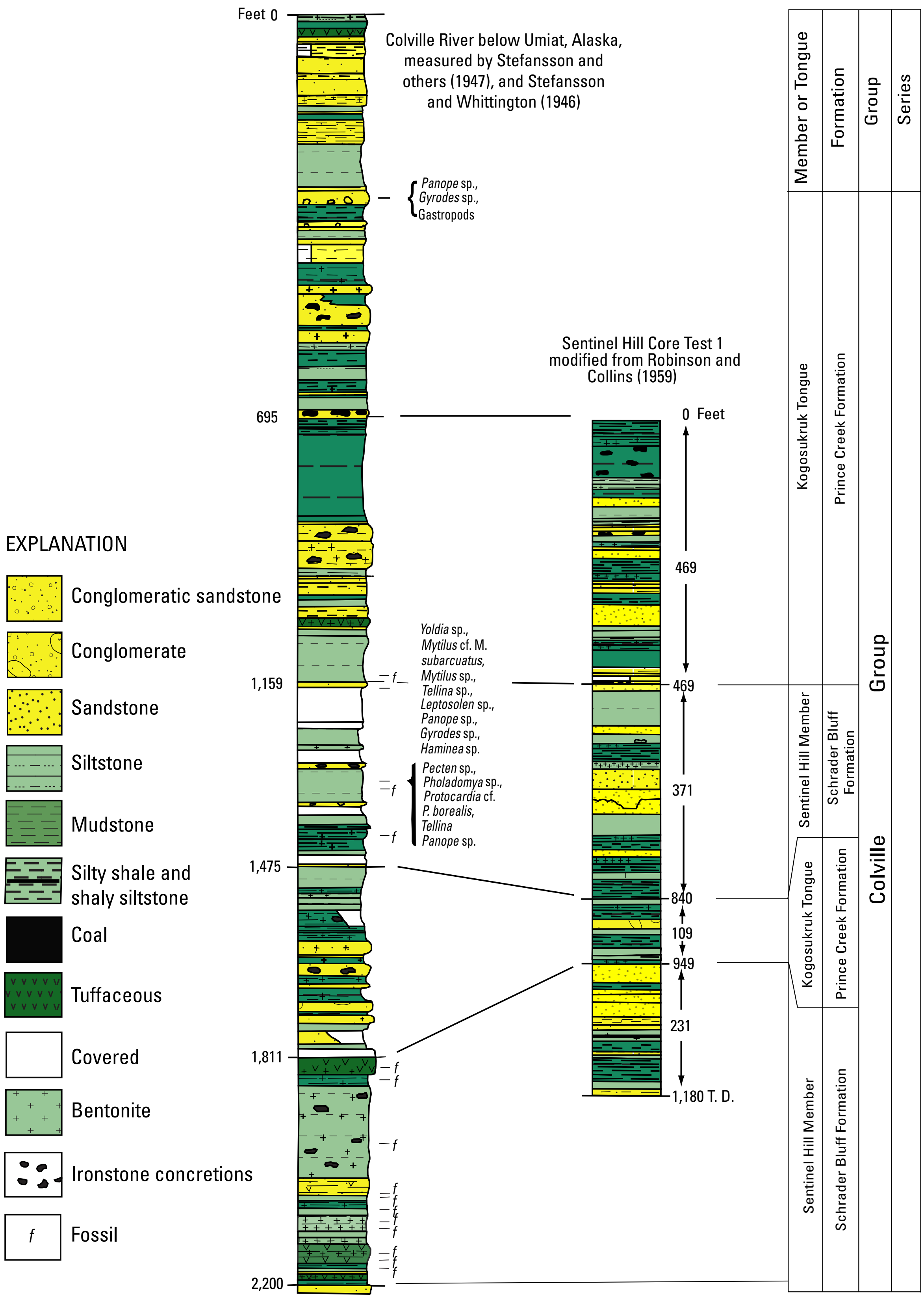

Figure 4. Composite stratigraphic column of the Schrader Bluff and Prince Creek Formations based on measured sections by Stefansson and others (1947) and Stefansson and Whittington (1946). This column is correlated to the stratigraphic section penetrated in the Sentinel Hill Core Test 1 well as described by Robinson and Collins (1959).

Creek Formation) from the marine rocks of the underlying Schrader Bluff Formation.

Locally, the contact between the Prince Creek and Schrader Bluff Formations is characterized by interfingering (fig. 3). In the 1,180-ft-thick succession penetrated in the Sentinel Hill Core Test 1 (fig. 4), for example, Robinson and Collins (1959) recognized a 371-ft-thick predominantly marine tongue of upper Schrader Bluff Formation above a 109-ft-thick basal unit of the predominantly nonmarine Prince Creek Formation. These thicknesses are revised by Flores and others (2007), following their interpretation of depositional environments and formation contacts in the core. Mull and others (2003) interpreted the Schrader Bluff and Prince Creek Formations as an interfingering sequence of shallow marine to marginal marine units and coastal plain units resulting from transgressive-regressive cycles within a dominantly progradational (regressive) system. The sequence was assigned a probable Campanian or younger age by Brosgé and Whittington (1966).

Palynological Ages and Regional Correlations

Palynomorph analysis results of 19 coal, carbonaceous mudstone, and shale samples collected from the Prince Creek Formation between the mouth of the Chandler River and Ocean Point are shown in table 1. Locations of the measured sections containing the samples are shown in figure 2, and table 1 lists the locations, rock intervals in which the samples were collected, microfossil assemblages and ages, and species abundances (observation frequency).

The samples contain moderately diverse and well-preserved, organic-walled palynomorphs. Ages range from late Campanian (sample M3 SH2) to middle late Maastrichtian (sample M8 CR013-1), with the majority being early Maastrichtian (table 1); one sample (8A-1), with an indeterminate age, is tentatively assigned a Paleocene age. Bisaccate gymnosperm pollen is the most abundant microfossil in all samples.

The late Campanian sample (M3 SH2) is from a coal bed in the lowermost part of the Prince Creek Formation, directly above the contact with the underlying Schrader Bluff Formation at Shivugak Bluff (fig. 2). The middle-late Maastrichtian sample (M8 CR013-1) is from a coal and carbonaceous shale bed in the upper part of the Prince Creek Formation (see table 1). The early Maastrichtian samples (M7-2 and M8-1) are mainly from coal, carbonaceous shale, and mudstone in the lower units of the Prince Creek. Because of the general northward dip of the Prince Creek Formation between Umiat and the Sentinel Hill area (Brosgé and Whittington, 1966), it was assumed that the Ocean Point beds were the youngest in the study area. Despite this assumption, samples (P-1-3, P-2, P-3, P5-1, P6-1, P6-3, and 02 P1-01) from hadrosaur-bearing coal and carbonaceous mudstone beds of the uppermost Prince Creek Formation in the Ocean Point area (see line of cross section in fig. 2) are early Maastrichtian, age equivalent to the strata exposed in the river bluffs between the mouths of the Chandler and Anaktuvuk Rivers. The youngest strata in the formation in the study area (sample M8 CR013-1) are located just below the mouth of the Anaktuvuk River (fig. 2).

For the Ocean Point Bluff locality, Phillips (1988, 1989) described marine fossil-bearing rocks of the (former) Kogosukruk Tongue. The early Maastrichtian age of these rocks indicates that they are likely equivalent to the (formerly recognized) Sentinel Hill Member of the upper part of the Schrader Bluff Formation. The observation that the section exposed at Ocean Point is older and stratigraphically lower than portions of the section to the south near the mouth of the Anaktuvuk River indicates that the Ocean Point area is structurally elevated. This interpretation is consistent with previous subsurface and seismic mapping of Lower and Upper Cretaceous horizons in NPRA (Bird, 1988, figs. 16.8 and 16.9), which reveals a broad, gently east-plunging structural nose in the area, possibly related to late reactivation of the Fish Creek platform (fig. 1).

Vertical Stratigraphic Framework and Sedimentologic Variations

The stratigraphic framework and sedimentologic variations within the upper part of the Schrader Bluff Formation and within the Prince Creek Formation were determined from measured sections (figs. 5–14) and cross sections constructed from photomosaics of continuous outcrops (figs. 15–18) along the Colville River Bluffs (fig. 2). The measured stratigraphic sections were used as control points, and the photomosaics were used to extend interpretations to beds in between. The following section presents descriptive observations, which are followed by interpretive discussions.

Upper Schrader Bluff Formation

Description

Figure 5 illustrates a stratigraphic section measured at Shivugak Bluff (see fig. 2 for location), which exhibits the vertical stratigraphic and sedimentologic variations of the upper part of the Schrader Bluff Formation. The upper part of that formation and the lower part of the Prince Creek Formation are represented in a 480-ft-thick section measured at Shivugak Bluff (fig. 5). The strata consist of interbedded mudstone, siltstone, tuff, and sandstone arranged in coarsening-upward, 50- to 120-ft-thick intervals or parasequence sets (figs. 5, 19, and 20). The lower three parasequence sets contain sandstones ranging from 5 to 30 ft thick with gradational bases and sharp tops; they are upward-coarsening parasequences consisting of gray bentonitic and burrowed mudstone at the base interbedded

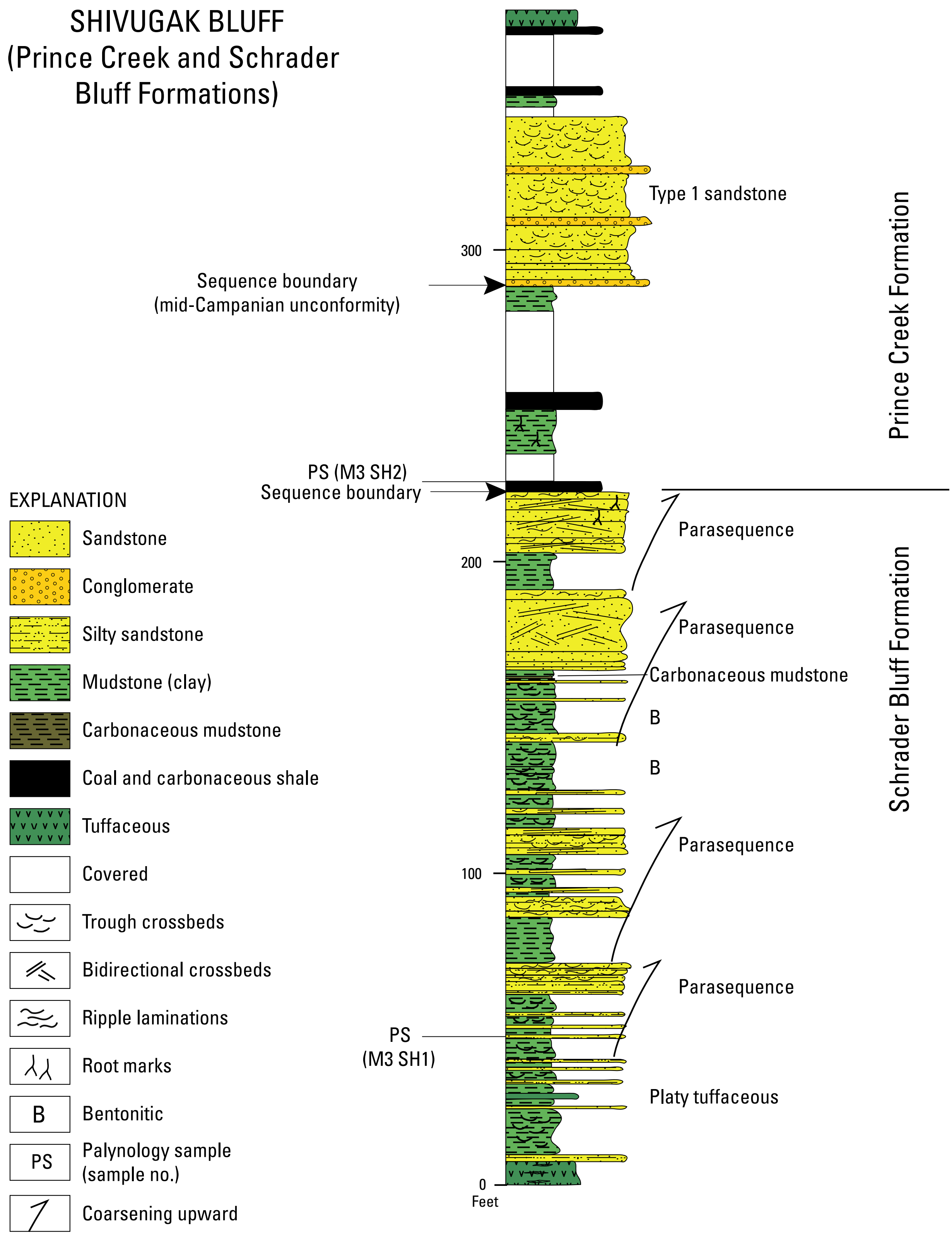

Figure 5. Vertical stratigraphic facies variations within measured section of the Schrader Bluff and Prince Creek Formations in Shivugak Bluff. See figure 2 for section location, and compare to outcrop profile in figure 15. Mid-Campanian unconformity adopted from Decker (2007).

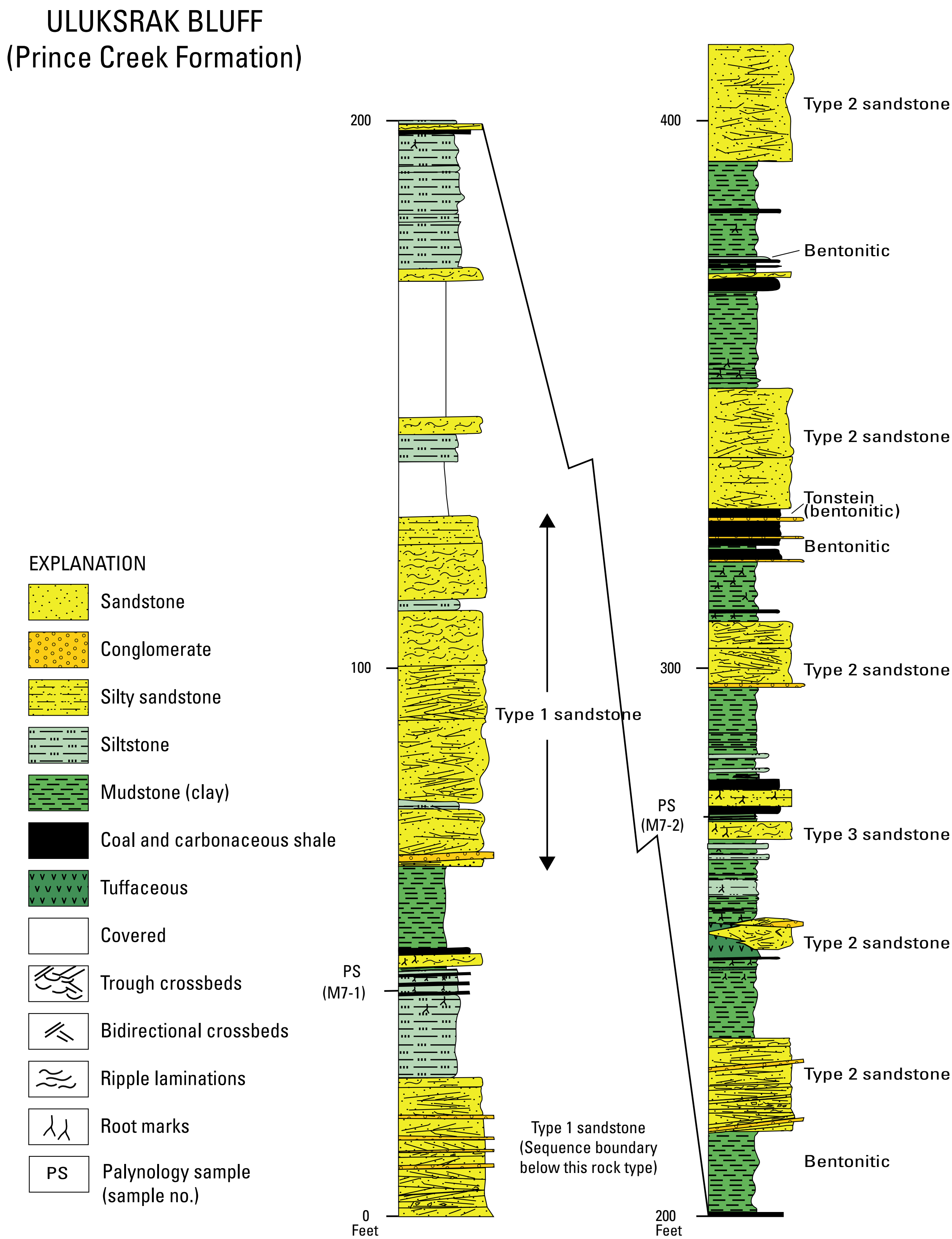

Figure 6. Vertical stratigraphic facies variations within measured section of the Prince Creek Formation in Uluksrak Bluff. See figure 2 for section location, and compare to outcrop profile in figure 16.

