FACIES ASSOCIATIONS, SAND BODY GEOMETRY, AND DEPOSITIONAL SYSTEMS IN LATE OLIGOCENE–PLIOCENE STRATA, SOUTHERN KENAI PENINSULA, COOK INLET, ALASKA: REPORT ON PROGRESS DURING THE 2006–07 FIELD SEASONS

by
David L. LePain[1], Marwan A. Wartes[1], Paul J. McCarthy[2], Richard Stanley[3], Laura J. Silliphant[4], Shaun Peterson[4], Diane P. Shellenbaum[4], Kenneth P. Helmold[4], Paul L. Decker[4], Jacob Mongrain[2], Robert J. Gillis[1]

INTRODUCTION

This preliminary report is a summary of progress made during the 2006–07 field seasons reconstructing depositional systems in Tertiary strata exposed in the Homer–Kachemak Bay area (fig. 1). This work is part of a Cook Inlet basin-wide effort to reconstruct depositional systems for use as a predictive tool in oil and gas exploration. The resulting framework will provide the context for evaluating sand body geometries, their internal heterogeneities, and compositional parameters controlling reservoir quality. The study area addressed in this report extends from Clam Gulch in the north to Coal Cove in the south. Tertiary strata in this area are only mildly deformed and provide a relatively clear view of depositional systems and sand body geometries along the eastern basin edge and their change from basin edge to more basin axial positions.

Quaternary deposits blanket Tertiary strata throughout most of the Kenai lowland and exposures are limited to coastal bluffs and isolated river cuts (Magoon and others, 1976; Bradley and others, 1999; fig. 2). Oligocene to Pliocene age strata in the study area consist of the Tyonek, Beluga, and Sterling Formations (fig. 3). Rocks assigned to the Tyonek Formation are exposed in aerially restricted coastal exposures between Barabara Point (northeast of Seldovia Bay) and Coal Cove (north side of entrance to Port Graham, fig. 2). The Beluga Formation is present in bluff exposures northwest of Homer and along the northwest shore of Kachemak Bay. The Sterling Formation crops out along the northwest shore of Kachemak Bay, north of Kachemak Bay along the Fox River, along Deep Creek, and along the east shore of Cook Inlet.

Measured stratigraphic sections and stitched digital photos acquired by the Alaska Division of Geological & Geophysical Surveys and the Alaska Division of Oil & Gas during the 2006–07 field seasons form the dataset upon which the preliminary interpretations presented in this report are based. Selected measured stratigraphic sections are presented in page format in an appendix at the end of this chapter; locations of measured sections are summarized in Table A1. Outcrop spectral gamma data were acquired for most of these measured sections, but are not included here pending further analysis of their significance.

REGIONAL GEOLOGY

Cook Inlet basin is part of a northeast-trending collisional forearc basin that extends approximately from Shelikof Strait in the southwest to the Wrangell Mountains in the northeast (fig. 1). The basin is bounded on the west and north by granitic batholiths and volcanoes of the Aleutian volcanic arc and Alaska Range, respectively, and on the east and south by the Chugach and Kenai mountains, which represent the emergent portion of an enormous accretionary prism (Haeussler and others, 2000; Nokleberg and others, 1994). High-angle faults, including the Bruin Bay, Castle Mountain, and Capps Glacier faults modified the west and north sides of the forearc basin (fig. 1) and juxtapose different age Mesozoic and Cenozoic sedimentary formations against each other and against arc-intrusive bodies (for example, Barnes and Cobb, 1959; Magoon and others, 1976). The Border Ranges fault bounds the east side of the forearc basin (fig. 1) and juxtaposes Mesozoic sedimentary rocks of the Peninsular terrane against highly deformed and metamorphosed Mesozoic rocks of the accretionary prism, assigned to the Chugach terrane (for example, Magoon and others, 1976; Bradley and others, 1999).

