MEASURED SECTIONS AND PRELIMINARY INTERPRETATIONS OF THE NANUSHUK FORMATION EXPOSED ALONG THE COLVILLE RIVER NEAR THE CONFLUENCES WITH THE AWUNA AND KILLIK RIVERS

by
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INTRODUCTION

On the south-central North Slope (fig. 1), the Torok and Nanushuk Formations (revised nomenclature of Mull and others, 2003; fig. 2) constitute a mid-Cretaceous clastic wedge that locally exceeds 5,000 m in thickness (Bird and Andrews, 1979). Deep-water shales and sandstones of the upper Torok Formation, deposited in basinal, slope, and outer-shelf settings, grade up-section and landward (toward the southwest) to shelf, shorezone (shoreface and delta-front), and nonmarine strata of the Nanushuk Formation.

The Alaska Division of Geological & Geophysical Surveys (DGGS) has led a multiyear, outcrop-based investigation of the sequence stratigraphy and reservoir potential of these units, focusing particularly on the better exposed Nanushuk Formation. This work resulted in numerous detailed measured sections throughout the central and east-central Brooks Range foothills (fig. 1) and greatly improves our understanding of this depositional system (LePain and others, 2008).

During the 2004 and 2005 field seasons, reconnaissance evaluations of Nanushuk exposures were undertaken along the Colville River, near the southern boundary of the National Petroleum Reserve–Alaska (fig. 1). The focus of the effort was to collect preliminary facies observations and assess potential candidates for future detailed measured sections. In 2006, twelve days were spent at three main exposures, resulting in several detailed measured sections addressed in this report.

Sheet D-1 illustrates the location of the three principal outcrops discussed here and includes a preliminary interpretation of a composite seismic line placing the surface outcrops in stratigraphic context within the Nanushuk–Torok depositional system. Within the limits of our ability to tie these outcrops to the regional grid of public seismic data (Miller and others, 2000), we interpret all three exposures as grossly time-equivalent, marking the lower to middle portion of the Nanushuk Formation in this area (see cyan horizon, Sheet D-1). However, the east- and northeast-prograding Torok–Nanushuk depositional system is highly time transgressive, and regional interpretation of this seismic horizon suggests it corresponds roughly to the early part of the latter third of Nanushuk depositional time.

MAIN OBSERVATIONS AND INTERPRETATIONS

Western Horseshoe Bend

Sheet D-2 summarizes a well exposed Nanushuk section just north of the Tuktu Escarpment on the north side of the Colville River, 14.5 km straight-line distance to the southwest (53 km upstream river distance) of the confluence with the Awuna River. The low structural dip of this long exposure allowed for three separate sections to be measured, capturing the clearly visible lateral stratigraphic variations. The lower part of the section includes a thick (~3 m) coal seam that splits into two thinner seams separated by a sandstone unit interpreted as a crevasse channel fill. The coaly section is overlain by a prominent series of downlapping deltaic foresets, interpreted as a bayhead delta (see photos in Sheet D-2). This delta was possibly sourced by a channelized system analogous to the crevasse fill that locally cut across the lower delta plain mire and filled a semi-protected interdistributary bay. Further upsection, an upward-coarsening, upward-thickening sandstone unit with well developed hummocky cross-stratification suggests a transgressive deepening or lateral facies shift to fully marine lower or middle shoreface settings.

Eastern Horseshoe Bend

Sheet D-3 shows the longest section measured in this study (~450 m), exposed on the north side of the Colville River about 3 km straight-line distance to the northeast (11 km downstream river distance) of the western horseshoe