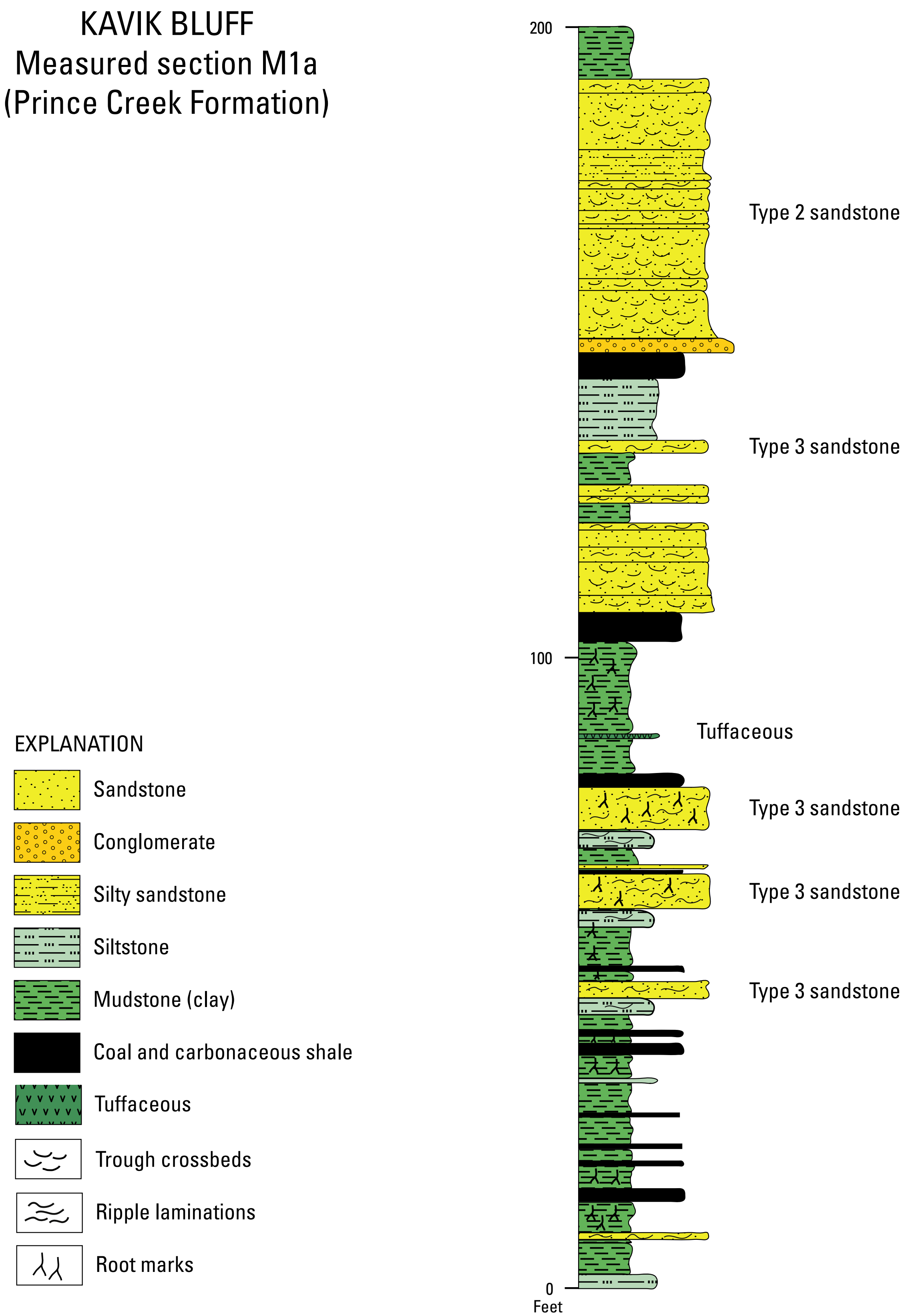

Figure 7. Vertical stratigraphic facies variations within measured section M1a of the Prince Creek Formation in the southernmost part of Kavik Bluff, between the mouth of the Anaktuvuk River and the vertical angle benchmark (VABM) at Kavik. See figure 2 for section location, and compare to outcrop profile in figure 17.

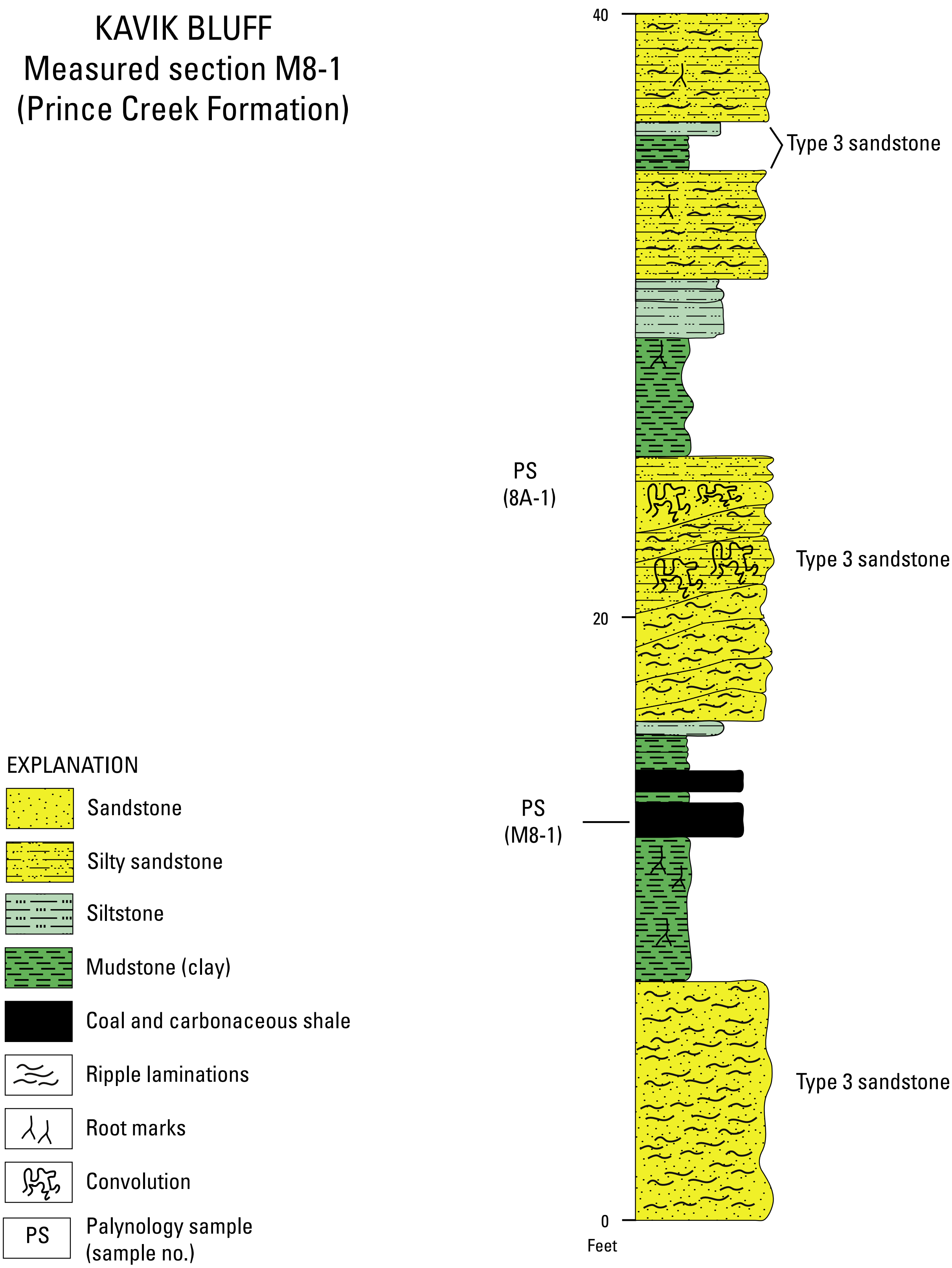

Figure 8. Vertical stratigraphic facies variations within measured section M8-1 of the Prince Creek Formation in the southern part of Kavik Bluff, between the mouth of the Anaktuvuk River and the vertical angle benchmark (VABM) at Kavik. See figure 2 for section location, and compare to outcrop profile in figure 17.

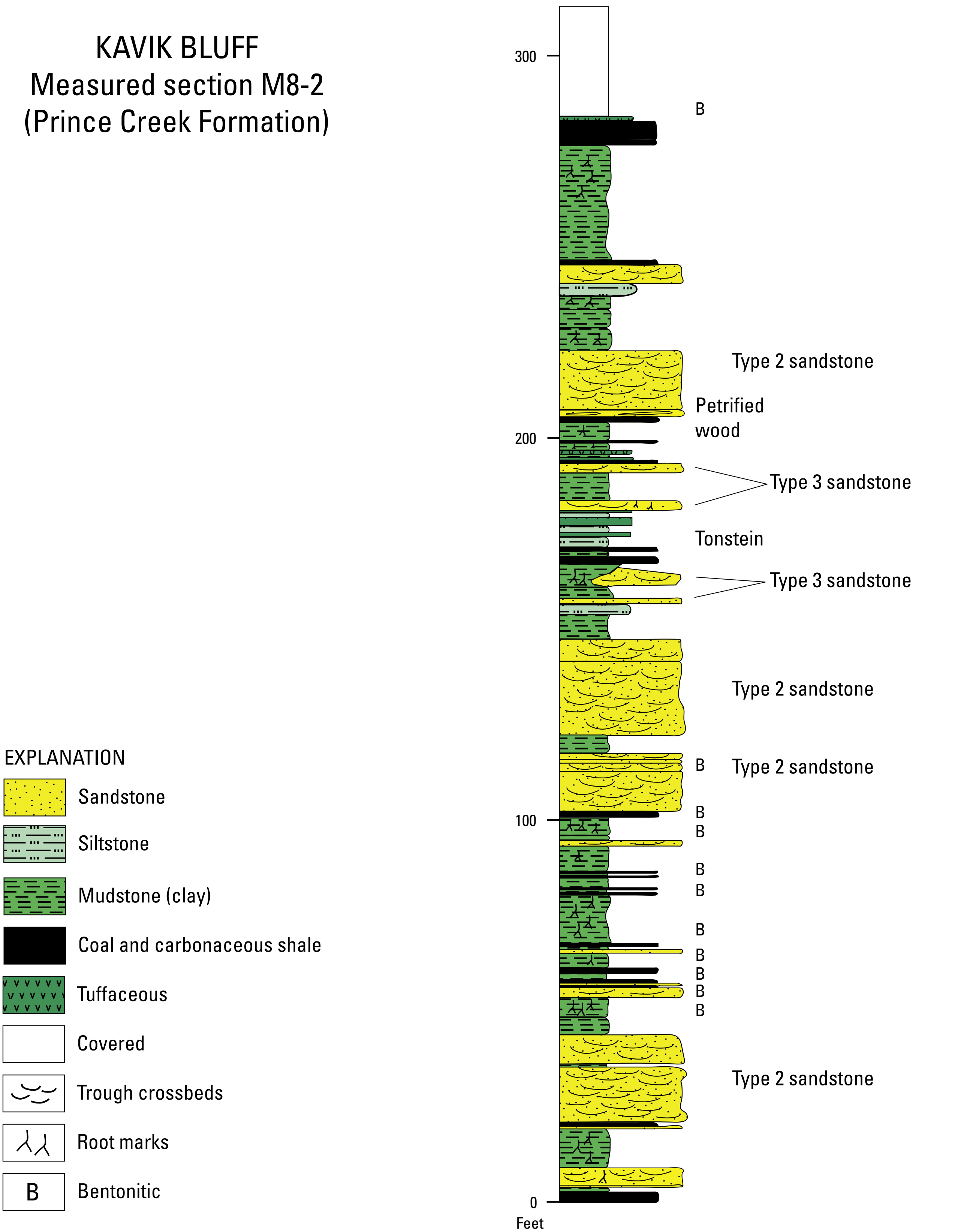

Figure 9. Vertical stratigraphic facies variations within measured section M8-2 of the Prince Creek Formation in the central part of Kavik Bluff, between the mouth of the Anaktuvuk River and the vertical angle benchmark (VABM) at Kavik. See figure 2 for section location, and compare to outcrop profile in figure 17.

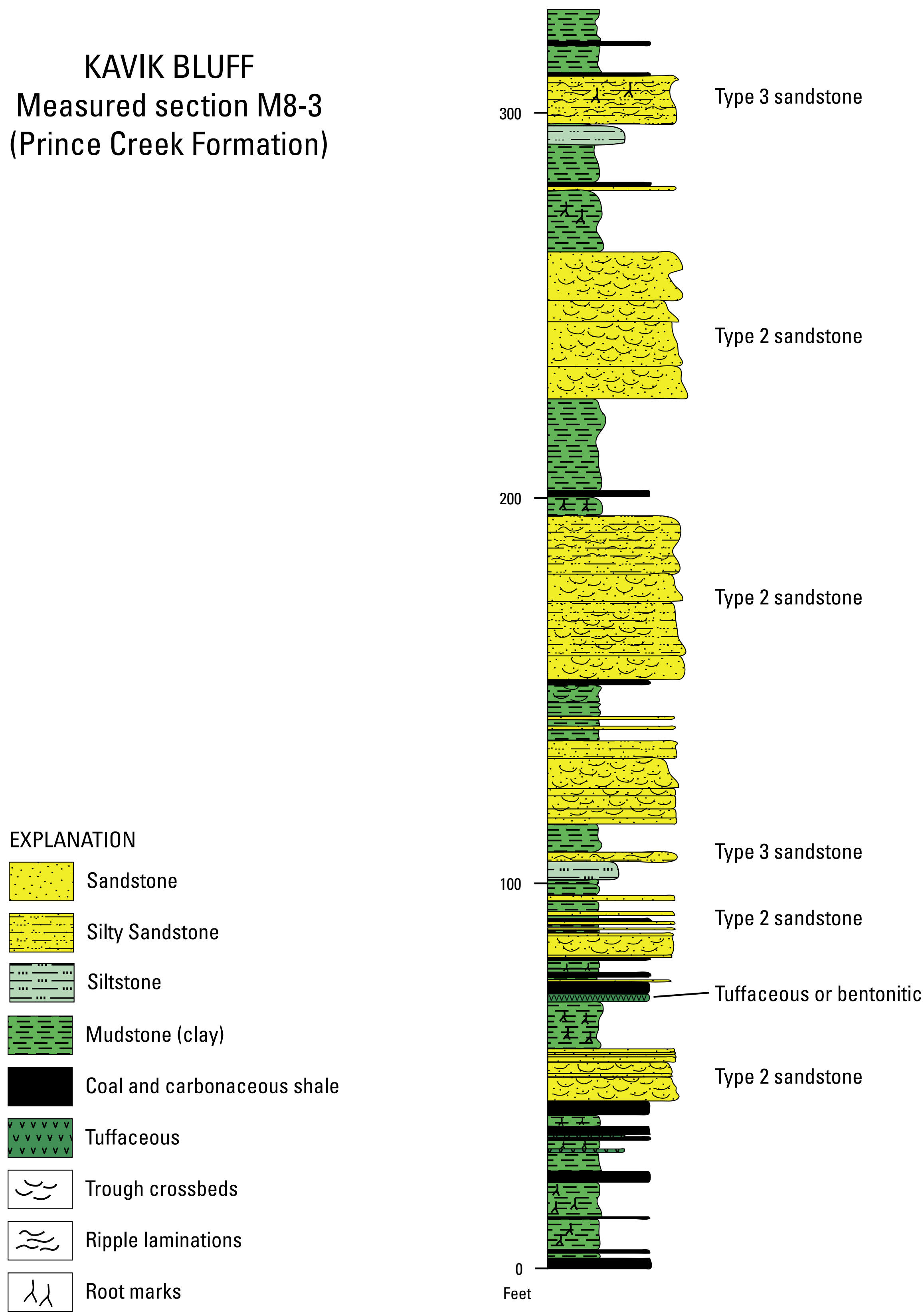

Figure 10. Vertical stratigraphic facies variations within measured section M8-3 of the Prince Creek Formation in the northernmost part of Kavik Bluff, between the mouth of the Anaktuvuk River and the vertical angle benchmark (VABM) at Kavik. See figure 2 for section location, and compare to outcrop profile in figure 17.

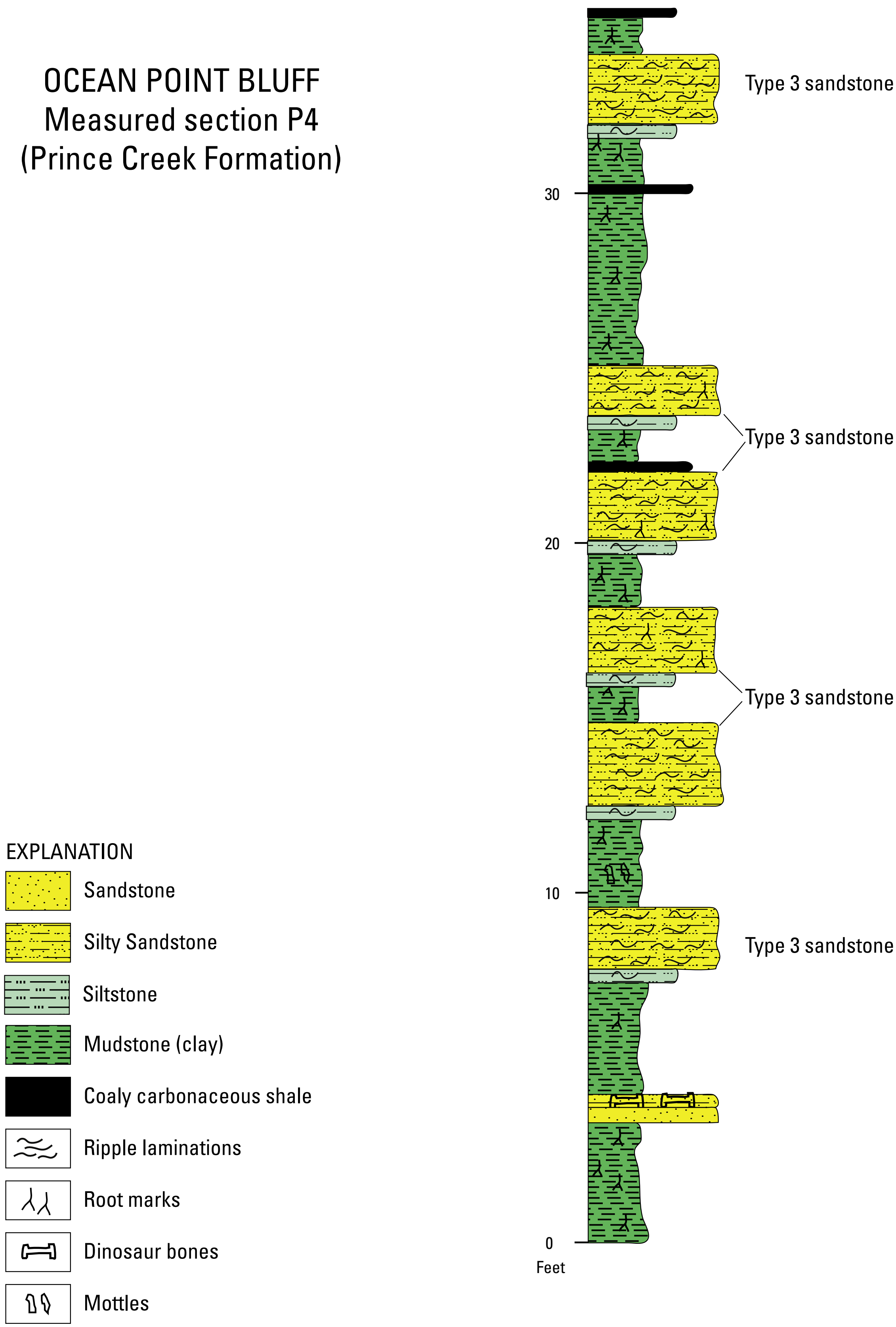

Figure 11. Vertical stratigraphic facies variations within measured section P4 of the Prince Creek Formation in the southern part of the Ocean Point Bluff. See figure 2 for section location, and compare to outcrop profile in figure 18.