[1]Alaska Division of Geological & Geophysical Surveys, 3354 College Road, Fairbanks, Alaska 99709-3707; dave.lepain@alaska.gov
[2]Department of Geology and Geophysics, P.O. Box 757320, University of Alaska Fairbanks, Fairbanks, Alaska 99775-7320
[3]U.S. Geological Survey, 345 Middlefield Road, MS 969, Menlo Park, California 94025
[4]Alaska Division of Oil & Gas, 550 West 7th Avenue, Suite 800, Anchorage, Alaska 99501

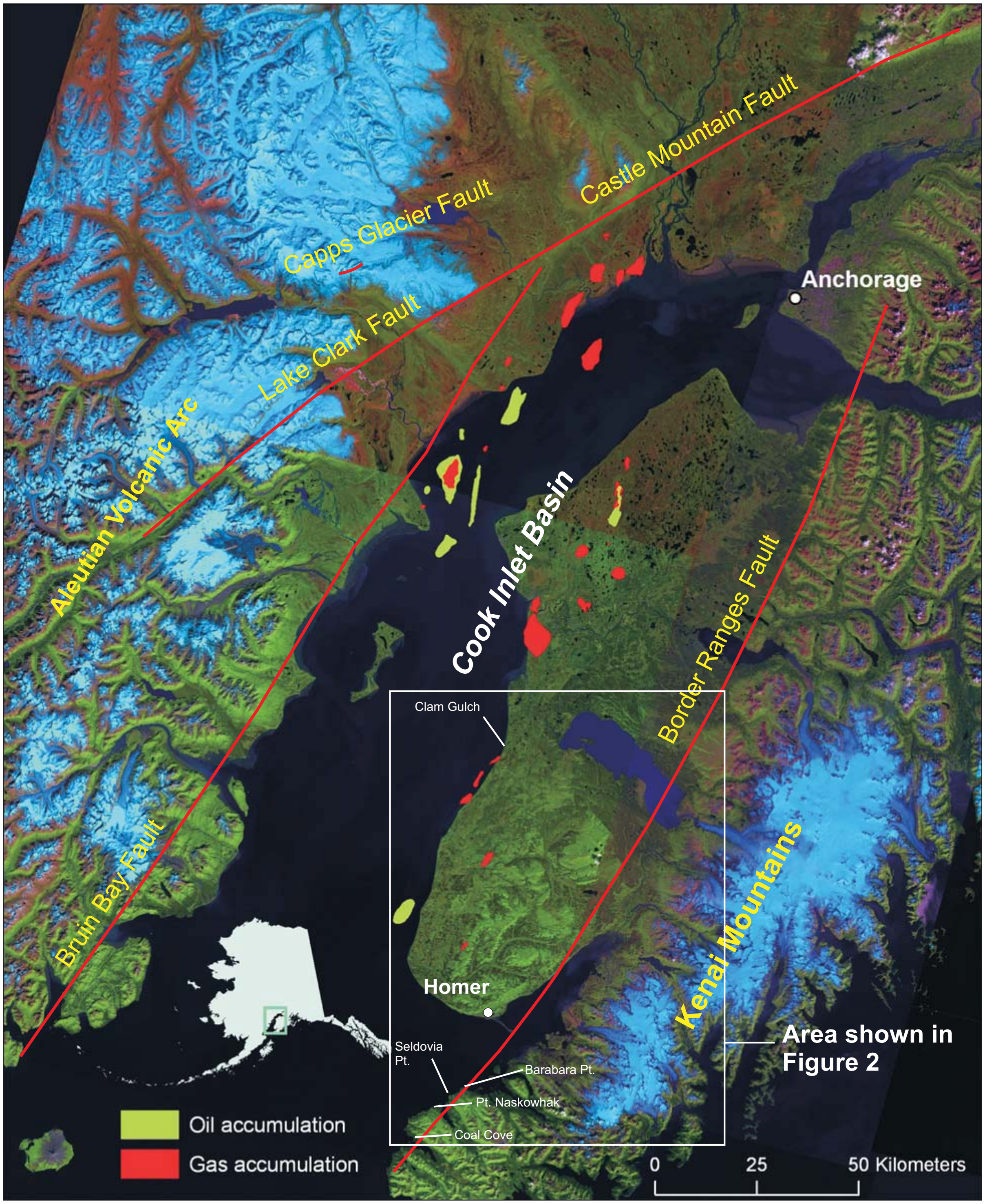


Figure 1. Landsat image showing Cook Inlet from just south of Augustine Island (lower left corner of image) to the southwestern corner of the Talkeetna Mountains (northeastern corner of image). Major faults that either bound the Tertiary basin and/or cut the Tertiary stratigraphy are shown in red with fault names in yellow. The white rectangle outlines the study area addressed in this report.