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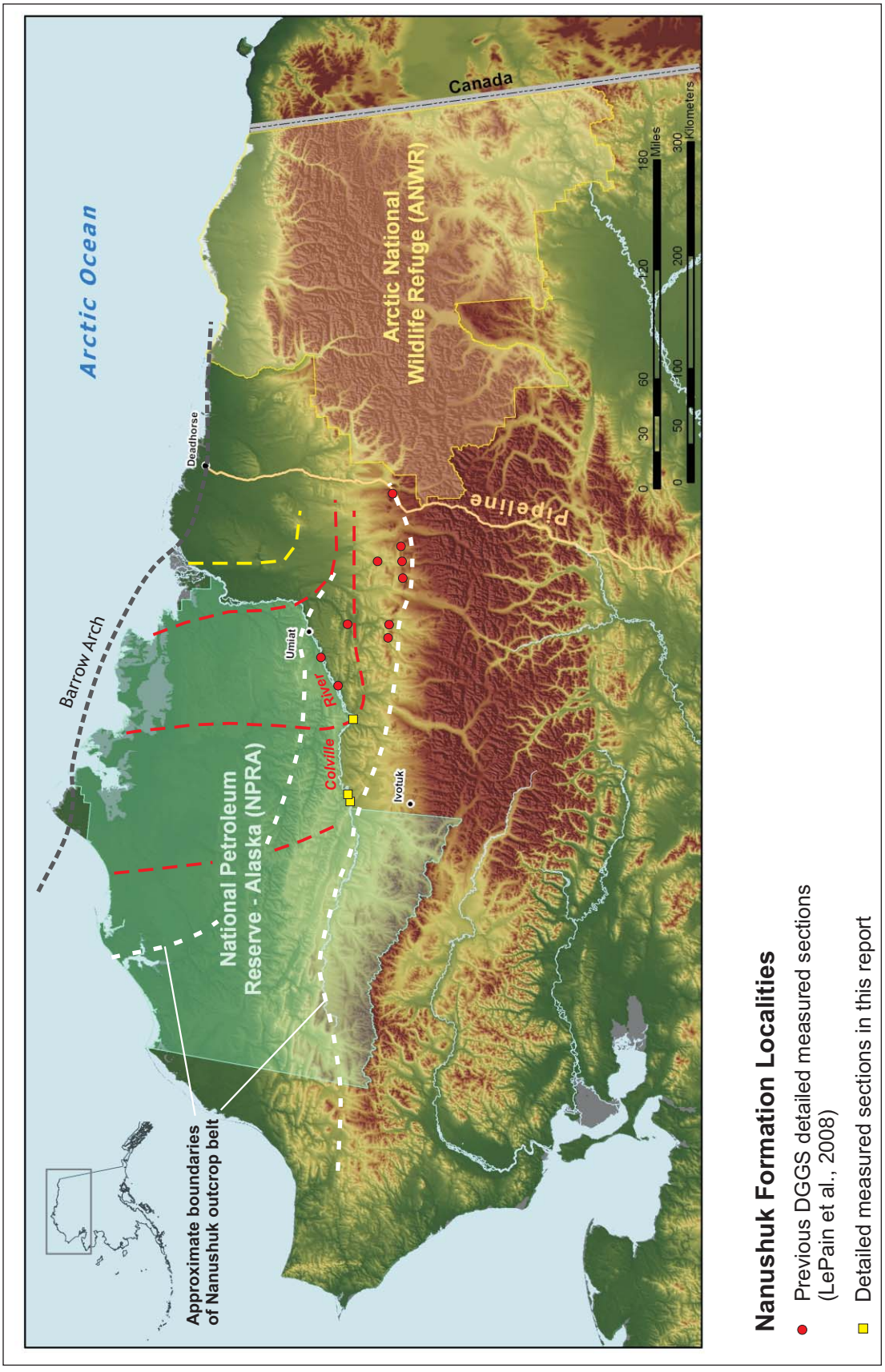

Figure 1. *Regional map of northern Alaska showing recent DGGS measured sections of the Nanushuk Formation. See Sheet D-1 for more detailed location map. Selected Nanushuk shelf edge positions through time are shown with dotted red lines; the terminal shelf edge is shown in yellow (from Houseknecht and Schenk, 2001).*

bend discussed above. The section dips moderately toward the north–northeast, and its base lies an estimated 1,000 m stratigraphically above the exposures at the western horseshoe bend. The outcrop exhibits repetitive parasequence scale cyclicity and interpreted facies associations ranging from coastal plain–bayfill to shoreface–delta front to shelf settings below fair-weather wave base. Appendix D-1 contains additional observations excerpted from field notes, too numerous to include on Sheet D-3, regarding grain size, sedimentary structures, trace fossils, hydrocarbon staining, sample specifics, and other details tied to specific stratigraphic positions within this measured section.

A possible growth fault was interpreted in the western portion of the long exposure; bed tracing suggests the feature would project into the upper portion of the measured section transect. A notable stratal geometry exhibited in this long outcrop is the proximal (westward) pinchout of shorezone sand bodies, which may have important implications for forming stratigraphically trapped Nanushuk reservoirs. We speculate that this pinchout may relate to transgressive ravinement at high-order flooding surfaces, and/or to lateral differences in sand accommodation driven by greater compaction of progressively-finer-grained, more distal sediments.