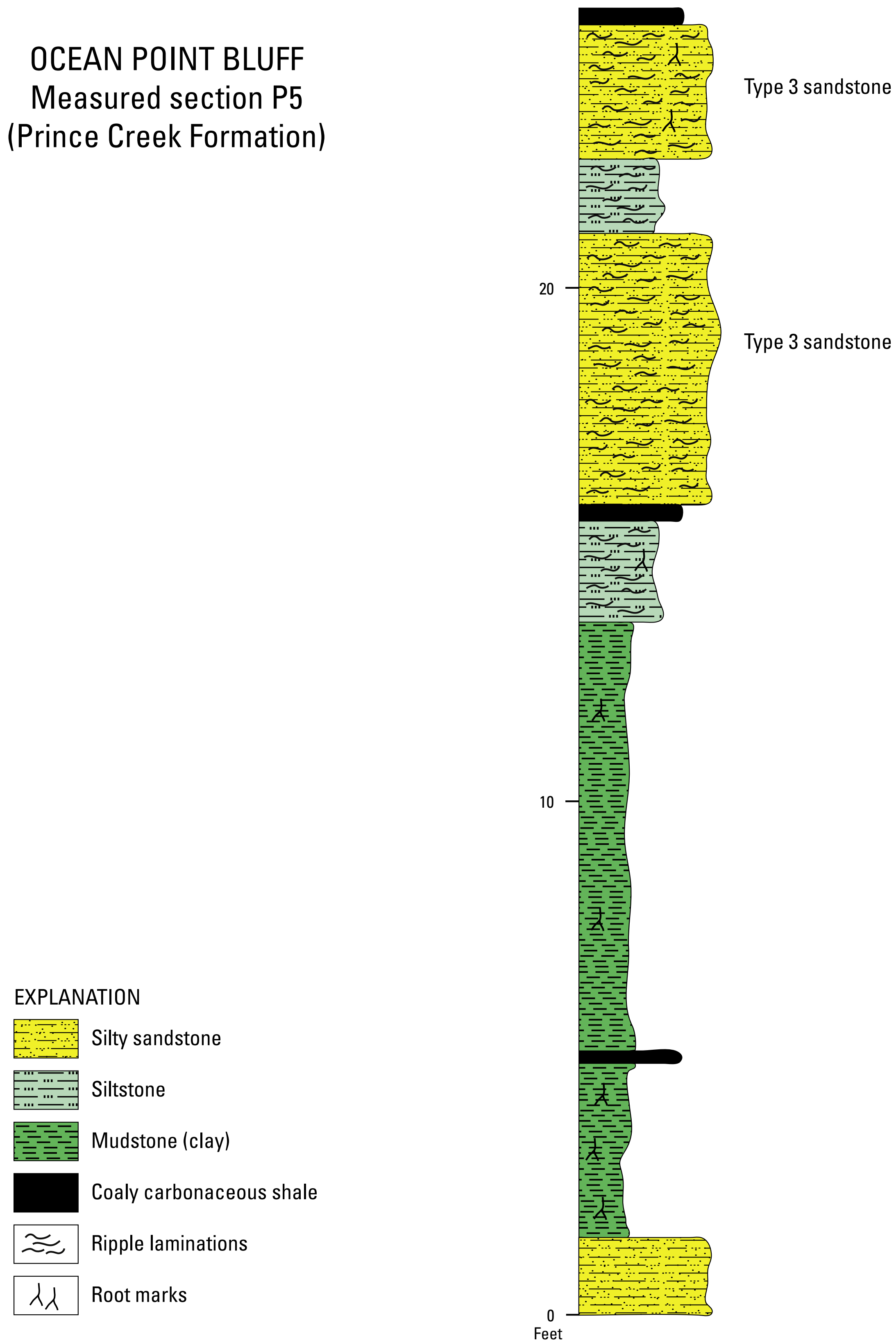

Figure 12. Vertical stratigraphic facies variations within measured section P5 of the Prince Creek Formation in the southern part of the Ocean Point Bluff. See figure 2 for section location, and compare to outcrop profile in figure 18.

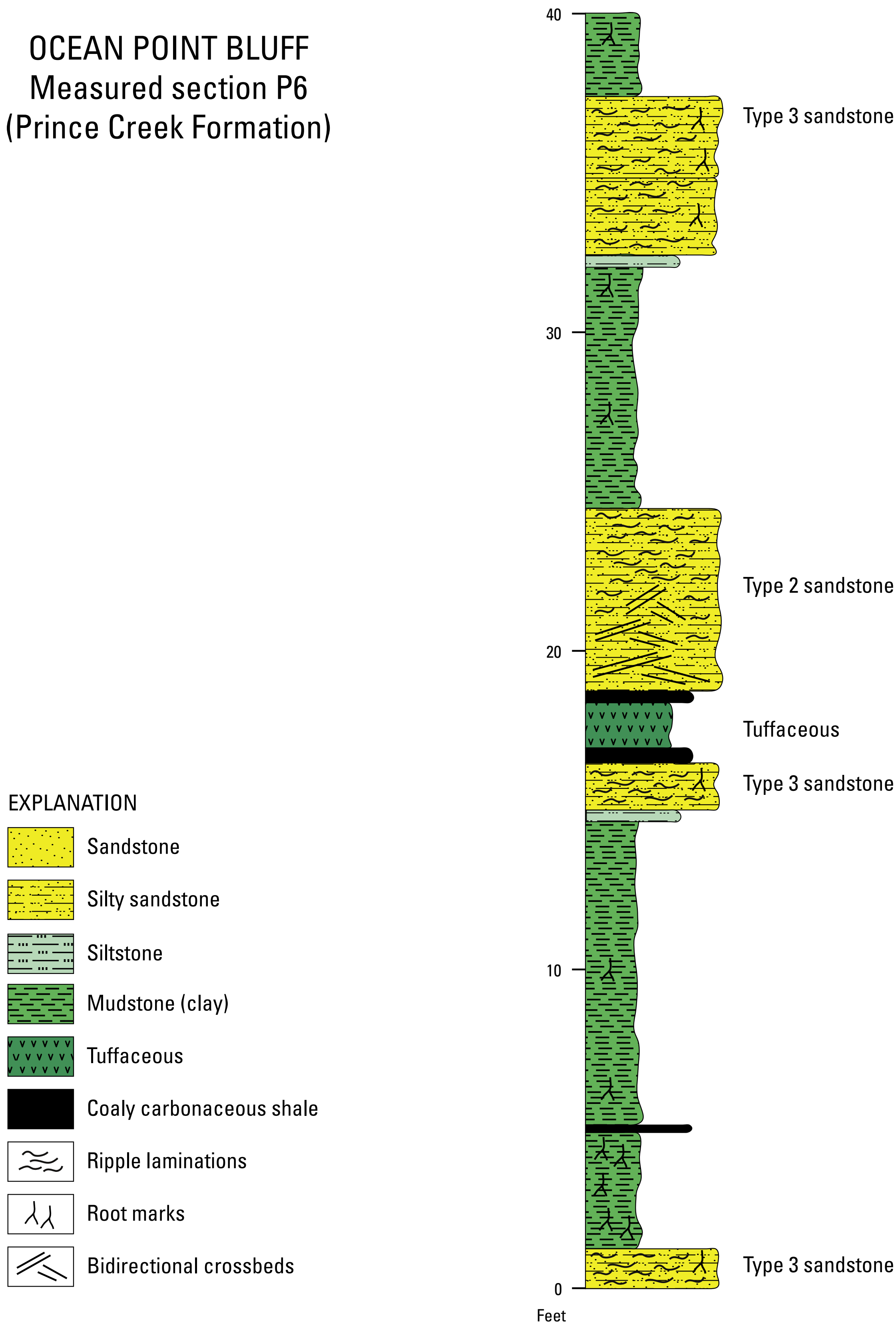

Figure 13. Vertical stratigraphic facies variations within measured section P6 of the Prince Creek Formation in the central part of the Ocean Point Bluff. See figure 2 for section location, and compare to outcrop profile in figure 18.

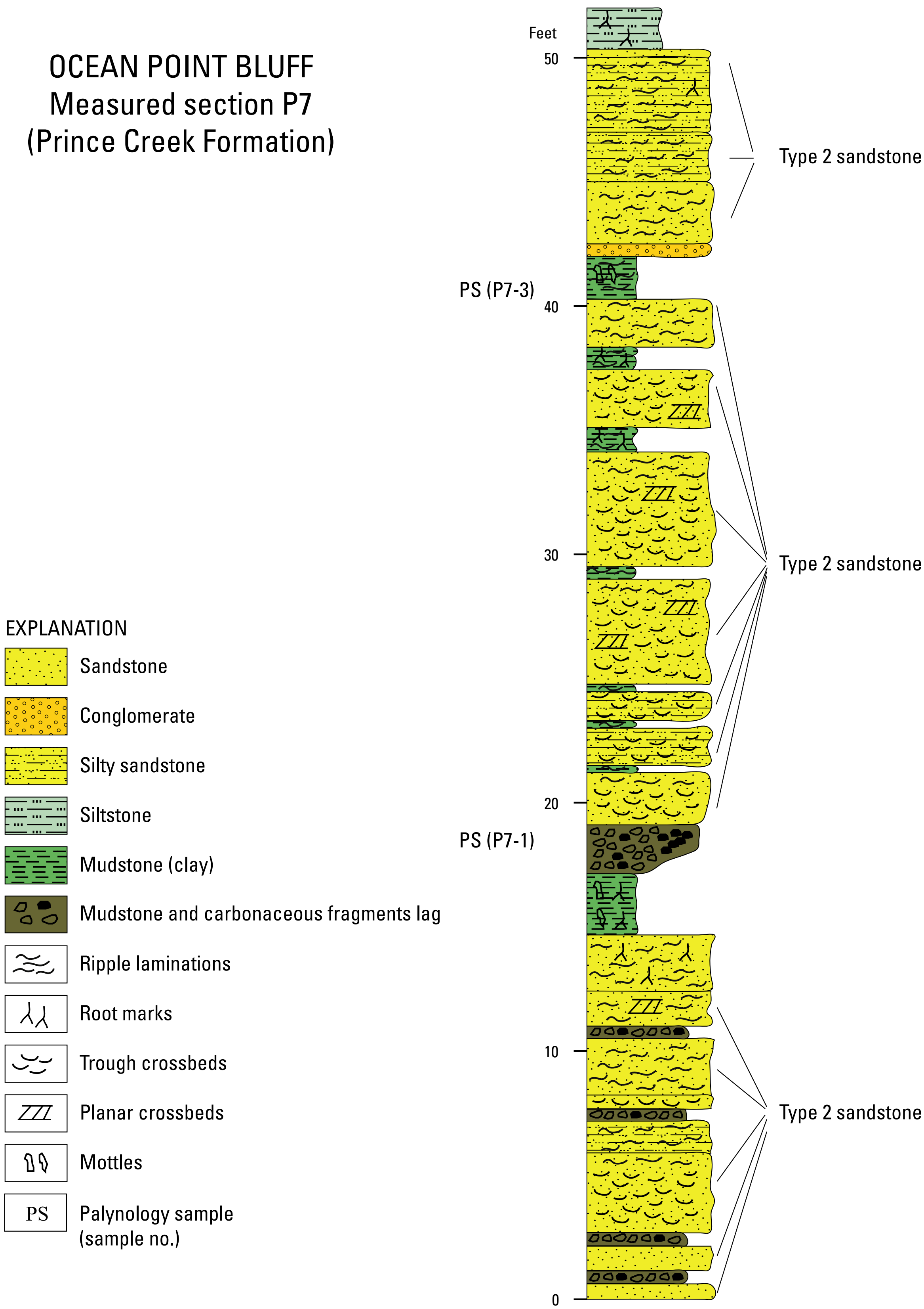

Figure 14. Vertical stratigraphic facies variations within measured section P7 of the Prince Creek Formation in the northern part of the Ocean Point Bluff. See figure 2 for section location, and compare to outcrop profile in figure 18.

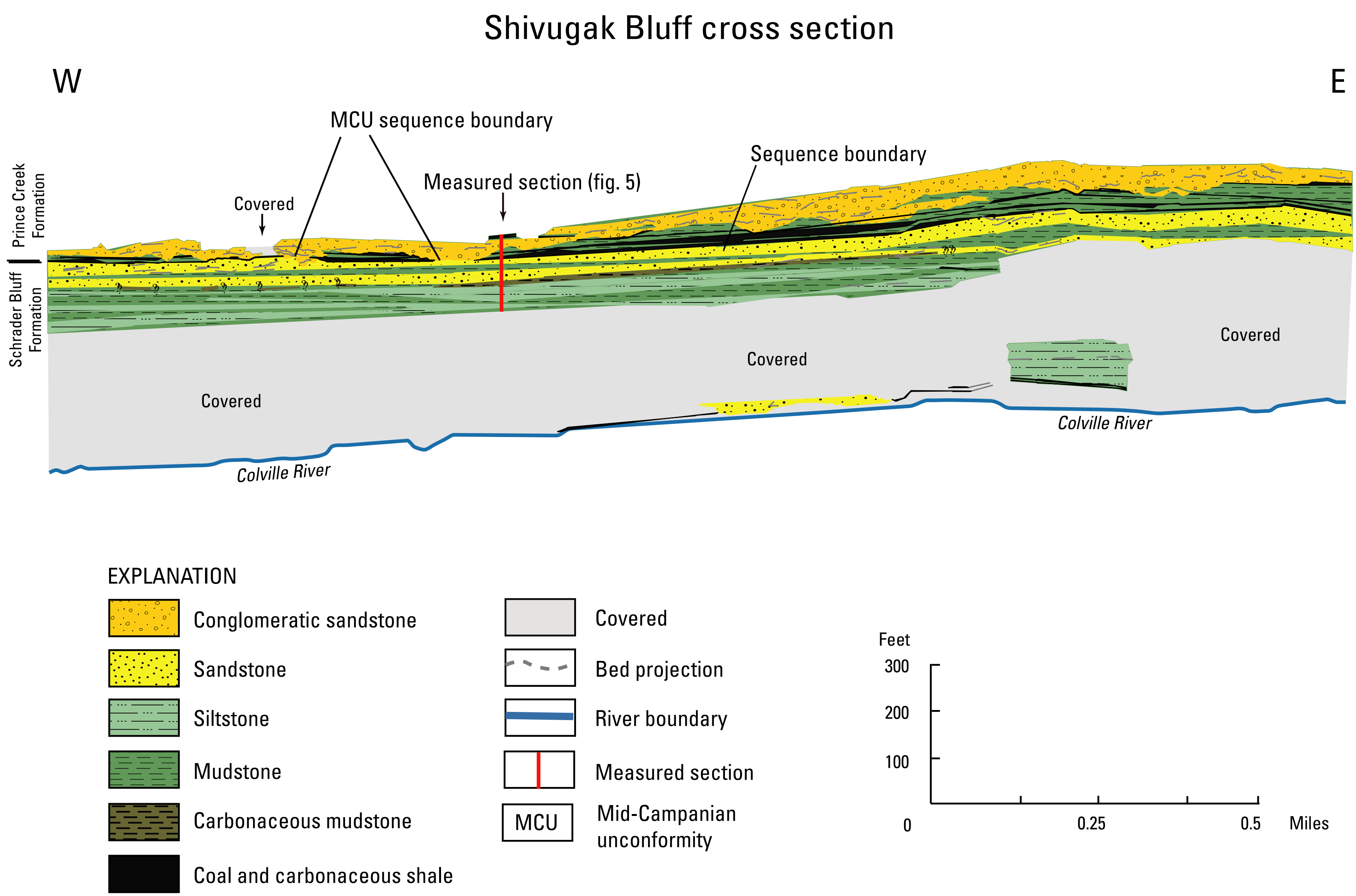

Figure 15. Cross section of the Schrader Bluff and Prince Creek Formations showing stratigraphic and sedimentologic facies variations of outcrops, position of measured section, and sequence boundaries along Shivugak Bluff. See figure 2 cross section location. Cross section was reconstructed from photomosaics. Mid-Campanian unconformity adopted from Decker (2007).

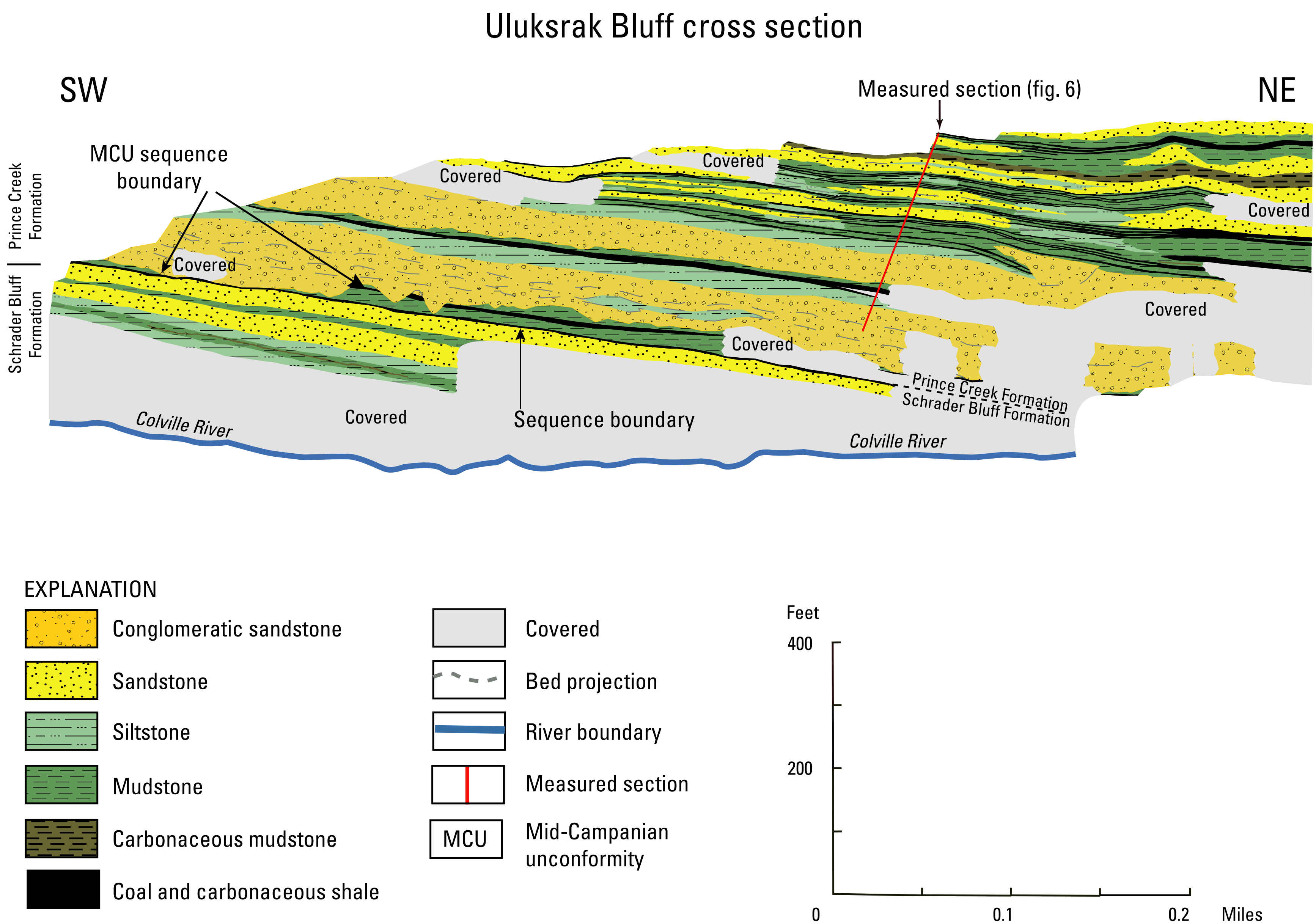

Figure 16. Cross section of the Schrader Bluff and Prince Creek Formations showing stratigraphic and sedimentologic facies variations of outcrops, position of measured section, and sequence boundaries along Uluksrak Bluff. See figure 2 for cross section location. Cross section was reconstructed from photomosaics. Mid-Campanian unconformity adopted from Decker (2007).