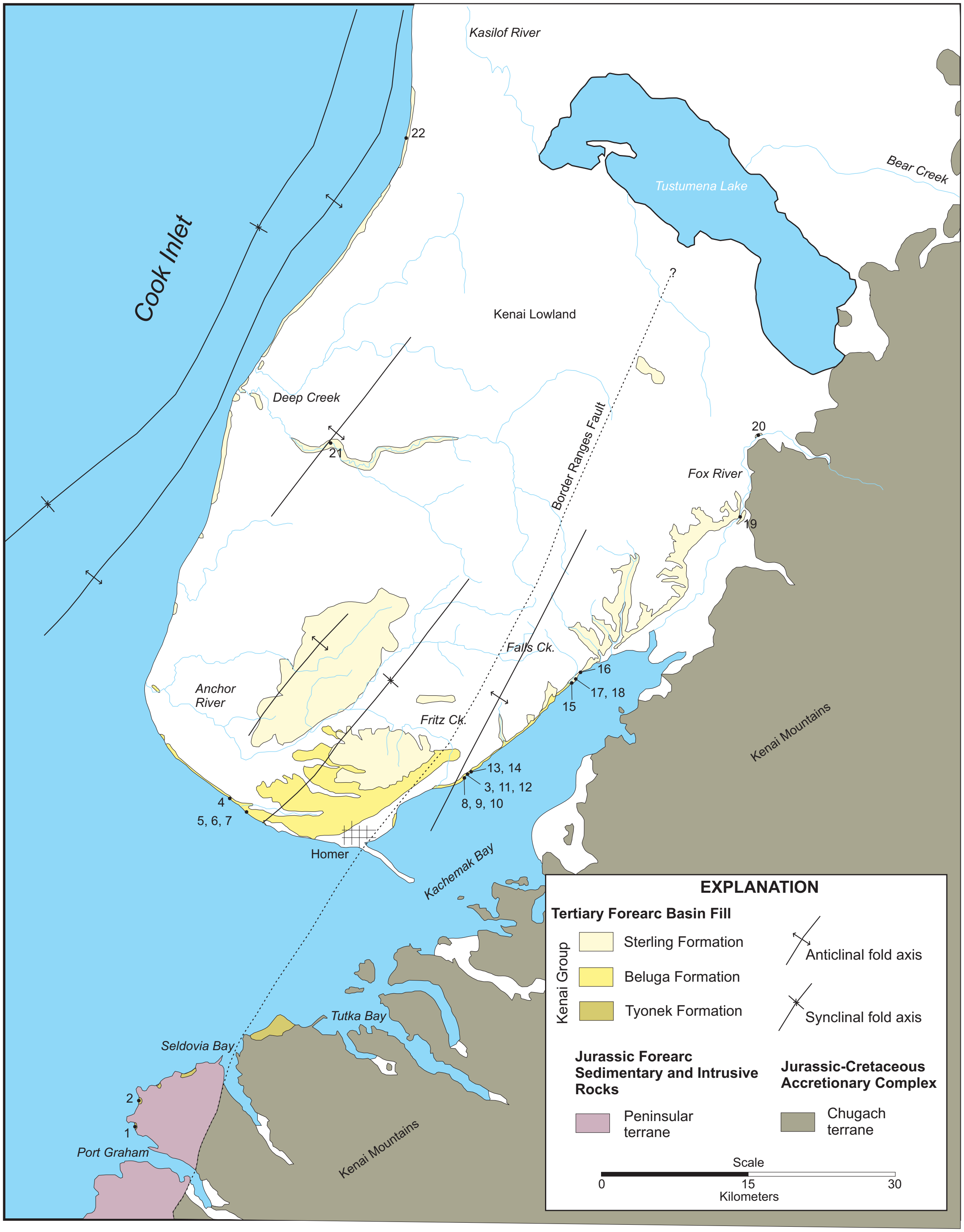


Figure 2. Map showing the generalized distribution of Tertiary formations in the study area and outcrop locations discussed in this report. The geology was taken from Magoon and others (1976).