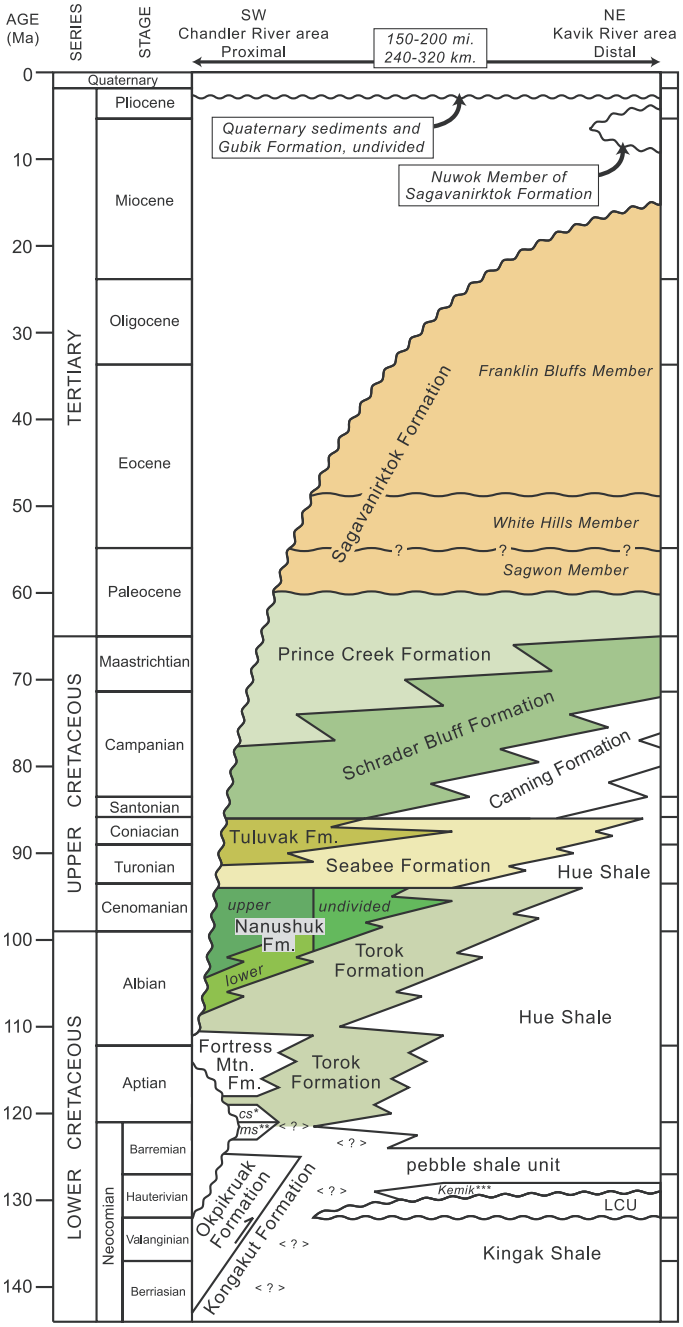

Figure 2. *Chronostratigraphic column showing revised Cretaceous and Tertiary stratigraphic nomenclature of Mull and others (2003). cs* = cobblestone sandstone (informal unit) of Fortress Mountain Formation; ms** = manganiferous shale unit (informal).*

Killik Bend

Sheet D-4 summarizes a ~160 m section of Nanushuk Formation exposed along the Colville River near the confluence with the Killik River, well downstream and approximately 41 miles due east of the eastern horseshoe bend section described above. The top of the section is in the hinge of a conspicuous, relatively tight syncline at the southeast end of the outcrop. Similar to the eastern horseshoe bend, this exposure includes parasequences recording high-frequency oscillation between coastal plain/nonmarine and delta front/shoreface facies. Thin coals and carbonaceous mudstones, locally featuring pedogenic structures, are repetitively associated with marine facies as indicated by pelecypods, starfish, and marine trace fossils. The ichnofossil assemblage is diverse in places, including Rosselia, Rhizocorallium, Gyrochorte, Planolites, and possible Thalassinoides. Appendix D-2 contains detailed observations excerpted from field notes, too numerous to include on Sheet D-4, tied to specific stratigraphic positions within this measured section.

SUMMARY

The purpose of this short report is to release our basic measured section data from along the Colville River and offer preliminary facies interpretations. All three localities exhibit lateral and vertical facies complexity typical of deltaic systems (fig. 3). Preliminary conclusions suggest a different depositional style than coeval deltaic systems documented in our earlier work to the east (LePain and others, in press). The new sections along the Colville River record considerably more high-frequency, parasequence-scale fluctuations ranging from outer shoreface to alluvial facies. This vertical variability in facies tracts is encouraging as it allows for more consistent tracking of shoreline migration and hence sequence stratigraphic interpretations. Based on facies analysis, these exposures appear to reflect the development of river-dominated deltas. This contrasts with the more pervasive wave influence observed to the east (for example, LePain and others, 2008). In general, our facies observations and interpretations agree with prior USGS work (for example, Huffman and others, 1981). In particular, our preliminary conclusions regarding regional differences in deltaic style were suggested in earlier stratigraphic studies comparing the Nanushuk Formation in the western and central foothills (for example, Ahlbrandt, 1979; Huffman and others, 1988).

FUTURE WORK

The Nanushuk Formation is locally prospective as a reservoir objective throughout much of the western North Slope and in the central and western Brooks Range foothills. In light of this importance, DGGS anticipates continuing field-based sedimentologic and stratigraphic studies of the Nanushuk Formation. In particular, we hope to extend westward the level of detailed observations captured in the east-central foothills (LePain and others, in press). In collaboration with the Division of Oil & Gas, additional future work will seek to extend our outcrop analysis into the subsurface, integrating additional publicly available two-dimensional (2-D) seismic data and nearby well control (for example, East Kurupa 1, West Kurupa 1, Knifeblade 1/1A, Sheet D-1).