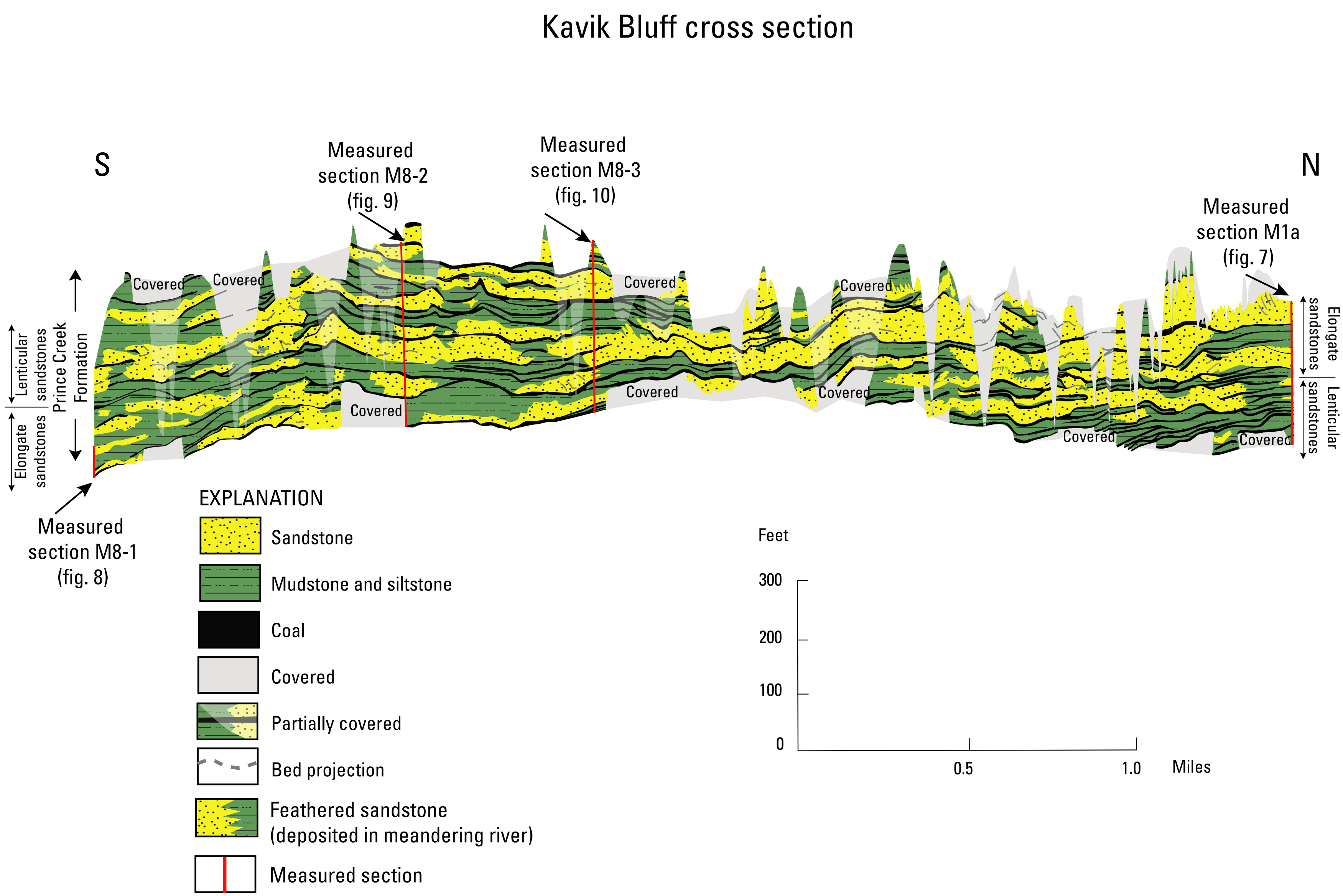

Figure 17. Cross section of the Prince Creek Formation showing stratigraphic and sedimentologic facies variations of outcrops and position of measured sections along the bluff between the mouth of the Anaktuvuk River and the vertical angle benchmark (VABM) at Kavik. See figure 2 for cross section location. Cross section was reconstructed from photomosaics.

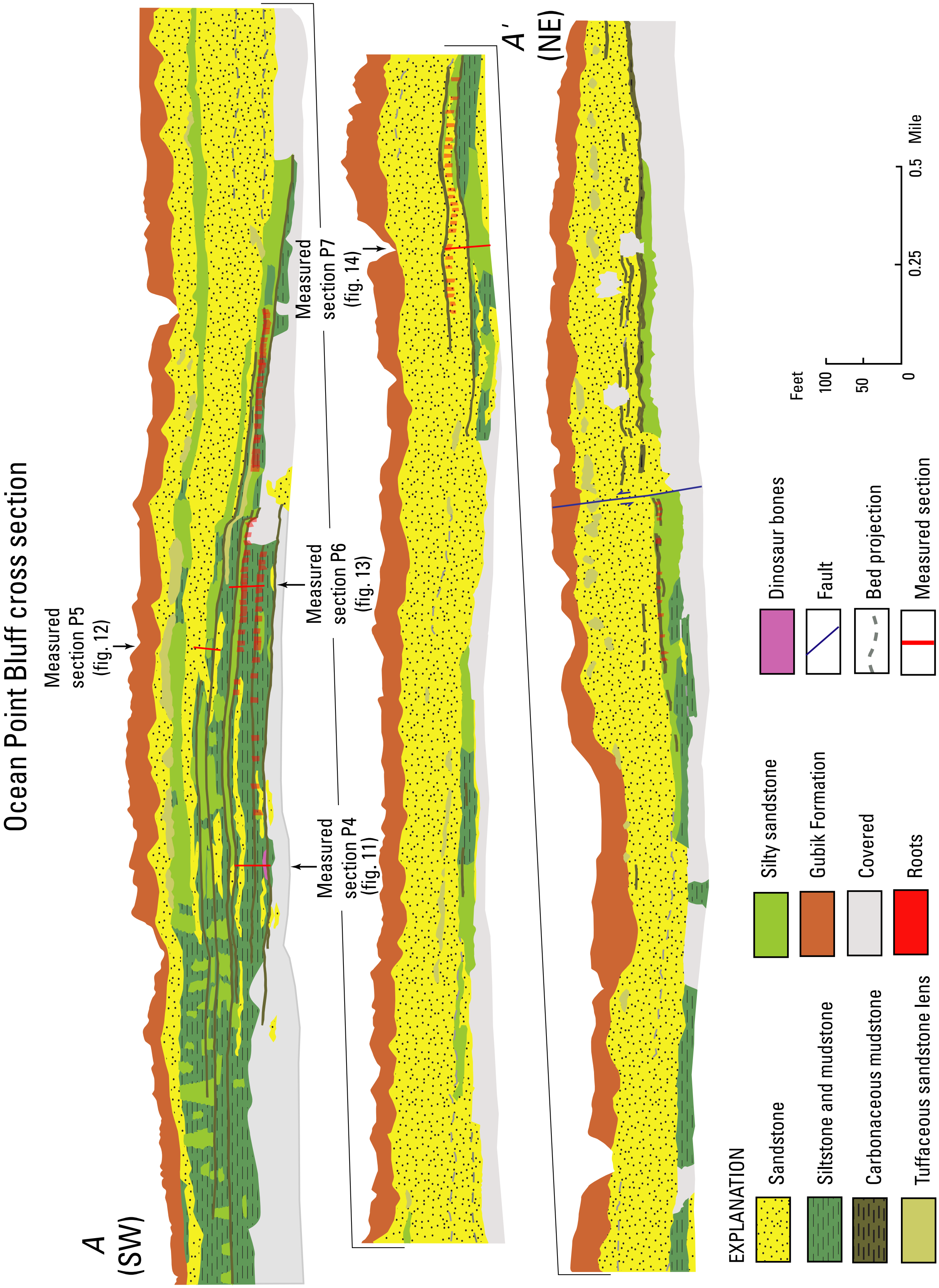

Figure 18. Cross section of the Prince Creek Formation showing stratigraphic and sedimentologic facies variations of outcrops and position of measured sections along the Ocean Point Bluff. See figure 2 for cross section location. Cross section was reconstructed from photomosaics.

with, and grading upward into, light gray rippled and burrowed siltstone and tuff beds that thicken upward and grade into the sandstone beds. The lowermost parasequence set contains a succession of thin to thick sandstone beds capping upward-coarsening mudstone-siltstone-sandstone cycles. The sandstones are light gray and fine grained, with mudstone and siltstone rip-up lags and sparse *Macaronichnus* burrows (Mull and others, 2003); they commonly exhibit hummocky and swaley cross stratification (HCS and SCS) sets as much as 2.5 ft high. The HCS and SCS are commonly associated with wave, ripple, and flat laminations that are locally bioturbated. The upper two parasequence sets contain tabular and bidirectional crossbedded sandstones, each as much as 55 ft thick (figs. 21*A* and 21*B*), that are fine to very fine grained and have fining-upward profiles from the underlying fine-grained sediments.

Figure 19. Photograph of lower part of the Schrader Bluff Formation showing platy, tuffaceous beds in Shivugak Bluff. For scale, the tuffaceous beds are from a few inches to 1 ft thick.

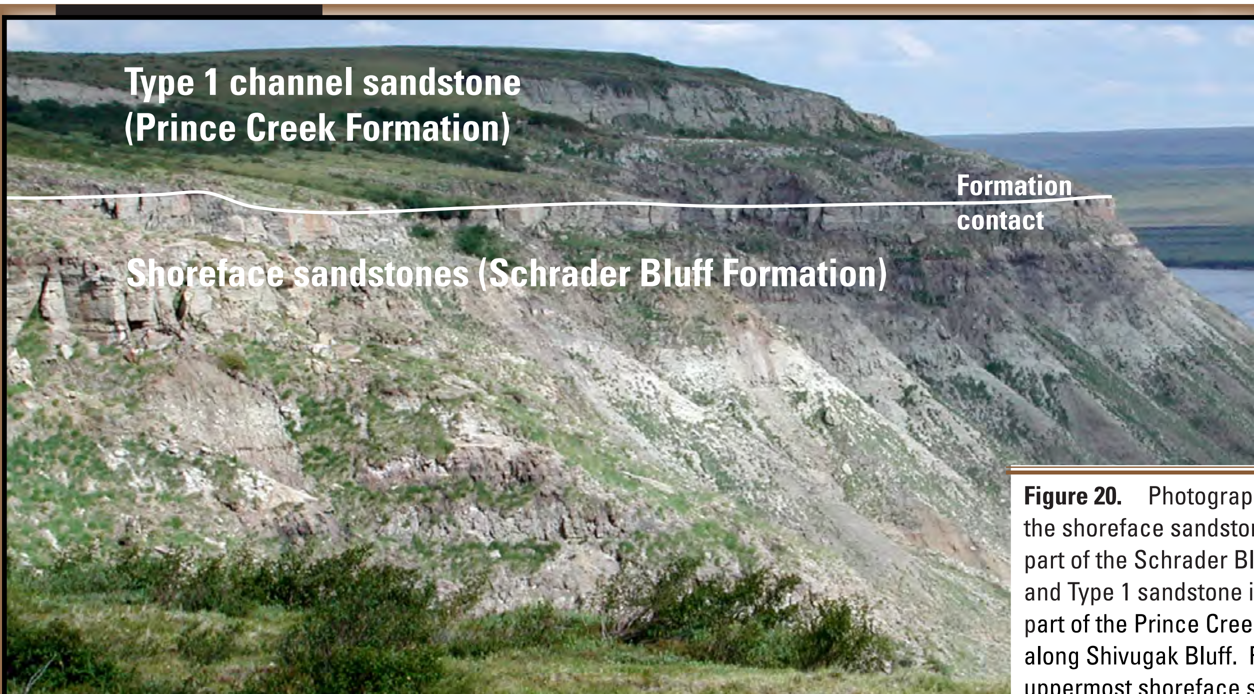

Figure 20. Photograph showing the shoreface sandstones in upper part of the Schrader Bluff Formation and Type 1 sandstone in lowermost part of the Prince Creek Formation along Shivugak Bluff. For scale, the uppermost shoreface sandstone and interbedded mudstone together are 65 ft thick.

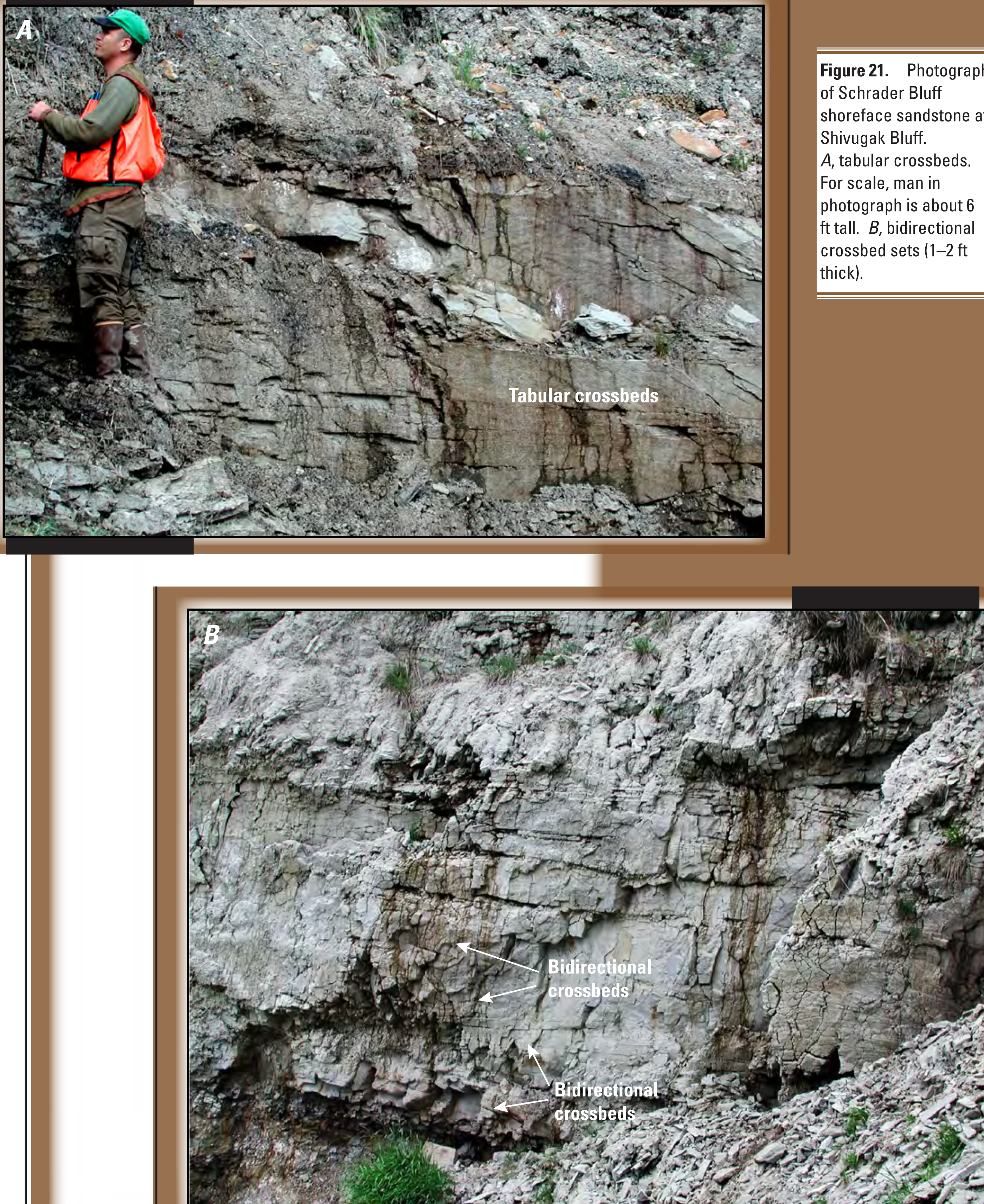

Figure 21. Photograph of Schrader Bluff shoreface sandstone at Shivugak Bluff. *A*, tabular crossbeds. For scale, man in photograph is about 6 ft tall. *B*, bidirectional crossbed sets (1–2 ft thick).

Interpretations

The coarsening-upward parasequence sets of mudstone grading upward into siltstone, tuff, and sandstone beds are interpreted as prograding offshore to delta-front deposits. The HCS and SCS; wave, ripple, and flat laminations; and *Macaronichnus* trace fossils indicate deposition in a storm-wave-dominated shoreface environment. During storms, the shoreface sand is reworked by shallowing, oscillatory waves, whereas during fair-weather conditions mud and silt settle from suspension offshore, where the sediments are bioturbated. The upper beach face and shoreface sandstones probably developed on a barred coastline, as indicated by the uppermost two sandstones with tabular and bidirectional crossbedded sandstones in figures 21*A* and 21*B*. That this coastline was affected by storm waves is indicated by the HCS and SCS.