Mesozoic strata of the Peninsular terrane represent the foundation upon which the Cenozoic forearc basin developed. The Peninsular terrane has been interpreted as part of a microcontinent that accreted to inboard terranes during Cretaceous time (Nokleberg and others, 1994; Plafker and others, 1989, 1994). The terrane consists of late Paleozoic through Mesozoic rocks having a regional composite thickness of nearly 12,200 m (Kirschner and Lyon, 1973). Mesozoic strata extend continuously at depth under Tertiary nonmarine deposits and are exposed along the upturned western and eastern margins of the forearc basin (Fisher and Magoon, 1978; Magoon and Egbert, 1986). Mildly deformed late Cenozoic nonmarine strata unconformably overlie Mesozoic strata and depositionally onlap Mesozoic strata along the eastern margin of the basin (Swenson, 2002). Tertiary nonmarine strata, which are up to 7,620 m thick in the axial region of the basin (Boss and others, 1976), consist of a complex assemblage of alluvial fan, axial fluvial, and alluvial floodbasin depositional systems (fig. 3; Swenson, 2002).

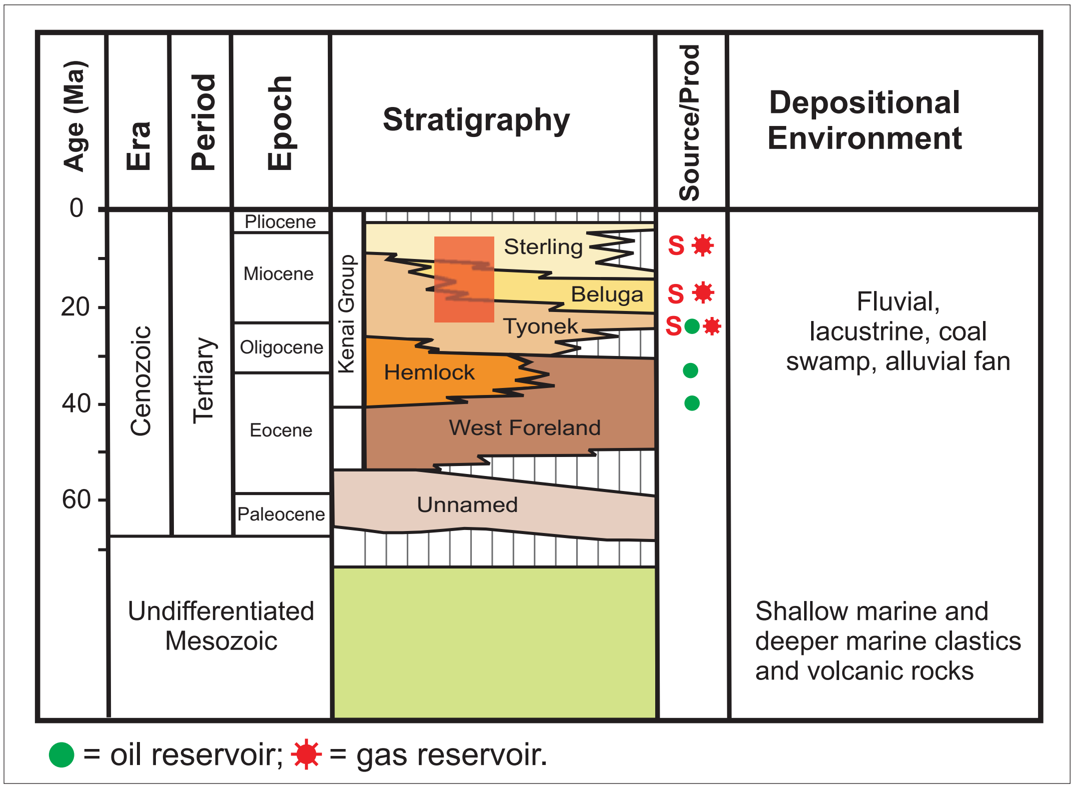


Figure 3. Simplified stratigraphic column showing Tertiary nonmarine formations in Cook Inlet basin. The vertical transparent red rectangle shows the stratigraphic focus of this report. Modified from Swenson (2002).