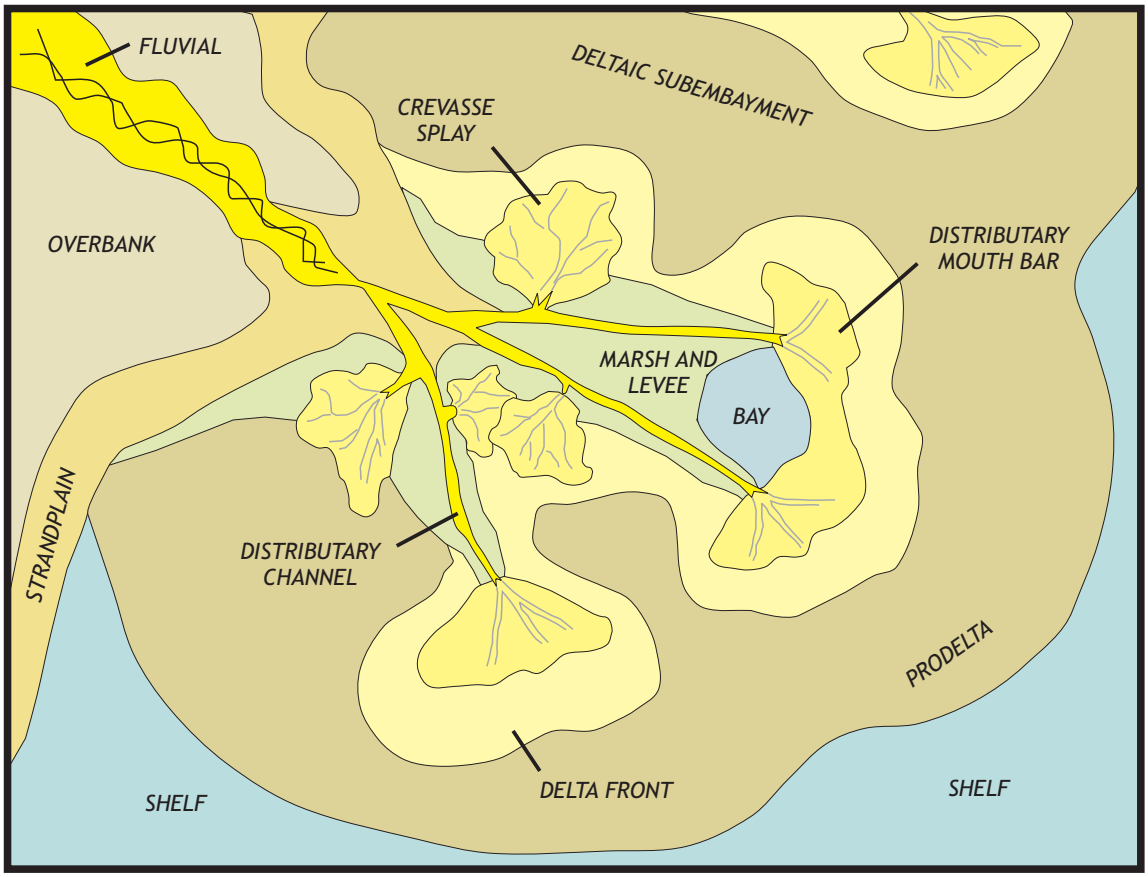

Figure 3. *Schematic diagram of a deltaic depositional system and common facies observed in the Nanushuk Formation (modified from Huffman and others, 1985).*

ACKNOWLEDGMENTS

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Text for reports with appendices:

This appendix is included in this PDF document for the reader's convenience.

In the full publication, the appendices and sheets are placed at the conclusion of all of the text. The separation of the appendices and sheets from their chapter in the full publication determines the page numbers; thus, you will find that the page numbers for this smaller piece of the larger document are not sequential.

APPENDIX D-1

MISCELLANEOUS OBSERVATIONS FROM P.L. DECKER FIELD NOTES EASTERN HORSESHOE MEASURED SECTION 06DL003 COLVILLE RIVER BETWEEN ETIVLUK AND AWUNA RIVER CONFLUENCES

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Miscellaneous observations from P.L. Decker field notes
Eastern Horseshoe measured section 06DL003
Colville River between Etivluk and Awuna River confluences

June 20–23, 2006

0 m	Latitude–longitude (NAD27 datum) = 68.97803°N, 155.65768°W Base of section just below base of lowest resistant sandstone–conglomerate bench at downstream end of horseshoe bend *Bedding: 109, 35NE*
0–4.5 m	Sandstone: lower to upper fine-grained, light brown weathering, light green-gray fresh, lithic, nondescript medium bedded, no trace fossils, no hydrocarbon odor or stain *Samples: 06DL003-2-1 → POROSITY and PERMEABILITY* *06DL003-2-2 → THIN SECTION*
4.5 m	Possible hummocky/swaley cross-stratification
5.5–13 m	Interbedded lower to upper fine-grained sandstone and granule–pebble conglomerate, planar laminated to small-scale hummocky/swaley cross stratification? Probable sigmoidal lateral accretion surfaces at 8–10 m *Sample: 06DL003-10 → LITHOLOGY (interbedded)*
13–15 m	Sandstone: medium-grained, abundant *Macaronichnus*, trough cross-bedded and pebble stringers *Samples: 06DL003-15-1 → POROSITY and PERMEABILITY* *06DL003-15-2 → THIN SECTION*
16.1 m	Top of interbedded sandstone–conglomerate package
16.1–17.6 m	Sandstone: medium-grained, plane-parallel laminated, capped by small-scale trough cross-bedded sandstone
17.6–19.6 m	Coal, grading to carbonaceous mudstone at top *Sample: 06DL003-18 → COAL (sulfur)*
19.6–20 m	Sandstone: medium-grained, finely laminated, carbonaceous
20–21.9 m	Sandstone: medium-grained, planar cross-laminated lower part, shallow trough cross-bedded upper part *Samples: 06DL003-21-1 → POROSITY and PERMEABILITY* *06DL003-21-2 → THIN SECTION*
21.9–24 m	Covered interval
24–25.4 m	Sideritized sandstone: fine-grained, rusty, ripple laminated to thin bedded
25.4–26 m	Sideritized mudstone: nodular, massive
26–~27 m	Sandstone: fine-grained, thin ripple laminated, *Arenicolites*?
28 m	Sandstone: fine-grained, climbing ripples