Prince Creek Formation (Lower Part)

Description

The Schrader Bluff Formation is in sharp contact with the overlying Prince Creek Formation, the base of which is marked by a 3-ft-thick bed of coal and carbonaceous shale (fig. 5). The lower part of the Prince Creek Formation was measured at Uluksrak Bluff (see location in fig. 2). As shown in figure 6, the 415-ft-thick section contains three types of sandstones. The lower part, more than 200 ft thick, contains Type 1 conglomeratic sandstones that are more than 70 ft thick and that contain vertically stacked beds with erosional bases (multiscours) that grade upward from pebble- and cobble-bearing beds to medium-grained, light gray, and poorly sorted beds (figs. 6, 16, and 22). The pebbles and cobbles consist mainly of black chert, are concentrated along erosional bases or trough-crossbed bases (fig. 23), and occur throughout the Type 1 sandstones as 2- to 5-in-thick imbricated framework lag conglomerate or as float pebbles supported in a sandy matrix in beds ranging from 1 to 5 ft thick (figs. 22 and 24). The lag conglomerates form lensoid units, with the float pebbles lying along low-angle cross laminations. The conglomeratic Type 1 sandstone is the most common type of sandstone in the lowermost 250–350 ft of the Prince Creek Formation. In that part of the formation there are only thin (a few inches to 1.5 ft thick) coal beds interbedded with rooted carbonaceous mudstone and siltstone.

Higher beds in the lower part of the Prince Creek Formation are both Type 2 and Type 3 sandstones (fig. 6). Type 2 sandstones are erosional based, fine upward from medium to fine grained, are light gray to white and bentonitic, and contain quartz and black chert pebble conglomerate. The sandstones are scour based, range from 5 to 30 ft thick, and form either single or multistacked bodies. They contain trough crossbeds ranging from a few inches to 2 ft high in the lower part and commonly exhibit climbing ripple laminated units from a few inches to 5 ft thick in the uppermost part of the units. Type 3 sandstones coarsen upward and are sharp based, light gray, rooted, and mainly very fine grained and rippled (fig. 7). This sandstone type is as much as 2 ft thick and occurs as single sand bodies commonly interbedded with mudstone, siltstone, and thin-bedded coal and carbonaceous mudstone.

Interpretations

Types 1 and 2 sandstones are characterized by erosional bases and mainly represent fluvial channel deposits. Type 1 conglomeratic sandstones, further distinguished by common framework- and matrix-supported pebble conglomerates, probably represent braided river deposits. The abundant coarse grain size (medium-grained to pebbles and cobbles) of this sandstone type indicates that it originated as bedload deposits typical of braided streams. The framework-supported conglomerate consisting of cobbles and pebbles indicates bedload deposition as channel lag gravels. Clast imbrication reflects deposition on a flat top of a longitudinal bar or on a channel floor (Steel and Thompson, 1983). The sand-matrix-supported pebbles, which overlie the lag gravels and are along foresets of crossbeds, were deposited on slip or dip slopes of sand bars probably during sheet flooding (Reading, 1978). These bars commonly split stream flow, creating subchannels that give rise to a braided pattern that is most apparent during low flow stage. During low flow, sands are deposited on lag gravels, and during subsequent high flow the pebbles in lag gravels are reworked and deposited along fronts of sand bars ranging from 1 to 5 ft high.

Type 2 sandstones, characterized by erosional bases overlain by single body or multiscoured bodies, probably mainly represent low-sinuousity river deposits. The single-body sandstone probably represents a single, stable, cut-and-fill fluvial channel. The multiscoured sandstone bodies represent deposits of a fixed, vertically aggrading fluvial channel. These fluvial channels reflect laterally stable channels between episodes of abrupt switching (Friend, 1983) and resemble those of anastomosed rivers incised in thick, fine-grained, overbank-flood plain sediments (Smith, 1983).

Type 3 sandstones—characterized by either sharp or gradational bases, coarsening-upward profiles, ripple laminations, and root marks—represent crevasse splay deposits. These sandstones result from deposition by floodwaters breaching the levee crest and spilling into flood plains and mires. Incursions of these sediment-laden floodwaters resulted in deposition of sheet-like sediments by numerous small, anastomosed channels (Smith, 1983). Crevasse splay sandstones are commonly interbedded with flood plain mudstones and siltstones. These fine-grained sediments reflect deposition of suspended sediments transported by either crevasse splays or overbank floodwaters, or both.

Figure 22. Photograph of pebbly, coarse grained, poorly sorted, and large-scale trough crossbedded fluvial channel sandstone (Type 1) of the Prince Creek Formation. Jacob staff is 3 ft long (for scale).

Figure 23. Type 1 sandstone containing pebbles mainly composed of subrounded black chert and volcanic rock fragments in the Prince Creek Formation. Knife is 6 in long (for scale).

Figure 24. Pebbles and cobbles in Type 1 sandstone are imbricated in framework-supported lag conglomerate and also occur as float pebbles in a sandy matrix within large-scale trough crossbeds. Ruler is 1 ft long (for scale).

Prince Creek Formation (Middle and Upper Parts)

Description

The vertical stratigraphic and sedimentologic variations of the middle and upper parts of the Prince Creek Formation are exhibited in figures 7 through 14 for the Kavik Bluff (see fig. 2 for location below the vertical angle benchmark [VABM] at Kavik) and Ocean Point Bluff. In general, the middle and upper parts of the formation in these areas are composed of interbedded coal, carbonaceous shale, mudstone, siltstone, tuff, sandstone, and conglomeratic sandstone beds.

Prince Creek coal beds range from a few inches to 11.5 ft thick and are interbedded with white tonstein, greenish bentonitic claystone, and carbonaceous shale and mudstone partings that contain root marks and abundant carbonized plant leaves and stems (fig. 25). The tonstein partings, as much as 6 in thick, are laterally extensive and make good marker units. The coal beds, which contain bright and dull vitrain bands that are a few inches thick, range in rank from lignite to subbituminous (Sable and Stricker, 1987; Wahrhaftig and others, 1994). The mudstone is gray to light gray, is bentonitic, and contains reddish ferruginous layers and nodules equivalent to the variegated layers in the Sentinel Hill Core Test 1 well (Flores and others, 2007) and macerated plant fragments. It is rooted, carbonaceous, and dark gray and occurs below the coal beds and as partings. The thickness of the mudstone beds ranges from a few inches to about 30–35 ft; the thickest mudstone units exhibit erosional bases. The siltstone is gray, rippled, ferruginous, and rooted and contains abundant plant fragments. Siltstone occurs either as beds a few inches to 10 ft thick or as lenses in the mudstone (a few inches thick and a few feet long).

The middle and upper parts of the Prince Creek Formation contain mainly Types 2 and 3 sandstones. Type 2 sandstones are erosional based, fining upward, fine grained, light gray to white, and bentonitic and contain quartz and black chert pebble conglomerate. These sandstones range from 10 to 60 ft thick; occur as either single body or multiscoured, stacked bodies; and are separated by mudstone drapes that are as much as a few inches thick (figs. 26*A* and 26*B*). Type 2 sandstones contain trough crossbeds ranging a few inches to 6 ft high and climbing ripple laminations from a few inches to 10 ft thick; the latter are common in the upper part of the sandstone beds. This sandstone type is common in the upper part of the Prince Creek Formation, where its architecture is laced with erosional-based mudstones (fig. 27). Figure 26*B* exhibits (1) the vertically stacked and laterally en echelon architecture of these erosional-based sandstone-mudstones and associated dipping (10E–15E) mud-draped sandstone-siltstone couplets, (2) the opposing dip of the accretionary bedding in vertically adjacent sandstone-siltstone couplets that grade into thick-bedded sandstones (see bottom of fig. 26*A* and left of fig. 26*B*), and (3) the general upward fining and widening of the sandstone bodies in the lower part and narrowing in the upper part.

Figure 25. Photograph of interbedded coal, carbonaceous mudstone, siltstone, and tonstein (white) beds in the Prince Creek Formation between the mouth of the Anaktuvuk River and the vertical angle benchmark (VABM) at Kavik. For scale, man in photograph is about 6 ft tall.

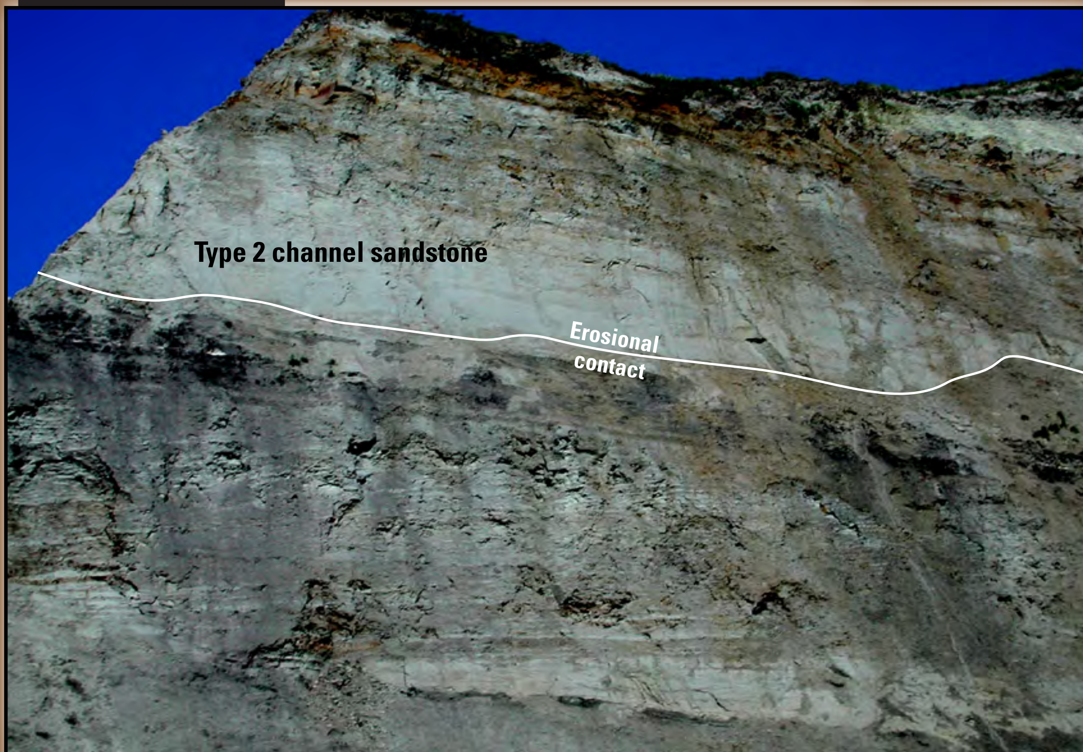

Figure 26*A*. Photograph of Type 2 erosional-based, fining-upward, multiscoured sandstone in the Prince Creek Formation between the mouth of the Anaktuvuk River and the vertical angle benchmark (VABM) at Kavik. Inclined sandstone and siltstone beds in the lower Type 2 sandstone are lateral accretion deposits. Type 2 channel sandstone is 50 ft thick.

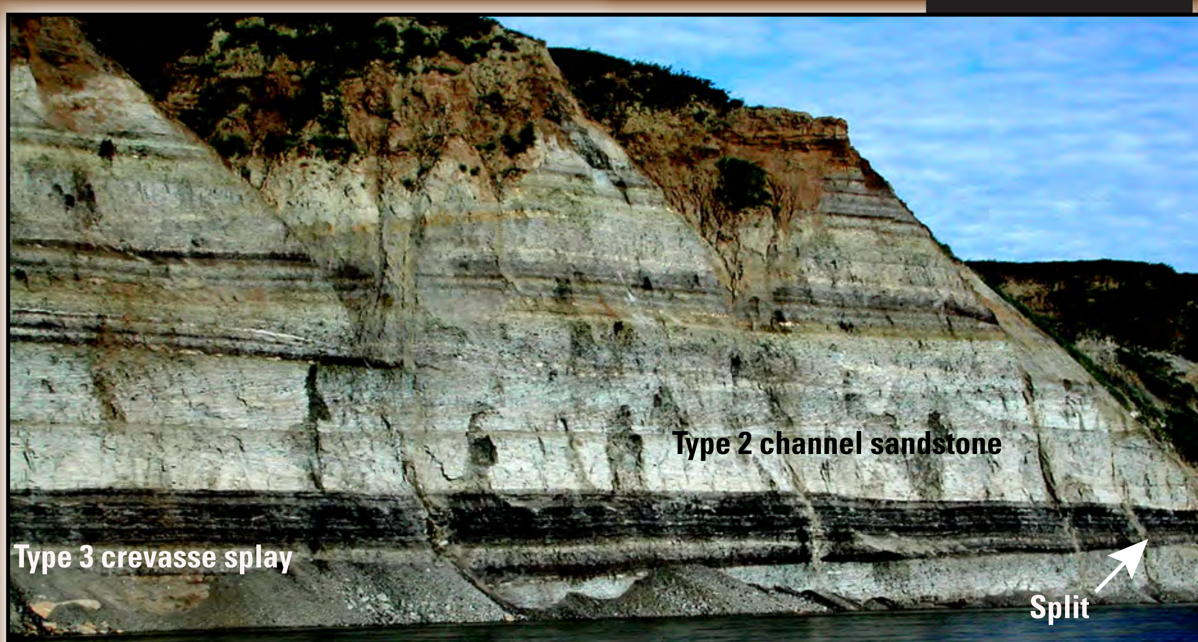

Figure 26*B*. Photograph of Type 2 sandstone complex consisting of vertically stacked, laterally en echelon sandstone overlain by erosional-based mudstone of the Prince Creek Formation. The coal bed below the sandstone is split by a Type 3 coarsening-upward splay deposit (see arrow); the coal bed merges as the splay deposit thins to the right. For scale, coal bed is 5 ft thick.

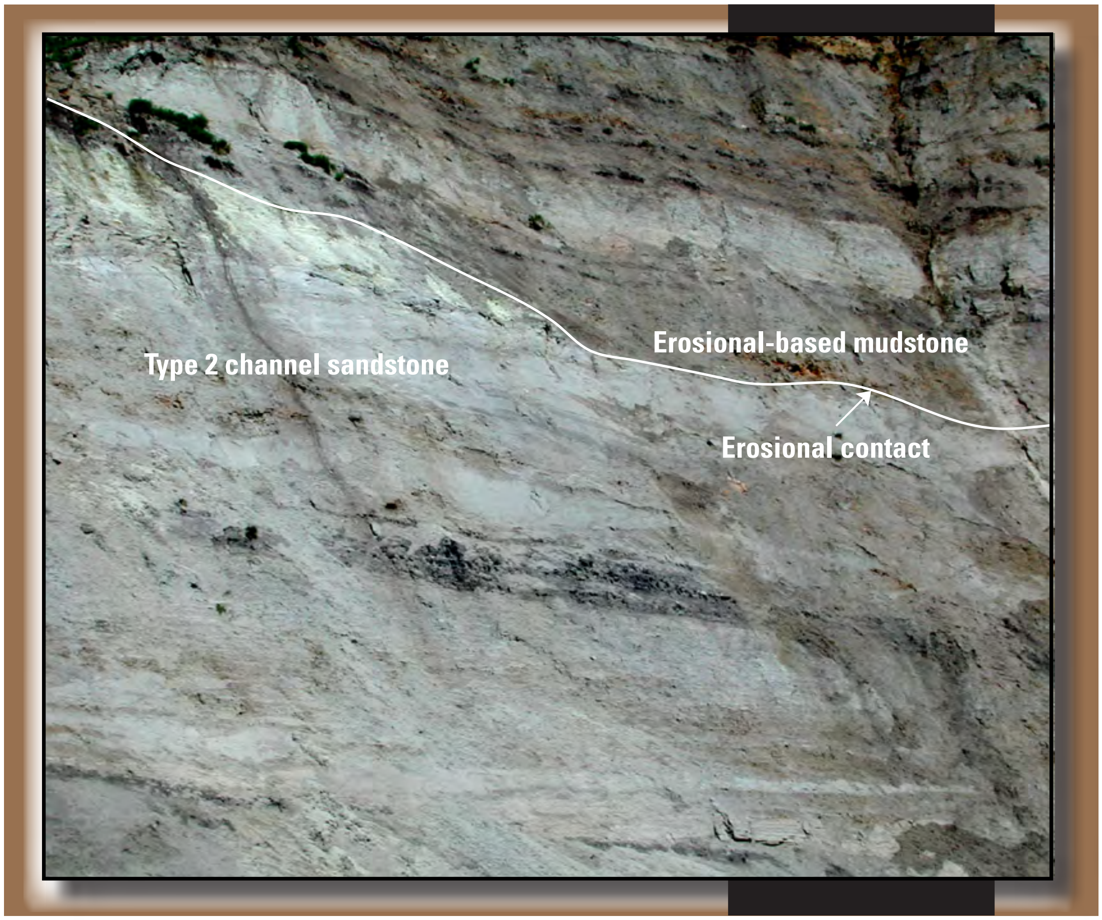

Figure 27. Photograph of erosional-based mudstone (abandoned channel plug deposit) of Prince Creek Formation between the mouth of the Anaktuvuk River and the vertical angle benchmark (VABM) at Kavik. For scale, the erosional-based mudstone is 15 ft thick.