29.3 m	Coal, 3 cm thick
30–100 m	Covered interval, except for a few outcrops of sandstone, etc. Offset section back down to river level using sandstone/coal contact at 131 m
102 m	Shale: dark gray–yellow bloom, fissile *Samples: 06DL003-102-1 → RockEval/TOTAL ORGANIC CARBON* *06DL003-102-2 → MICROPALEONTOLOGY*
123–124 m	Growth-position tree to 20 cm diameter in sideritized sandstone. Main part preserved only 10 cm diameter
131 m	Base of sandstone/top of coal used to offset section from top of slope back down to river level
134 m	Top of sideritic marker bed involved in bidirectional thrusting; section involved is ~132–138 m
142 m	Coal, black, cleated, bituminous or sub-bituminous *Sample: 06DL003-142 → COAL (sulfur)*
143m	Carbonaceous shale *Sample: 06DL003-143 → MICROPALEONTOLOGY*
152 m	Slickensides parallel bedding; plunge 10 to 038
154–156 m	Sideritic siltstone concretions: buff weathering, medium gray fresh, up to 1 m x 5 m, irregular, elongate parallel bedding. Some appear at first glance to erosionally truncate underlying mudstone/sandstone, but actually are replacive; visual effect is enhanced by differential compaction. Appear to be early formed features
182.3 m	Carbonaceous shale: subfissile, soft *Sample: 06DL003-182.3 → MICROPALEONTOLOGY*
182.5 m	Tonstein ash in coal. Bentonitic tuff: very light tan, sticky, vitric, speckled with hand lens, irregular thickness 5–10 cm interbed in coal and carbonaceous shale interval. Occurs in mostly covered slope between 176 and 185 m, but is absent a short distance laterally where only 176–178.8 m interval is obscured by cover *Sample: 06DL003-182.5 → GEOCHRONOLOGY*
183 m	Coal, black, cleated, bituminous or sub-bituminous *Sample: 06DL003-183 → COAL (sulfur)*
186 m	Slickensides on calc-filled shear joint or minor fault; plunge 56 to 010 (indicates backthrusting toward 190)
202–206.5 m	Covered interval
206.5–208 m	Sandstone: lower very-fine-grained, brown, thin-bedded to ripple-laminated, heavily rooted? (is this one of the zones we later realized were burrowed by *Diplocraterion*, etc?) overlain by similar lithology with abundant ball and pillow structure suggestive of rapid emplacement of overlying marine sandstone
208–209.7 m	Sandstone: fine-grained, hummocky/swaley cross-stratification, sharp based, massive–amalgamated with clay pebbles in lower two-thirds, thin-bedded upper third, ripple-laminated top; very light hydrocarbon odor, no geochemical sample

214–216 m	Sandstone: upper very-fine-grained, quartz + lithic grains, very well sorted, hummocky/swaley cross-stratification; very similar to sandstone between 208 and 209.7 m. Thins laterally to <1 m within 40 m downstream and within 10 m upstream. At 215.2 m, sampled sandstone with good light oil odor and stain *Samples: 06DL003-215-1 → POROSITY and PERMEABILITY* *06DL003-215-2 → THIN SECTION* *06DL003-215-3 → RockEval/TOTAL ORGANIC CARBON, BIOMARKERS* Erosive scour on upstream side cuts out ~ 60 cm of underlying med brown lower very-fine-grained, rippled sandstone with abundant small (1–2 cm wide, 1–5 cm tall) *Diplocraterion* traces Top of underlying, partly truncated medium brown lower very fine-grained bed at 215 m has both straight-crested wave ripples and ladderback ripples. Straight ripple crests: azimuth 143 (not restored)
216 m	*Bedding: 105, 30NE*
228.3–227.8 m	Excellent tempestites: hummocky cross-stratified and thin-ripple-laminated lower very-fine-grained sandstone–siltstone
239.5–240 m	Sandstone: upper fine-grained, thin rippled beds, abundant mud-lined burrow shafts not quite vertical, mostly truncated *Rosselia*, at least one small *Rosselia* with mud bulb; diminutive *Diplocraterion* traces at top of bed (first thought to be roots, but reinterpreted all as burrows)
254 m	Sandstone: upper very-fine-grained, quartz + lithics, very well sorted, swaley cross-stratified to low-angle, long-wavelength hummocky cross-stratification, fair light oil odor *Sample: 06DL003-254 → RockEval/TOTAL ORGANIC CARBON, BIOMARKERS*
255 m	Sandstone: fine-grained, low-amplitude hummocky/swaley cross-stratification, rippled top; straight crested ripples: azimuths 131 and 132 on 30°-dipping bed Float: ammonite (sampled), fair preservation, asymmetric, 4 cm diameter; bivalve impression
257–257.3 m	Sandstone: planar to wavy laminated, carbonaceous (grain size?)
257.3 m	Sandstone: lower very-fine-grained (different bedding than immediately underlying unit)
257.8–258 m	Contact with 20 cm erosional relief; overlying unit is lower to upper fine-grained sandstone; underlying unit is lower very-fine-grained sandstone down to 257.3 m
258 m	Sandstone: lower to upper fine-grained, faintly planar laminated to massive-amalgamated, mud chips and chert pebbles at scoured base *Samples: 06DL003-258-1 → POROSITY and PERMEABILITY* *06DL003-258-2 → THIN SECTION*
259.2 m	Sandstone: upper very-fine- to upper medium-grained, rare chert pebbles and plant fragments with red-brown oxidized halos, poorly sorted, occasional *Schaubcylindrichnus frey* (formerly known as *Terebellina*), 2 x 5 mm; interpreted as transgressive unit
264–266 m	Intensely developed, large ball and pillow structure
267 m	*Planolites* traces, meniscate, dense at rippled top of sandstone with large, abundant ball and pillow structure in upper 35 cm
272 m	*Diplocraterion* traces, 1 cm diameter U-tube, 7 cm across trace, good spreiten

272.5 m	*Bergaueria* trace
272.5–273 m	Sideritized sandstone–mudstone: mottled light yellow, bioturbation index ~ 0.5
273–274 m	Grits with medium–coarse sandstone, chert–quartz pebbles, large wood fragments, burrowed, mottled transgressive surface of erosion and transgressive sandstone cap *Samples: 06DL003-274-1 → POROSITYandPERMEABILITY* *06DL003-274-2 → THIN SECTION*
280 m	Mudstone: medium gray weathering, dark brown fresh, slightly silty, blocky–chippy, firm *Sample: 06DL003-280 → MICROPALEONTOLOGY*
305 m	Mudstone: medium brown–purplish-brown weathering, dark brown fresh, silty, blocky, firm *Sample: 06DL003-305 → MICROPALEONTOLOGY*
348.3–350.2 m	Sandstone: (lower of two prominent sandstone exposed near center of steep scree-covered slope) lower very-fine-grained, thin-bedded to laminated, extensively rippled, carbonaceous partings, abundant *Gyrochorte* (bilobate) horizontal grazing traces. *Bedding on top of sandstone: 119, 13NE*
350.2–356 m	Mudstone: dark gray-brown, firm, subfissile weathering, blocky fresh *Sample: 06DL003-352 → MICROPALEONTOLOGY*
356–382.5 m	Covered interval
383.5–386.7 m	Sandstone: (upper of two prominent sandstone exposed near center of steep scree-covered slope) lower very-fine-grained, thin-bedded to laminated, wave-rippled, common *Gyrochorte*; top of bed rippled, no transgressive grit, no shale exposed above *Bedding at 385 m: 085, 8N*
421.2 m	Base of upper cliffs; bottom of lower of two uppermost benches; lower parasequence is upward-coarsening and -thickening shoreface succession. Cone-in-cone in 3 cm sideritic mudstone
439–440 m	Coarse-grained uppermost portion of shoreface succession; sporadically deposited in zone 1–2 m thick; possible transgressive grit cap or foreshore facies. Top of parasequence at 440 m
440–442 m	Shale: medium–dark gray, yellow bloom
442–443.7 m	Covered interval
443.7–449 m	Apparently abrupt, but unexposed basal contact overlain by sandstone–granule–pebble conglomerate beds capping measured section
449 m	Top of section at top of cliffs

APPENDIX D-2

MISCELLANEOUS OBSERVATIONS FROM P.L. DECKER FIELD NOTES KILLIK BEND MEASURED SECTION 06DL007 COLVILLE RIVER

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Miscellaneous observations from P.L. Decker field notes
Killik Bend measured section 06DL007
Colville River