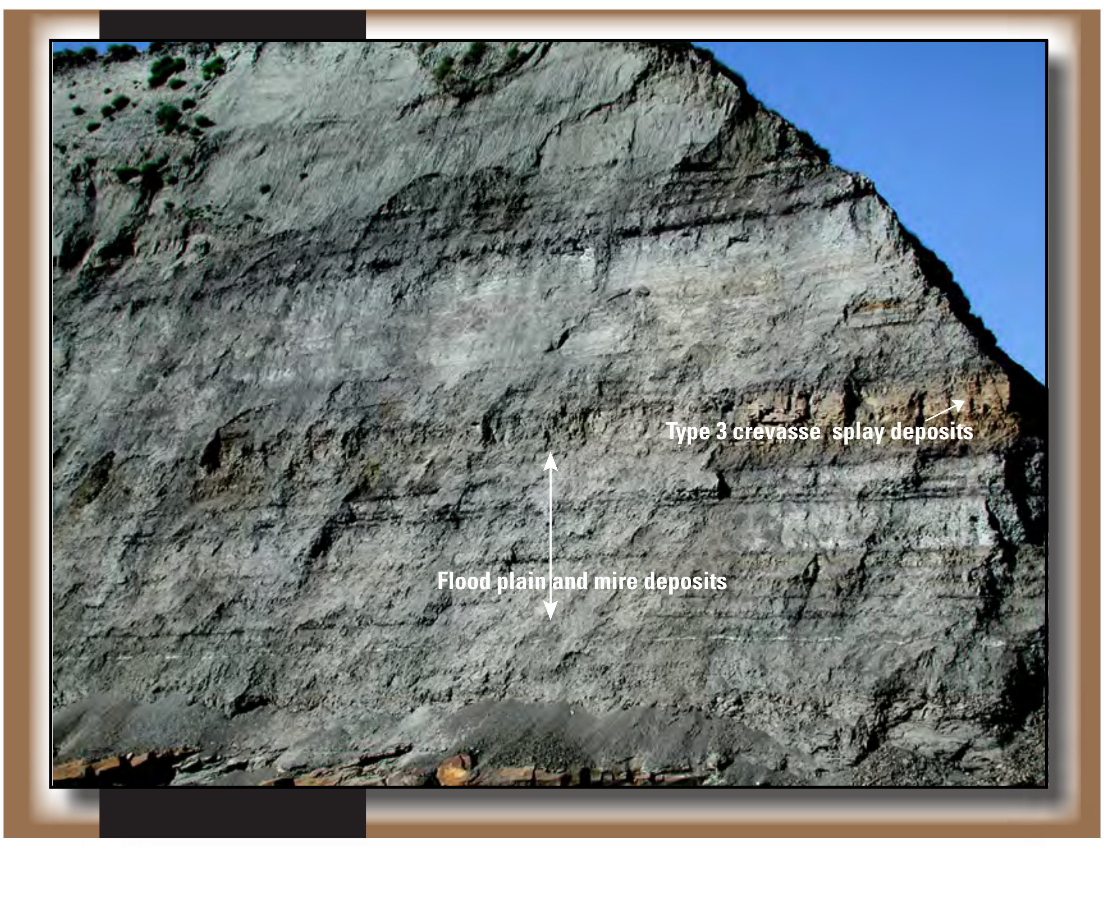

Figure 28. Photograph of interbedded sandstone, mudstone, and siltstone with minor coal and carbonaceous shale beds representing flood plain and coarsening-upward crevasse splay (Type 3 sandstones) deposits of the Prince Creek Formation. For scale, the crevasse splay deposits are 7 ft thick.

Type 3 Prince Creek sandstones are light gray, rooted, and sharp to gradational based; they coarsen upward from mudstone and siltstone to mainly very fine grained and rippled, mainly by climbing ripple laminations (figs. 28 and 29). These sandstone beds are as much as 10 ft thick and occur either as a single body or as paired sand bodies commonly interbedded with mudstone, siltstone, and thin-bedded coal and carbonaceous mudstone (fig. 28). The coal beds are commonly split by these coarsening upward Type 3 sandstones, as shown in figure 26*B*.

On the basis of the volume of coarse- and fine-grained strata as well as of coal beds, the middle and upper parts of the Prince Creek Formation may be divided into two major facies assemblages, one dominated by Types 2 and 3 sandstones and the other dominated by a mudstone-siltstone, coal-rich facies (fig. 17). Volumetrically, sandstones constitute approximately 60 percent, and mudstone, siltstone, and coal beds constitute the remainder (fig. 17). The alternating sandstone-dominated and mudstone-siltstone-dominated, coal-rich facies are well displayed in figures 5–18.

Interpretations

Type 2 sandstones, characterized by erosional bases overlain by multiscoured bodies and grading into mudstone-draped sandstone-siltstone couplets, probably mainly represent meandering river deposits (fig. 26*B*). Each multiscoured sandstone body is dominated by trough crossbeds and exhibits a fining-upward profile, and the dipping mudstone-draped sandstone-siltstone couplets are dominated by root marks and ripple laminations. The sandstone bodies represent mixed bedload and suspended load deposition of randomly shifting and migrating high-sinuosity channels, as in meandering river systems. Switching of the fluvial channel within the meander belt is indicated by the opposed dip (epsilon crossbeds) of the mudstone-draped sandstone-siltstone couplets and associated erosional-based mudstones (clay-rich deposits; fig. 26*B*); the latter indicates abandonment of the fluvial channel by avulsion or neck cutoff and the eventual filling of the fluvial channel with suspended sediments. The mudstone-draped, rippled sandstone-siltstone couplets and associated thick-bedded, crossbedded sandstones mainly represent a lateral accretion by a point bar on an inclined surface. The thick, crossbedded sandstones were deposited in the deeper parts of the channel that were subjected to vigorous currents, whereas the up-dip, mudstone-draped, sandstone-siltstone couplets were deposited in the shallow part of the channel that was mainly affected by water-level fluctuations and slack-water conditions. In the shallow part of the channel, small chute channels or bars, infilled by sand and mud, may have formed during flood and waning stages. In contrast, Type 2 sandstones that are single body with just an erosional base represent cut-and-fill, low-sinuosity, anastomosed fluvial channels, which were stabilized by thick, fine-grained overbank and flood plain sediments (fig. 30). Sedimentation of anastomosed fluvial channels occurs by vertical accretion of both the channel floor and overbank or flood plain sediments.

Figure 29. Photograph of fine-grained, ripple laminated (climbing ripples) sandstone interbedded with a thin coal and mudstone layer above Type 2 sandstone of the Prince Creek Formation. Some rootlets indicated by ferruginous marks are in the sandstone. Hammer is 1 ft long (for scale).

Type 3 sandstones—characterized by either sharp- or gradational-base, coarsening-upward profiles with underlying mudstones and siltstones, ripple laminations, and root marks—represent crevasse splay deposits. These strata resulted from

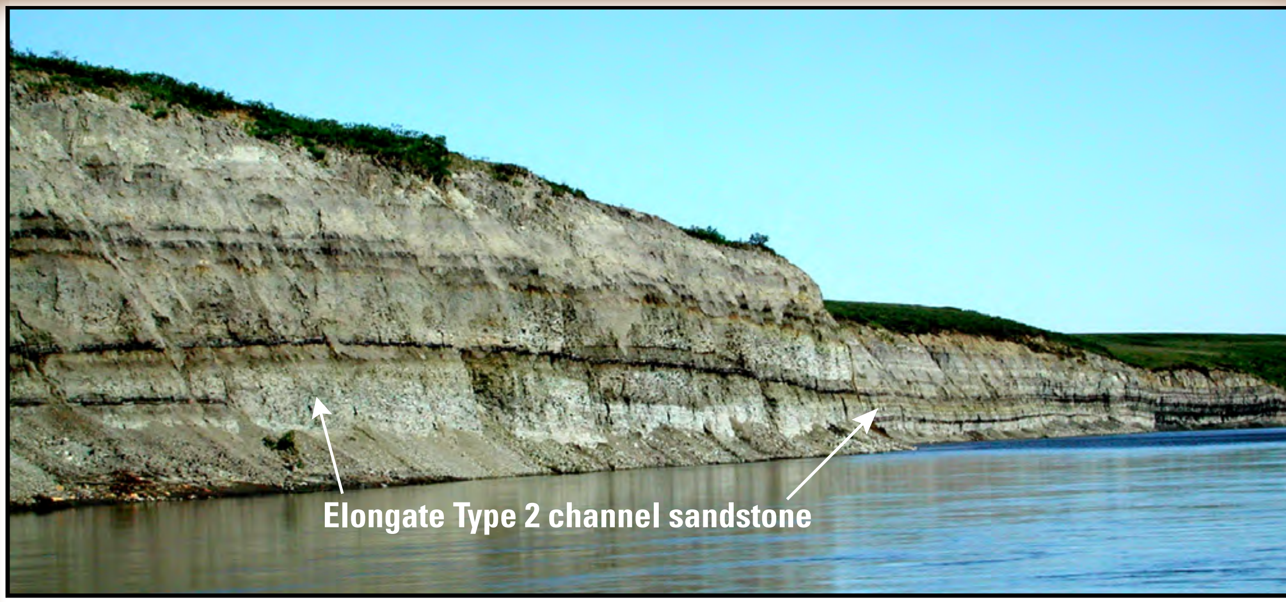

Figure 30. Photograph of elongate fluvial channel sandstone (Type 2) bounded by interbedded silty sandstone, siltstone, mudstone, coal, and carbonaceous mudstone. The fluvial channel sandstone feathers or dovetails with thick coal and carbonaceous mudstone beds and with finer grained rocks toward the right (northward) of the photograph. Colville River is in the foreground. For scale, the Type 2 channel sandstone is 25 ft thick.

deposition by floodwaters that breached the levee crest and spilled into flood plains. Further incursions of these sediment-laden floodwaters from fluvial channels to the peat-forming mires deposited sheet-like and lobe-shaped deposits, as indicated in figure 26*B*.

Crevasse splay sandstones commonly overlie and are interbedded with flood plain mudstones and siltstones. These fine-grained strata contain variegated paleosols in the Sentinel Hill Core Test 1 well (Flores and others, 2007) and reflect deposition of suspended sediments transported by crevasse splays or overbank floodwaters into the flood plain. The coarser grained beds (sandstones) represent deposition of bedload sediments via crevasse channels during floods, which prograded into the flood plain with suspended sediments. In mires normally beyond the influence of this floodwater sedimentation, plant matter accumulated as peat, but the presence of mudstone and sandstone partings in coal beds suggests intermittent detrital incursions during flood events into the peat-forming mires, as shown in figures 25 and 26*B*, indicating that the peat mires probably were mainly low lying or flat topogeneous mires prone to floods. The tonstein and bentonitic partings indicate deposition of volcanic ash into the mires. Thick mudstones characterized by erosional bases represent abandoned channel deposits that were infilled by suspended mud during floods. These abandoned channels (oxbows) are associated with meandering rivers, where meander loops are abandoned and rapidly plugged at both ends, as well as with abandoned chute channels on point bar surfaces.

Stratigraphic Facies Variations Within the Sentinel Hill Core Test 1 Well

The Sentinel Hill Core Test 1 well, as described and interpreted by Robinson and Collins (1959), provides an additional one-dimensional view of the vertical stratigraphic variations of the Prince Creek Formation and of the upper part of the Schrader Bluff Formation. This well—which was cored continuously with good recovery in the depth interval of 100–1,180 ft—was redescribed by Flores and others (2007) to establish sedimentological facies and to interpret the depositional environments.

The Prince Creek Formation as distinguished by Robinson and Collins (1959) is predominantly nonmarine, and the Schrader Bluff Formation is predominantly marine. They subdivided the sequence as follows (in ascending order): Sentinel Hill Member of the Schrader Bluff Formation, 231 ft; Kogosukruk Tongue of the Prince Creek Formation, 109 ft; Sentinel Hill Member of the Schrader Bluff Formation, 371 ft; and Kogosukruk Tongue of the Prince Creek Formation, 469 ft (fig. 4). These stratigraphic subdivisions were based on the presence of coal and plant fossils in the nonmarine units of the Prince Creek Formation and of marine macrofossils and microfossils (for example, *Mytilus* sp. and *Eoeponidella* *strombodes*) in the marine strata of the Schrader Bluff Formation.

The lithologic observations by Robinson and Collins (1959) from the Sentinel Core Test 1 well are compared and correlated to those of the measured stratigraphic sections and stratigraphic cross sections in the Kavik, Uluksrak, and Shivugak Bluffs, which are located about 4, 10, and 13 mi, respectively, from the well site (fig. 2).

Correlations of the Sentinel Hill Core Test 1 to Colville River Bluffs Exposures

The Prince Creek and Schrader Bluff Formations in the upper part (469 ft and 371 ft thick, respectively) of the Sentinel Hill Core Test 1 are probably equivalent in part to the Prince Creek Formation at Kavik Bluff and to the Prince Creek and Schrader Bluff Formations at the Uluksrak and Shivugak Bluffs. Flores and others (2007) redefined the contacts of the Prince Creek and Schrader Bluff Formations in the test well (on the bases of facies, depositional environments, and sequence stratigraphic surfaces) as follows (the first-named depth is from Robinson and Collins [1959], and the second is that of Flores and others [2007]): (1) in the upper part, the contact was moved from the 469-ft depth within a coal-bearing interval to the 690-ft depth at the erosional base of a conglomeratic channel-sandstone complex interpreted as a sequence boundary; (2) in the middle part, the contact was moved from the 840-ft depth within a coal-bearing interval to the 746-ft depth at the erosional base of a conglomerate interpreted as a ravinement lag and sequence boundary; and (3) in the lower part, the contact remained about the same (949 ft), which is below the lowermost coal beds and above a shoreface sandstone.

In the Shivugak and Uluksrak Bluffs (figs. 15 and 16), the Prince Creek Formation, which contains mainly Types 2 and 3 sandstones, is equivalent to the upper Prince Creek Formation in the Sentinel Hill Core Test 1. Flores and others (2007) described similar sandstone types in the well cores; these sandstone types were interpreted as fluvial channel and flood plain crevasse splay sandstones. Similarly, these sandstone types are interbedded with finer grained flood plain deposits (silty sandstone, siltstone, and mudstone) and with coal interbedded with carbonaceous deposits (shale and mudstone) that formed in freshwater bogs and tonsteins (volcanic ash or tuffaceous layers) as airfall deposits.

The lowermost Prince Creek Formation in the Uluksrak and Shivugak Bluffs (figs. 15 and 16)—which is dominated by Type 1 sandstone with minor coal, carbonaceous shale, mudstone, and siltstone—is probably equivalent to the lowermost interval of the upper part of the Prince Creek Formation in the Sentinel Hill Core Test 1. This interval in the core test contains, from bottom to top, (1) multiscoured conglomeratic, fine- to coarse-grained sandstones (Type 1) overlain by (2) thin coal beds, which in turn grade upward into (3) interbedded silty to fine-grained sandstones, siltstones, and mudstones. The lower Type 1 sandstone of this 180-ft-thick interval is interpreted by Flores and others (2007) as a paleovalley deposit that was incised into the marine lower shoreface deposits of the upper Schrader Bluff Formation; the erosional base of the paleovalley represents a sequence boundary. The overlying interval of interbedded Type 3 sandstone, coal, mudstone, and siltstone beds represents coastal bay-estuarine environments. At Uluksrak and Shivugak Bluffs (figs. 15 and 16), braided stream deposits also overlie the erosion surface that was incised into the marine upper shoreface deposits of the Schrader Bluff Formation, but in these areas the braided stream deposits are overlain by thicker coal beds, indicating more freshwater bog settings. The Schrader Bluff Formation in the Uluksrak and Shivugak Bluffs, which is more than 400 ft thick (figs. 15 and 16), is probably laterally equivalent to the thicker lower tongue of the Schrader Bluff Formation in the Sentinel Hill Core Test 1; the upper tongue of the Schrader Bluff Formation in the core test is probably missing farther updip at Shivugak Bluff because of erosion during sea-level drop (paleovalley incisement).

The lower coal-bearing part of the Prince Creek Formation in the Sentinel Hill Core Test 1 may be correlated below the lowermost conglomeratic channel sandstone, which is shown in figure 5. The conglomerate sandstone in the Sentinel Hill Core Test 1 is interpreted as Type 1 sandstone deposited above an erosion surface incised into underlying thin coal and carbonaceous shale beds. The erosional base of the Type 1 sandstone is interpreted as a sequence boundary, which in turn is underlain by a marine shoreface sandstone. The thinned nonmarine Prince Creek Formation is overlain by a thin conglomerate interpreted as a ravinement lag, which may be laterally equivalent to the ravinement lag at the 746-ft depth in the Sentinel Hill Core Test 1 (see Flores and others, 2007). These ravinement lags were formed from reworked older sediments during marine transgression or sea-level rise. The ravinement lag is overlain by interbedded marine shoreface sandstone and mudstone beds, which were partly eroded during sea-level drop in the Sentinel Hill Core Test 1 area.

Lateral Stratigraphic Variations

The cross sections in figures 15–18 were constructed from photomosaics to display the lateral stratigraphic and sedimentologic variations within the upper part of the Schrader Bluff Formation and within the Prince Creek Formation in the Colville River Bluffs. Figures 15 and 16 exhibit the lateral variations in the upper part of the Schrader Bluff Formation and the lowermost part of the Prince Creek Formation at Shivugak and Uluksrak Bluffs. Figures 7 and 18 exhibit the lateral variations in the middle and upper parts of the Prince Creek Formation between the mouth of the Anaktuvuk River and Ocean Point. These locations and place names are shown in figure 2.

Shivugak to Uluksrak Bluffs

Description

The stratigraphic cross sections along Shivugak and Uluksrak Bluffs show laterally extensive, tabular (more than 0.5–1 mi long and as much as 55 ft thick), marine sandstone beds in the uppermost part of the Schrader Bluff Formation (figs. 15 and 16). These tabular sandstone beds cap coarsening-upward parasequence sets that extend laterally from the Shivugak to Uluksrak Bluffs for a distance of more than 6 mi. These sandstone beds overlie discontinuous, thin to thick, coarsening-upward tuffaceous sandstones interbedded with siltstone and mudstone. The top of the Schrader Bluff Formation is a rooted erosional surface capping the uppermost tabular, coarsening-upward sandstone bed, which is overlain by a coal bed as much as 2 ft thick.

This basal coal of the Prince Creek Formation is overlain by a few interbedded coal and mudstone-siltstone beds. These strata are overlain by a fining-upward, erosional-based, chert-pebble conglomeratic, multiscoured sandstone unit (figs. 15 and 16) that is locally incised as deeply as 75 ft into the underlying Prince Creek Formation coals and mudstones and into the uppermost coarsening-upward sandstone of the Schrader Bluff Formation (fig. 15). The conglomeratic sandstones form a laterally extensive blanket-like unit from Shivugak to Uluksrak Bluffs; the erosional base was informally recognized as mid-Campanian unconformity (MCU) by Decker (2007). Coal beds interbedded with the conglomeratic sandstones are as much as 5 ft thick and are laterally continuous from Shivugak to Uluksrak Bluffs.

Two conglomeratic sandstone beds as much as 55 ft thick were observed in Uluksrak Bluff (fig. 16), whereas only one conglomeratic sandstone bed was observed in Shivugak Bluff, where the upper bed is either obscured or has coalesced with the lower bed. In Uluksrak Bluff, the uppermost lenticular conglomeratic sandstone bed is overlain by interbedded numerous coal beds and lenticular sandstone beds. The lenticular sandstone beds are en echelon relative to coal beds that are in part laterally equivalent to the sandstone beds.

Overlying the tabular sandstone beds at the top of the Schrader Bluff Formation are thin- to thick-bedded coals of the Prince Creek Formation that extend laterally for more than 1 mi (figs. 16, 17, and upper part of measured section in fig. 6). The coal beds are interbedded with thin-bedded, blanket-like sandstones. The coal interval is sparsely interbedded with thick, laterally extensive sandstone beds (fig. 16). Thus, the cross sections in figures 16 and 17 depict an alternating succession of the sandstone-dominated, coal-poor facies and the mudstone-siltstone-dominated, coal-rich facies.

Interpretations

The tabular, bidirectional crossbedded sandstone beds of the upper Schrader Bluff Formation shown in figures 15 and 16 represent barrier-shoreface facies. These beds—which are vertically stacked, coarsening-upward sequences—were deposited on a prograding paleoshoreline. The presence of HCS and SCS, wave, ripple, and flat lamination-bearing sandstone reflects in part reworking of the sands by storm-generated currents (Reading, 1978). The contact between the uppermost tabular sandstone bed of the Schrader Bluff Formation and the lowermost coal bed of the overlying Prince Creek Formation represents a surface of regional erosion into the shoreface resulting from lowering of relative sea level; the contact is considered a forced regressive surface or sequence boundary as recognized by Mull and others (2003).

The erosional surface at the base of the blanket-like conglomeratic sandstone beds (Type 1) in the lowermost part of the Prince Creek Formation appears to be the result of a later, though possibly genetically related, fall in base level that took place following the deposition of at least 75 ft of basal Prince Creek Formation coals and mudstones. This surface presumably developed through headward incision of a broad paleovalley whose infilling by braided stream bedload conglomerates and sands reflects high sediment supply, which is suggestive of tectonic activity in the source terrane. Later, a subsequent change to higher accommodation, lower depositional gradient conditions, controlled either by basin subsidence or eustatic sea-level rise, caused a change in fluvial depositional architecture. The deposition of the en echelon, lenticular sandstones, which range from 0.1 to 0.5 mi wide and are as much as 20 ft thick, reflects fluvial channels infilled by sands and subsequently abandoned. These narrow, small streams periodically were diverted (avulsed) into topographic lows in the flood plains. The flat-lying or topogeneous mires in open wet flood plains accumulated thin peat deposits and eventually encroached over stable, abandoned, alluvial-belt platforms, thereby forming thin to thick, laterally extensive "dirty" coal beds.

Anaktuvuk River to VABM Kavik

Description

The stratigraphic cross section from the bluffs between the mouth of the Anaktuvuk River and the vertical angle benchmark (VABM) at Kavik (fig. 2) represents an interval in the Prince Creek Formation above the section described in Uluksrak Bluff (fig. 17). The cross section shows both fining-upward lenticular and elongate sandstone beds (based on length to thickness ratios) interbedded with coal, mudstone, siltstone, and silty sandstone beds. The lenticular sandstone beds are erosional based, are as much as 80 ft thick, and have lateral extents of more than 2.5 mi. The erosional base is commonly overlain by pebble conglomerates as much as 5 ft thick that contain abundant quartzite and metavolcanic fragments. These sandstone beds contain "feathered" tops marked by clay-draped lateral accretion surfaces. The elongate sandstone beds are erosional based, are as much as 40 ft thick, and have lateral extents from less than 0.1 to 1 mi. These beds are associated with tabular, 5- to 10-ft-thick, rippled silty sandstone beds underlain by coarsening-upward mudstone and siltstone beds. The coal beds, as much as 6 ft thick and with lateral extents more than 3.5 mi, split, merge, pinch out, and are cut out by the erosional-based sandstones. The architecture of these fluvial deposits is shown in figure 30; note that at the right and left sides of the photograph the elongate sandstone can be observed feathering into thick, interbedded sandstone, siltstone, mudstone, coal, and carbonaceous mudstone.

The stratigraphic cross section for these exposures (fig. 17) may be divided into a lower part dominated by elongate sandstone beds and an upper part dominated by lenticular sandstone beds. The elongate sandstone beds are physically separate but coeval units along the north-south direction (or from right to left in the cross section), whereas the lenticular sandstone beds show an en echelon stacking pattern. The en echelon pattern of the lenticular sandstone beds is particularly apparent where the thickest portions of successive sandstone bodies do not directly overlie one another but are slightly en echelon, with the thickest portion overlying the fine-grained, coal-bearing intervals. In addition, the sandstone beds wedge out by interfingering laterally with various fine-grained strata and coal. A few of the lenticular sandstone beds are broader at their tops than at their bases.

Interpretations

The architecture of the sandstone beds and associated fine-grained, coal-bearing sediments in the Prince Creek Formation indicates fluvial deposition of meandering and anastomosed channel systems. The en echelon arrangement of the lenticular sandstone beds in the upper part of the interval probably resulted from abrupt channel switching in response to favorable flood plain gradients. Where a meander has been largely infilled by lateral accretion of the point bar toward a relatively stationary cut bank, a flooding stream tends to be diverted just upstream, cutting off the meander by developing a chute channel across the adjacent flood plain. The abandoned meander channel bars stood as high and well-drained ridges before subsiding and being covered by mire deposits that encroached from adjoining flood plain wetlands.

That the meandering fluvial channels evolved from anastomosed channels is indicated by the coeval elongate sandstone beds, which dominated the lower part of the interval. These narrow fluvial channels may have evolved from crevasse splay channels, as they are associated with coarsening-upward mudstone, siltstone, and silty sandstone. The crevasse splays resulted from the breaching of levees during floods that spilled over into the flood plains. As flood sediments prograded into the flood plain, crevasse channels transformed into well-developed, contemporaneous, narrow, deep, anastomosed fluvial channels (fig. 30; Flores, 2003). After partial infilling, this system of crevasse splay-fluvial channels evolved into wetland mires that accumulated peat. Eventually this system transformed into an alluvial plain drained by meandering fluvial channels that evolved from the anastomosed fluvial channels (Flores, 2003). The progression from anastomosed to meandering streams may reflect a change from high to low alluvial-plain gradient as influenced by an increase of accommodation space through basin subsidence or eustatic sea-level rise.

Ocean Point Bluff

Description

The stratigraphic cross section of the Prince Creek Formation in the Ocean Point Bluff (fig. 18) appears to represent an older interval than that exposed in bluffs from the mouth of the Anaktuvuk River to VABM Kavik Bluff. The cross section shows lenticular sandstone beds interbedded with carbonaceous mudstone, siltstone, and silty sandstone beds. The lenticular, fining-upward sandstone beds are erosional based, are as much as 50 ft thick, and have lateral extents of less than 1 mi. The sandstone beds exhibit multiple erosional surfaces marked by rip-up mudstone lag deposits. The sandstone beds are interbedded with, and grade laterally into, rooted carbonaceous mudstone, siltstone, and silty sandstone. In the southern part of the cross section, the carbonaceous mudstone is overlain by fossil hadrosaur bones. These dinosaur bones are common throughout the interval.

The erosional-based lenticular sandstone beds are laterally en echelon, with the thickest part of the beds overlying the fine-grained, carbonaceous-mudstone-bearing interval. In addition, the sandstone beds wedge out and interfinger laterally with the rooted fine-grained rocks and carbonaceous mudstone; the latter are interbedded with tabular, rooted, and rippled silty sandstone beds. Both sandstone beds commonly contain tuffaceous lenses.

Interpretations

The Prince Creek Formation at Ocean Point (fig. 18) mainly represents an alluvial belt consisting of extensive deposits of slightly meandering fluvial channels partly underlain and flanked to the south (top left in fig. 18) by overbank-flood plain finer grained deposits and coaly carbonaceous mudstone (fig. 31). Lenticular sandstone beds exhibiting multiple scours and broad, lateral extents indicate deposition in the shifting, migrating subchannels of a moderately wandering, low-sinuosity fluvial channel system. The en echelon arrangement of the lenticular sandstone beds indicates abrupt abandonment of these fluvial channels after infilling.

The presence of coaly carbonaceous mudstones interbedded with rooted, fine-grained strata indicates active inundation of the flood plain by flood sediments, which promotes mixing of mud with peat mires. The common occurrence of the tabular, rooted, and rippled silty sandstones reflects crevasse splay deposition on the flood plains. The hadrosaur bones probably represent either in situ accumulation

Figure 31. Photograph of fining-upward sandstone (trough crossbedded to rippled upward) underlain by interbedded siltstone, mudstone, and coaly carbonaceous mudstone of the Prince Creek Formation at Ocean Point Bluff. For scale, the sandstone is 40 ft thick.

of remains of the animals drowned on the flood-ravaged, sediment-laden flood plains or represent carcasses transported onto or redistributed on the flood plains during floods.

Previous Stratigraphic Sections, Correlations, and Interpretations of the Ocean Point Area

Phillips (1988, 1989) measured and described 25 stratigraphic sections of the Prince Creek and Schrader Bluff Formations along the bend of the Colville River near Ocean Point. Our study area and the stratigraphic interval of the Prince Creek Formation corresponded to those of Phillips (1988, 1989; his measured sections 7 through 14) (fig. 18). In the eastern part of the study area, Phillips (1989) described overbank flood plain deposits of interbedded rooted, coarsening-upward mudstone, siltstone, and crevasse splay sandstone similar to those we describe in our measured sections and interpret as flood plain-crevasse splay deposits. In addition, Phillips described organic-rich siltstone interbedded with tephra; these overbank flood plain deposits are similar to the carbonaceous mudstone and tuffaceous siltstone we describe in our measured sections.

In the western part of the study area, Phillips (1989, p. 102) described “sand-filled channels,” which he interpreted as major fluvial distributaries that meandered across a coastal plain. He described the sandstones as being fine to medium grained, containing large- to small-scale trough and tabular crossbeds, and having erosional bases marked by mud rip-up clasts, carbonized woody fragments, plant debris, and rare dinosaur bone fragments. These sandstones are similar to what we described as lenticular fluvial sandstones deposited in a low-sinuosity channel system.

Two bone beds containing hadrosaurian remains (Clemens and Allison, 1985; Brouwers and others, 1987; Davies, 1987; Nelms, 1989) associated with organic-rich siltstone beds were described by Phillips (1988, 1989; his measured sections 6, 7, and 9—a lower bone bed in sections 6 and 7 and an upper bone bed in section 9). These disarticulated and vertically size-graded bones were interpreted by Phillips (1989) as having accumulated in the flood plain and later being reworked and redeposited by overbank flooding. Hadrosaurian bones in the fluvial distributary sandstones were interpreted as basal lag deposits of the distributary fluvial channels (Phillips, 1989).

Summary of Fluvial System Deposits Between Shivugak and Ocean Point Bluff

The continuous exposures between Shivugak and Ocean Point Bluff along the Colville River exhibit, in ascending order, (1) deposits of barrier shoreface-delta front system in the Schrader Bluff Formation and (2) braided, high-sinuosity meandering, anastomosed, and low-sinuosity meandering fluvial systems in the Prince Creek Formation (fig. 32). These sequences represent late Campanian to late Maastrichtian depositional systems that were affected by base level changes as influenced by tectonism, basin subsidence, and sea-level fluctuations.

The barrier shoreface-delta front deposits—consisting of vertically stacked coarsening-upward parasequences of the Schrader Bluff Formation in the Shivugak and Uluksrak Bluffs—represent progradational sequences that were affected by shoaling and deepening cycles caused by minor fluctuations of sea level (fig. 32). The erosional contact at the top of the uppermost coarsening-upward sequence, however, suggests a major drop of base level (relative sea level) that permitted a semiregional, subaerial unconformity to develop at the contact between the Schrader Bluff and Prince Creek Formations. This drop of relative sea level may have been followed by a relative sea-level rise that accommodated coal deposition directly on top of the unconformity above the coarsening-upward barrier shoreface sequence of the Schrader Bluff.

Accommodation space created by the sea-level rise was maintained with additional accumulation of some coal beds in the lowermost Prince Creek Formation at Shivugak and Uluksrak Bluffs (fig. 32). Ensuing deposition of conglomeratic sandstones across the deeply incised surface (MCU of Decker [2007]) that overlies these coal beds reflects infilling of incised paleovalleys by braided streams. The erosion probably resulted from base level change caused by a second fall of relative sea level. Sediment infilling by braided streams (high-gradient sheet flow) may indicate combined tectonic uplift (high sediment supply) and sea-level rise (accommodation).

Fluvial deposits in the lower to upper parts of Prince Creek Formation exposed between Uluksrak Bluff, the mouth of Anaktuvuk River, and VABM Kavik exhibit a change in architecture from deposition in braided streams to deposition in anastomosed or meandering streams, reflecting a change from moderate- to low-gradient drainages (from fixed to mobile channel belts) (fig. 32). Both the moderate-gradient anastomosing and low-gradient meandering stream systems may have developed in a subsiding upper to lower coastal plain. Anastomosed streams representing vertical aggradation developed on the coastal plain during an episode of high accommodation (rapid subsidence or eustatic highstand). The meandering streams that represent mainly lateral aggradation formed during an episode with less accommodation, which was possibly due to slowed subsidence of the coastal plain. The meandering pattern of the fluvial channels associated with interdistributary deposits (Phillips, 1989) near Ocean Point reflects a laterally aggrading fluvial system in a lower coastal plain environment during early Maastrichtian time. Continued aggradation and northeastward progradation may have brought more proximal fluvial facies (for example, middle or upper coastal plain) to the Ocean Point area as Prince Creek Formation deposition extended into later Maastrichtian time, but palynomorph data indicate that strata of that age are not preserved there.

Numerous occurrences and widespread distribution of thin to thick coal beds in the Prince Creek Formation coincide with the fluvial deposits formed by the anastomosed and meandering streams formed in a subsiding basin (fig. 32). In similar situations in Upper Cretaceous coal-bearing units in the Western Interior of the United States, occurrence of thick coal beds is attributed largely to the increased amount and rate of regional subsidence of Rocky Mountain foreland basins (Flores and Cross, 1991). Ultimately, the key factor for the accumulation and preservation of thick, widespread coal deposits is surplus accommodation space (Flores and Cross, 1991), whether it is due to basin subsidence or sea-level rise. Studies have shown that almost all coals formed at the top of, and landward of, shoreface facies within progradational events that constitute the transgressive-regressive sequences (Sears and others, 1941; Weimer, 1960; Beaumont and others, 1971; Fassett and Hinds, 1971; Ryer, 1984, Flores and Cross, 1991); however, the thickest, most extensive, and greatest volume of coals are in locations where the shoreface facies of successive progradational events are vertically stacked (Ryer, 1984; Flores and Cross, 1991).

Thus, the Schrader Bluff and Prince Creek Formations, interpreted by Mull and others (2003) as a large-scale prograding couplet of shallow marine to marginal marine and coastal plain facies, probably contain significant internal depositional cycles that reflect minor fluctuations of relative sea level and tectonically varying sediment supply during deposition of these rocks between Shivugak Bluff and Ocean Point. These geologic controls on the base level of the coastal plain impacted the architecture of fluvial channel deposits, coal beds, and associated nonmarine facies of the Prince Creek Formation.

Applications to Oil and Gas Fields in the Central North Slope

The outcrops along the Colville River Bluffs were correlated to hydrocarbon reservoirs in the Prudhoe Bay area northeast of the National Petroleum Reserve in Alaska (fig. 33). Decker (2007) presents a stratigraphic cross section of a Brookian sequence and relates Brookian horizons between the Umiat and Milne Point fields. This cross section (see figs. 33 and 34) utilized our descriptions of the Shivugak Bluff outcrops and cores from the Sentinel Hill Core Test 1

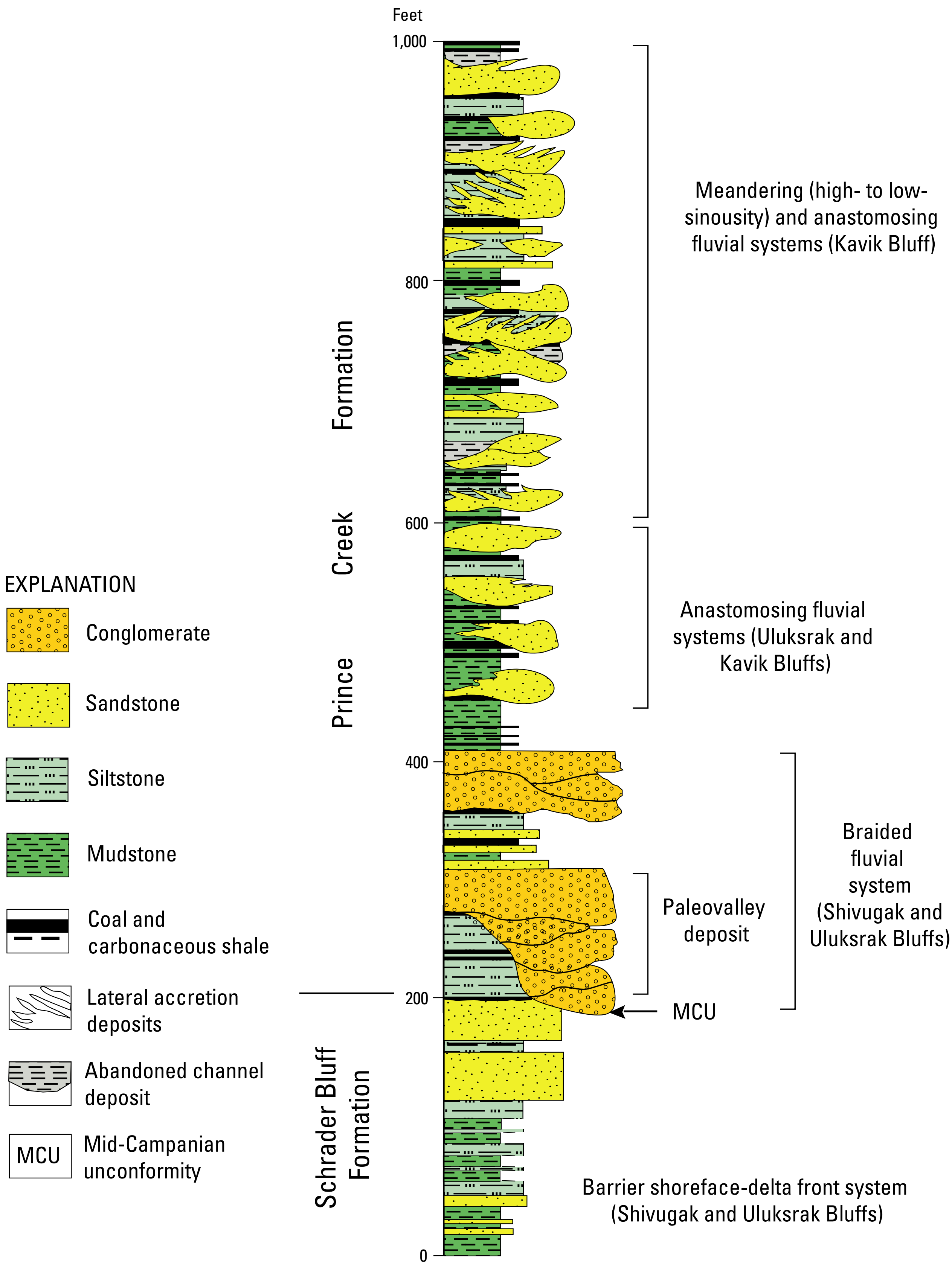

Figure 32. Composite stratigraphic section showing variations in fluvial architecture of the Prince Creek Formation overlying coarsening-upward barrier shoreface-delta front system of the Schrader Bluff Formation. Mid-Campanian unconformity adopted from Decker (2007).