June 26–29, 2006

0 m	Latitude–longitude (NAD27 datum) = 68.99067°N, 153.98618°W Base of section at lowest exposed bed just above river level at north end of exposure; light greenish-gray sandstone parasequence
0–2 m	*Rosselia*, textbook 3-dimensional exposures of robust forms, concentric mud bulbs up to 6.5 cm diameter x 17 cm long
15 m	Sandstone: medium–dark olive green, lower medium-grained, pervasive *Macaronichnus*, high visible porosity, friable *Samples: 06DL007-15-1 → POROSITY and PERMEABILITY* *06DL007-15-2 → THIN SECTION*
16.5 m	Top of lower, upward-coarsening parasequence; *Macaronichnus* in upper trough-cross-bedded, amalgamated sandstone, overlain here by covered, coal, and carbonaceous mudstone interval
27 m	Discrete surface capping silty sandstone, overlain by lower medium-grained sandstone with and symmetric to slightly asymmetric ripples
27.5–27.6 m	Omission surface, pronounced grain size jump, moderate erosional relief
28.5 m	Sandstone: medium grayish-brown weathering, lower medium-grained, mottled, tight *Samples: 06DL007-28.5-1 → POROSITY and PERMEABILITY* *06DL007-28.5-2 → THIN SECTION*
28.7–29 m	*Rosselia* colony in upper fine- to upper medium-grained sandstone; multistory occupation in beds 2–10 cm thick
31.3 m	Sandstone: light greenish-gray weathering, lower fine-grained, fair visible porosity, scattered *Teredo*-bored fossil wood *Samples: 06DL007-31.3-1 → POROSITY and PERMEABILITY* *06DL007-31.3-1 → THIN SECTION*
35–36 m	Sandstone event beds 5–10 cm thick with sharp basal surfaces grading upward to slightly darker, carbonaceous, rippled sandstone preserved in upper parts, indicative of cyclical flows with only minor basal erosion; common branch- to log-sized *Teredo*-bored wood clasts; interval capped by 15–20-cm-thick sideritic horizon with lenticular concretions upwards of 5 m long; unit interpreted as distributary mouth bar sandstone
36–39.8 m	Sandstone: light brown weathering, lower fine-grained, massive, low-angle, and trough-cross-bedded; channelized basal surface incises (~1–2 m?) into underlying sandstone event beds, abundant *Teredo*-bored wood clasts and some bedding surfaces completely matted with wood fragments mostly 2–4 cm diameter; abundant *Skolithos* shafts 0.5 cm wide, 30–40 cm long at 37.5–38 m. Unit interpreted as distributary channel sandstone *Samples: 06DL007-37-1 → POROSITY and PERMEABILITY* *06DL007-37-2 → THIN SECTION*
40.1 m	Top of 15–20 cm siderite marker bed offset at low-angle thrust

	Thrust: 010, 18E Calcite-filled extension joints: ~010, 70W
40.5–40.9 m	*Skolithos* in ~1 m bed with low-angle trough cross-beds; uppermost bed of probable distributary channel facies; bed not evident in footwall of small thrust described at 40.1 m, probably absent due to offlapping/laterally accreting geometry of distributary channel beds
42–42.3 m	Sandstone: medium gray, rusty brown mottled, lower very-fine-grained, argillaceous, intensely burrowed (rusty mottling), *Thalassinoides* 1–2 cm diameter defined by locally branched, irregularly cylindrical, curved, subvert to inclined and subhorizontal burrows
43.2 m	Claystone: light green-gray, slightly silty, sparsely carbonaceous, moderately firm, crumbly *Sample: 06DL007-43.2 → MICROPALEONTOLOGY*
45.8–46 m	Small, forked and non-forked rootlets in upper 20 cm of irregular bedded sandstone with ~10 cm beds; base scoured into thin, irregular bedded sandstone with carbonaceous ripple-laminated caps and partings
48.7 m	Shale: dark gray, fissile, ~20–30 cm thick *Sample 06DL007-48.7 → MICROPALEONTOLOGY*
49.6–51.7 m	Sandstone: Red-brown-orange-tan mottled weathering, upper very-fine- to upper fine-grained, irregular bedded and irregular erosional profile, beds 3–10 cm, heavily bioturbated with abundant but mostly partial *Rhizocorallium* and *Paleophycos* up to 1.5 cm diameter creating lenticular splitting character, carbonaceous debris on bioturbated laminae *Sample: 06DL007-50 → THIN SECTION*
51–51.7 m	Sandstone: medium–light gray, upper very-fine-grained, laminated to 1 cm thin beds, *Rhizocorallium*, some *Paleophycos*
51.7–54 m	Sandstone: medium gray, lower fine-grained, rooted with roots to 10 cm tall, beds 2–10 cm thick, upward thickening; mottled, light brown, very thin clay drapes at bed partings, pedogenically and/or bioturbationally churned *Sample: 06DL007-53.5 → THIN SECTION*
59.7–60 m	Sideritized horizon used as marker bed for thrust fault with ~4.5 m offset; overlies shale interval (thickness not recorded here)
60–~62 m	Sandstone: light brown-red weathering, light gray fresh, lower fine-grained, plane-parallel laminated *Sample: 06DL007-60.5 → THIN SECTION*
62.9–68.8 m	Upward-coarsening and -thickening package: medium–dark gray, green-gray, and olive-streaked shale in lower part, becoming silty to very-fine-grained current-rippled sandstone in upper 1 m, capped by lower to upper fine-grained bioturbated sandstone with good *Rhizocorallium* in uppermost 5 cm; this interval is lowest of three consecutive, very similar upward-coarsening and -thickening intervals up to 72.4 m, capped finally by carbonaceous shale and coal; cyclical successions interpreted as probable bay-fills with mud grading upward into crevasse splay siltstone–sandstone
68.8–71.2 m	Upward-coarsening and -thickening mudstone–siltstone–sandstone package: second of three consecutive probable bay-fill cycles; upper sandstone is light green-gray, lower very-fine- to upper fine-grained, lithic–micaceous, asymmetric ripple-laminated, sparsely rooted; cap is slightly coarser, mottled, *Rhizocorallium* up to 5 x 12 cm with 1 cm diameter tubes *Sample: 06DL007-70.5 → THIN SECTION (non-reservoir lower very-fine-grained sandstone)*