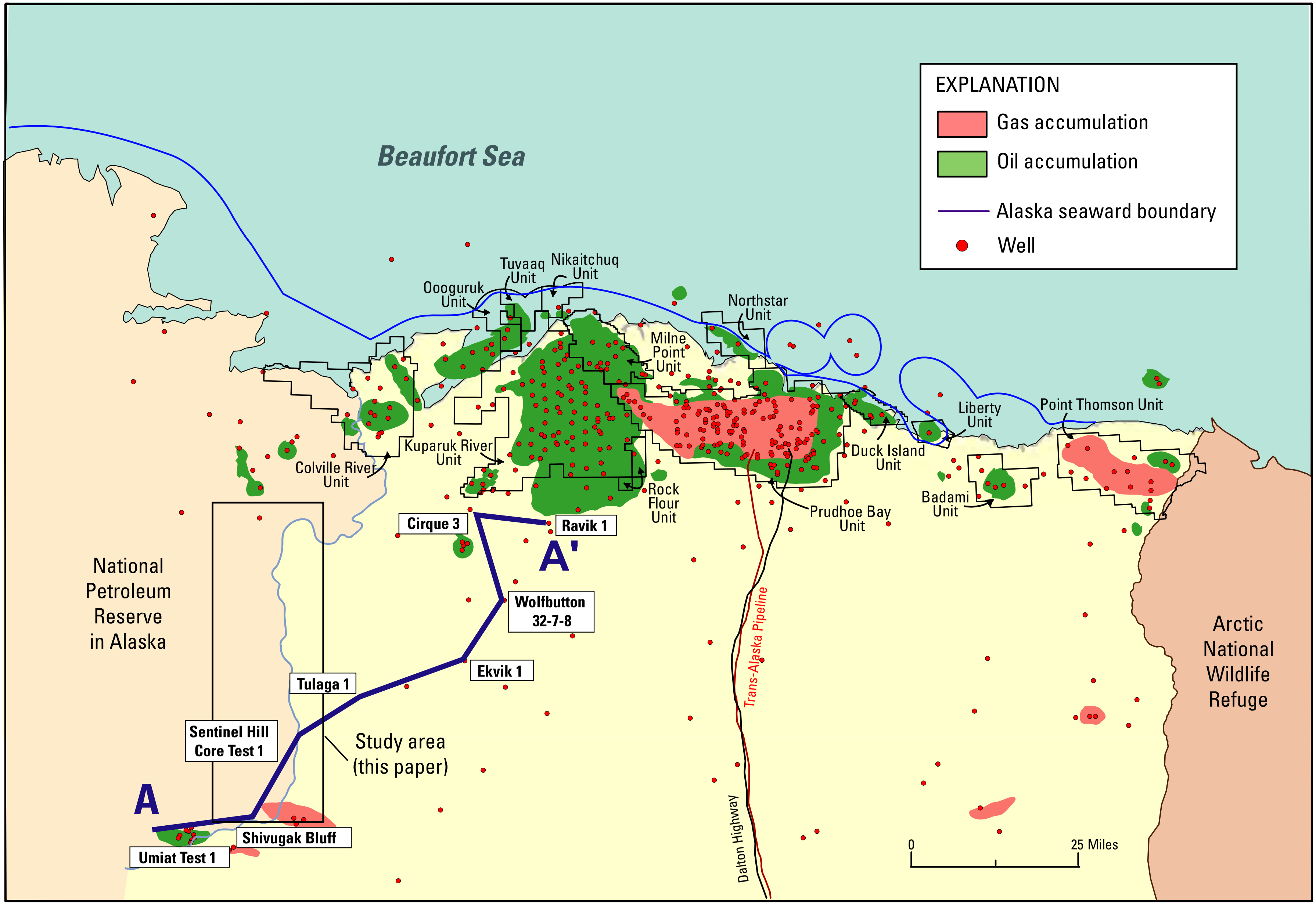

Figure 33. Map showing location of the stratigraphic cross section of the Brookian sequence (A–A') shown in figure 34. Modified from a map drawn by Decker (2007) for the area between Umiat field and oil and gas accumulations in the central North Slope. Location of our study area along the Colville River Bluffs is also shown.

well, as well as the results of palynological studies by Flores and others (2007). The palynological ages range from early Campanian through early Maastrichtian, but they are mostly late Campanian.

The palynology data from the Sentinel Core Test 1 well, combined with the mudlog data, indicate that the shallow or upper part of the section in the ARCO Tulaga 1 well immediately north of the Sentinel Hill Core Test 1 is mostly nonmarine Prince Creek Formation (fig. 34). Applying the new stratigraphic nomenclature of Mull and others (2003), the age ranges given in this paper, and data from Flores and others (2007), Decker (2007) (1) correlates some strata formerly identified as Sagavanirktok Formation (including the informally named “Ugnu sandstones”; see northernmost part of fig. 34) as the youngest part of the Prince Creek Formation and (2) suggests that the contact of the Prince Creek and Sagavanirktok Formations as redefined in outcrops by Mull and others (2003) cannot be placed with confidence in the subsurface of the cross section shown in figure 34.

The palynostratigraphy and correlations of the Shivugak Bluff outcrops and Sentinel Hill Core Test 1 significantly impact the Cretaceous stratigraphic sequence correlations shown in figure 34. The palynostratigraphy of the Prince Creek and Schrader Bluff Formations in the Shivugak Bluff outcrops and Sentinel Hill Core Test 1 indicates that these rock units are probably older than any of the producing Schrader and Ugnu intervals in the West Sak, Milne Point, Ugnu, and Orion-Polaris fields (Decker, 2007). Decker (2007; oral commun., 2006) ascribes the younger of the sequence boundaries at the Shivugak Bluff as correlative with the mid-Campanian unconformity (MCU) surface interpreted in seismic sections and wells as representing a submarine erosion and mass-wasting surface that extends deep into the depositional basin in the west-central North Slope. The same erosional surface is evident in seismic data in the vicinity of the Chevron Malguk 1 well (Houseknecht, 2003; Houseknecht and Schenk, 2005).

The informally recognized MCU extends from Shivugak Bluff at the base of the Prince Creek Formation through the Sentinel Hill Core Test 1 at the base of the upper Prince Creek Formation (Flores and others, 2007) and in the ARCO Tulaga 1 well (fig. 34). Further basinward, the MCU is at the base of the middle Schrader Bluff Formation from the BP Kuparuk Uplands Ekvik 1 well to the ConocoPhillips Alaska Ravik State 1. The MCU is interpreted to have removed outer shelf and deepwater strata of the lower Schrader Bluff and Seabee Formations. Correlations by Decker (2007) based on the MCU and younger flooding surfaces (fig. 34) indicate a strong probability that the Prince Creek and Schrader Bluff interval exposed along the Colville River Bluffs is largely time equivalent to the middle part of the Schrader Bluff Formation, which contains the Tabasco reservoir, and thus is older than the major viscous oil reservoir sandstones of the upper Schrader Bluff Formation.

Conclusions

Stratigraphic and sedimentologic studies of the Upper Cretaceous rocks along the Colville River Bluffs show a transition in depositional environments from a barrier shoreface system in the Schrader Bluff Formation to braided, high-sinuosity meandering, anastomosed, and low-sinuosity meandering fluvial systems in the Prince Creek Formation. The Prince Creek fluvial deposits, which are late Campanian to late Maastrichtian in age, were affected by base level changes that were influenced by tectonism, basin subsidence, and sea-level fluctuations.

The barrier shoreface deposits consisting of vertically stacked, coarsening-upward parasequences of the Schrader Bluff Formation in the Shivugak and Uluksrak Bluffs and in the west-central North Slope represent progradational sequences that were affected by shoaling and deepening cycles caused by fluctuations of sea level. This vertical stack of parasequence deposits may have served to stabilize accumulation of voluminous coal deposits in the Prince Creek Formation that is exposed in the Colville River Bluffs. The erosional contact at the top of the uppermost coarsening-upward sequence, however, indicates a significant drop of base level (relative sea level) that permitted a semiregional, subaerial unconformity to develop at the contact between the Schrader Bluff and Prince Creek Formations. This drop of relative sea level may have been followed by a relative sea-level rise to accommodate coal deposition directly on top of the unconformity above the Schrader Bluff coarsening-upward, barrier shoreface-delta front sequence. This rise was followed by a second drop of relative sea level, with formation of incised valley topography and an equivalent surface of a major marine erosion or mass wasting, which can be traced from the Colville River Bluffs basinward to the subsurface in the west-central North Slope.

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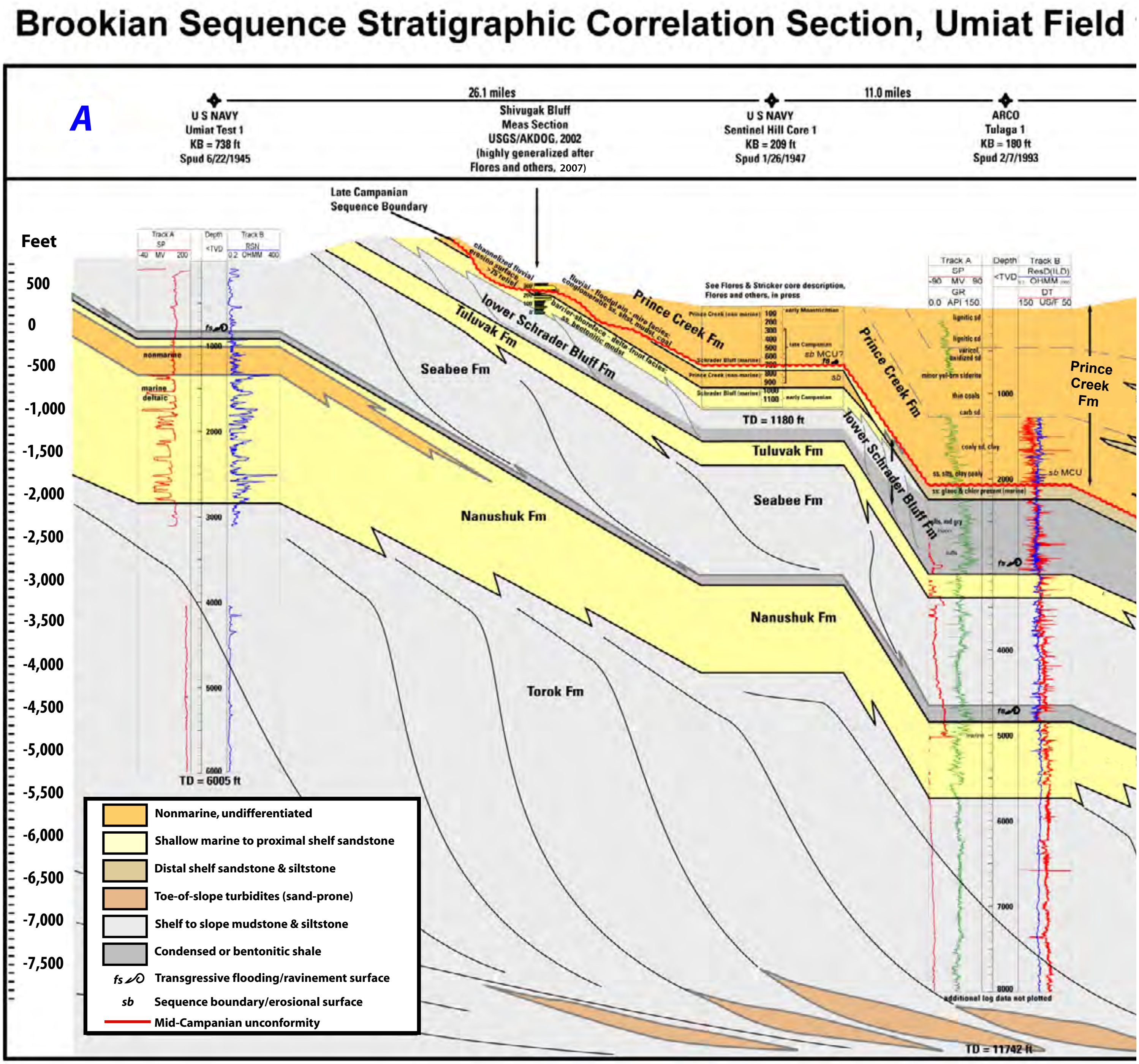
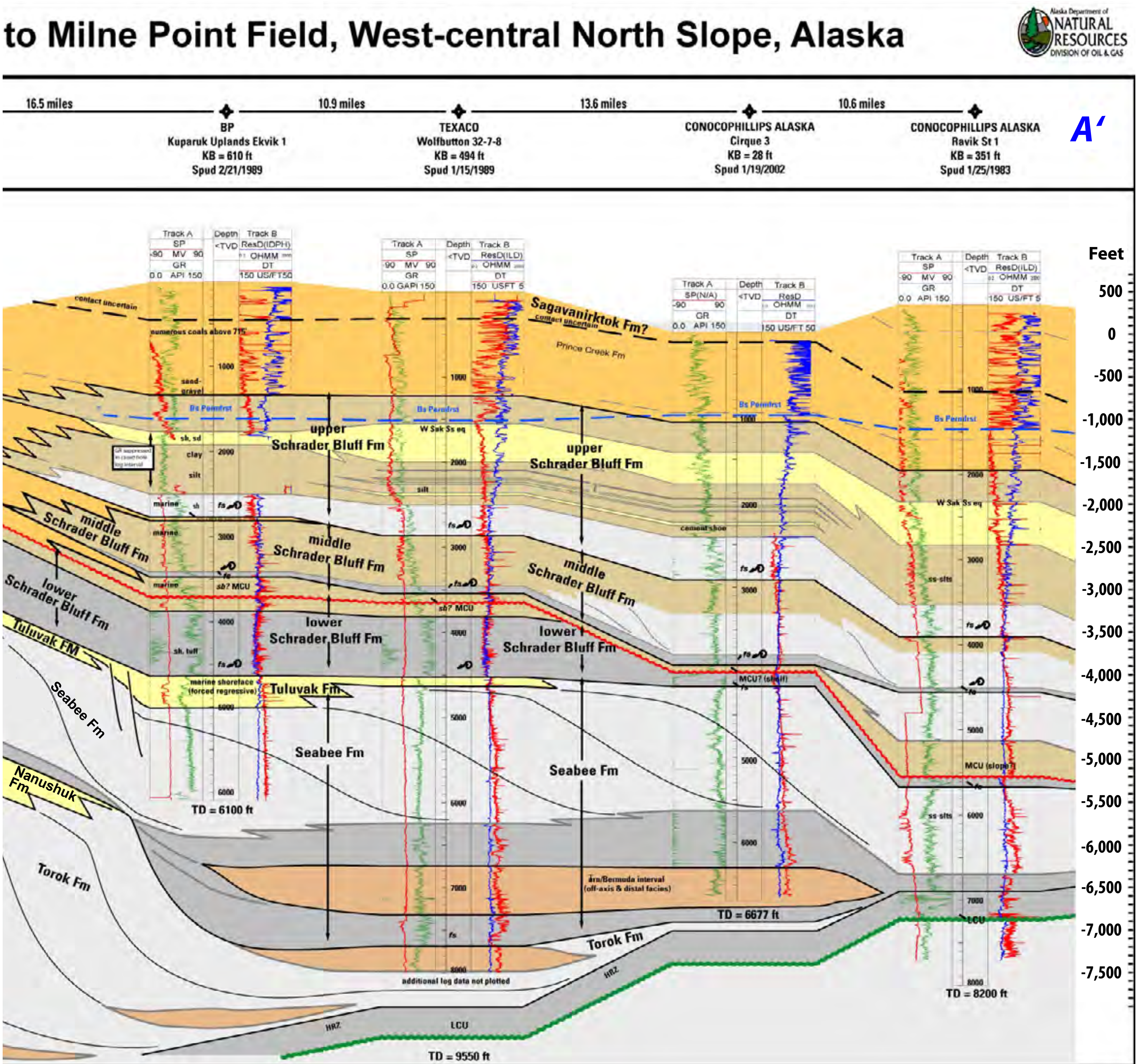


Figure 34. Stratigraphic cross section of the Brookian sequence from U.S. Navy Umiat 1 well to ConocoPhillips Ravik 1 well in the west-central North Slope, Alaska. See figure 32 for line of section. Modified from Decker (2007). Fm, Formation; LCU, Lower Cretaceous unconformity; MCU, mid-Campanian unconformity; HRZ, highly radioactive zone.


to Milne Point Field, West-central North Slope, Alaska
Alaska Department of NATURAL RESOURCES DIVISION OF OIL & GAS
16.5 miles
10.9 miles
13.6 miles
10.6 miles
BP
Kuparuk Uplands Ekvik 1
KB = 610 ft
Spud 2/21/1989
TEXACO
Wolfbutton 32-7-8
KB = 494 ft
Spud 1/15/1989
CONOCOPHILLIPS ALASKA
Cirque 3
KB = 28 ft
Spud 1/19/2002
CONOCOPHILLIPS ALASKA
Ravik St 1
KB = 351 ft
Spud 1/25/1983
A′
Feet
Sagavanirktok Fm?
Prince Creek Fm
upper Schrader Bluff Fm
middle Schrader Bluff Fm
lower Schrader Bluff Fm
Tuluvak Fm
Seabee Fm
Nanushuk Fm
Torok Fm
TD = 6100 ft
TD = 6677 ft
TD = 8200 ft
TD = 9550 ft
additional log data not plotted
LCU
HRZ
MCU (slope?)
W Sak Ss eq
Bs Permfrst
contact uncertain

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