72.4–72.8 m	Carbonaceous shale and coal: ~40 cm total thickness; base used as marker for measuring through small reverse fault Fault: 071, 61SE, slickensides rake 70SW, displacement ~3–4 m
72.8 m	Top of coaly interval, used as marker bed for small thrust *Fault: 095, 55S, slickensides not readily measurable*
79.5 m	Pebbly sandstone surface at top of mottled, irregular bedded, rusty weathering sandstone overlying coaly interval; surface interpreted as transgressive surface of erosion
79.5–80.2 m	Sandstone: fine–medium-grained, heavily bioturbated, rippled, micaceous mud drapes, fairly straight-crested ripples with ~8 cm wavelength; "string of pearls" trace ~2 cm diameter and other crawling traces 1–2 cm diameter at 79.7 m
80.2 m	Sharp basal surface of swaley/hummocky cross-stratified sandstone; bed bottom has sole marks with slight preferred orientation, but inaccessible for measurement *Bedding: 065, 50SE*
90.5 m	Large *Inoceramus* impression on bedding (photos); *Gyrochorte*, robust, 1 cm diameter
95 m	Sandstone: lower medium-grained, plant debris, trough-cross-bedded; interpreted as wave-influenced delta front (upper shoreface equivalent) *Samples: 06DL007-95-1 → POROSITY and PERMEABILITY* *06DL007-95-2 → THIN SECTION*
97.5 m	Top of trough-cross-bedded upper member of wave-influenced delta front unit
97.5–102.5 m	Upward-coarsening and -thickening mudstone–siltstone–sandstone package; change to mostly lower very-fine-grained sandstone occurs at ~101.5 m. Upper sandy meter contains abundant marked rounded depressions–possible dinosaur track impressions
104.3 m	Siltstone: occasional *Diplocraterion* 3 cm wide, 4 cm tall
104.5 m	Robust sideritized traces on bedding planes in siltstone; subhorizontal, curved, U-shaped to rounded acute angle bends, non-spreitenated; also diminutive *Diplocraterion* 1–2 cm tall, *Skolithos* to 8 cm long
104.8 m	Excellent 3-dimensional expression of depression features—possible dinosaur track impression on bed bottom: rounded sandstone-filled depression 40 cm diameter, ~ 15 cm deep
111–111.3 m	Excellent roots to 1–2 cm wide, 30 cm long, forks at multiple depths
112.2–115.8 m	Sandstone: upper fine- to lower medium-grained, light red-gray weathering, trough cross-bedded, large scale, beds massive- to thick-bedded, local mudstone rip-up conglomerate with coaly debris in basal part up to 60 cm thick; possible fluvial channel; same unit as sandstone on skyline to north of syncline *Samples: 06DL007-113-1 → POROSITY and PERMEABILITY* *06DL007-113-2 → THIN SECTION*
120 m	Coal *Sample: 06DL007-140 → COAL (sulfur)*
138.1–138.2 m	Buff, flat-topped, convex-based, sandstone-filled cast in medium–dark gray, thin-bedded sandy siltstone and silty sandstone; probable gutter cast or possible dinosaur track filled with contrasting sediment

140.6–142.5 m	Shale: dark rusty red, heavily oxidized, fissile; overlain by light olive–light brown planar laminated siltstone
~150 m (float)	Fossil bivalve, articulated, well preserved cast ~3 cm wide, 4 cm long, 2 cm thick with both beaks, etc. (in float below steeply-dipping beds near synclinal axis; unlikely to have been derived from much higher or lower in section)
152 m	Carbonaceous shale: dark olive-gray *Sample: 06DL007-152 → MICROPALEONTOLOGY*
~153.3–153.6 m	Coal, ~30 cm thick *Samples: 06DL007-153.4 → VITRINITE* *06DL007-153.5 → COAL (sulfur)*
154 m	Silty mudstone: medium olive-gray *Sample: 06DL007-154 → MICROPALEONTOLOGY*
156–160.5 m	Sandstone: lower very-fine- to lower fine-grained, mottled rusty and light gray weathering, nonplanar thin-bedded 1–10 cm, carbonaceous; gradational base overlying mottled light brown–light gray, thin laminated carbonaceous sandy siltstone and interbedded silty sandstone
160.5–161.5 m	Covered interval
161.5–162 m	Sideritic mudstone
162–163.5 m	Sandstone: lower to upper fine-grained
163.5–164 m	Carbonaceous mudstone, poorly exposed
164–166.5 m	Sandstone: upper fine- to lower medium-grained, light pinkish gray to light red-brown weathering, medium–thick bedded, trough-cross-bedded, granule–pebble sideritic mud clasts; highest bed exposed in syncline
166.5 m	Top of section Latitude–longitude (NAD27 datum) = 68.98625 °N, 153.97368 °W