PREVIOUS WORK ON TERTIARY STRATA

Stratigraphy

Stratigraphic nomenclature applied to Tertiary strata in the Cook Inlet region has evolved since Dall and Harris (1892) first proposed the name Kenai Group for coal-bearing sediments exposed on the southern Kenai Peninsula. Dall (1898) subsequently extended the group to include similar strata from as far north as Norton Sound to as far south as British Columbia. Subsequent usage was more restrictive, including only the coal-bearing strata on the Kenai Peninsula (Calderwood and Fackler, 1972). Barnes and Cobb (1959) mapped and described coal-bearing strata in the Homer district and referred to these rocks as the Kenai Formation. Exploratory drilling for hydrocarbons in the 1950s and 1960s demonstrated that the thickness of Tertiary strata in the basin significantly exceeded the thickness of coal-bearing strata exposed on the Kenai Peninsula (Calderwood and Fackler, 1972). For this reason Calderwood and Fackler (1972) formally elevated the unit to group rank and defined five formations, each with subsurface type sections, as comprising the Kenai Group. From oldest to youngest these include the West Foreland Formation, Hemlock Conglomerate, Tyonek Formation, Beluga Formation, and Sterling Formation (fig. 3).

Subsequent work led Boss and others (1976) to restrict the Kenai Group to three formations (Tyonek, Beluga, and Sterling) on the basis of an interpreted unconformable relation between the West Foreland and overlying Tyonek Formation. These authors considered the Hemlock Conglomerate to be a member of the Tyonek Formation.

Calderwood and Fackler (1972) correlated two subsurface formations to surface exposures on the Kenai Peninsula. They correlated the subsurface Beluga Formation with the type locality for Wolfe's (1966) Homerian floral stage, and correlated the subsurface Sterling Formation with the type locality for Wolfe's Clamgulchian floral stage. Kirschner and Lyon (1973, fig. 11, p. 403) show isopach maps with generalized locations where these formations crop out at the surface. A geologic map compiled by Magoon and others (1976) showed the distribution of the Beluga and Sterling in outcrop, as well as aerially restricted exposures of Tertiary rocks along the coastline southwest of Homer, between Barabara Point and Coal Cove. These exposures include reference localities for Wolfe's (1966) Seldovian floral stage and were mapped as Tyonek by Magoon and others (1976).

Many geologists have investigated the stratigraphy and environmental significance of parts of the Tertiary succession in outcrop around the basin. Barnes and Cobb (1959) mapped Tertiary rocks on the Kenai Peninsula as part of an effort to evaluate the coal resources of the region. Wolfe (1966) and Wolfe and others (1966) defined three provincial floral stages based on plant megafossils recovered from Tertiary exposures on the southern Kenai Peninsula. The Seldovian stage was based on plant megafossils collected in the vicinity of Capps Glacier on the northwest side of the basin and Seldovia Point on the southeast side of the basin. The Seldovia Point flora was interpreted by Wolfe and Tanai (1980) as an early to middle Miocene warm temperate assemblage. Wolfe and others (1966) noted that the Seldovian flora could extend back in time to late Oligocene. The Homerian stage was based on plant fossils collected from exposures along the west shore of Kachemak Bay and immediately west of Homer and was interpreted as a cool–temperate assemblage of late Miocene age. The Clamgulchian stage was based on fossils collected from bluff exposures at Clam Gulch, on the east shore of Cook Inlet, that Wolfe and others (1966) interpreted as a cool temperate assemblage of probable Pliocene age. These workers provide no information on the depositional systems responsible for depositing the Tertiary successions they studied.

Reinink-Smith (1990, 1995) used K-Ar techniques to date tephra layers in Tertiary strata along the east shore of Cook Inlet (Sterling Formation) and along the west shore of Kachemak Bay (Beluga and Sterling Formations). Reinink-Smith concluded that the lower Beluga and lower Sterling Formations were deposited during periods of increased volcanic activity in the basin more than 10.5 m.y. and approximately 7.5 m.y. ago, respectively. Reinink-Smith's focus was to use tephra layers as correlation tools and her work did not address the depositional settings of the Beluga and Sterling Formations.

Dallegge and Layer (2004) used the $^{40}Ar^{39}Ar$ method to date 37 tephra beds in the Beluga and Sterling Formations in outcrop on the Kenai Peninsula and a single altered tephra sample from the Tyonek Formation in core from well 14CC in the Pioneer Unit in the Matanuska Valley. Their work demonstrates the existence of numerous high-angle faults in outcrop, some with significant displacements, which would otherwise be difficult to recognize due to poor exposures. The single date they obtained from the Tyonek Formation yielded a weighted mean age of 48.65 ± 2.31 Ma (early Eocene).

Depositional Systems and Provenance

Flores and others (2004) examined the Tyonek Formation between Barabara Point and Seldovia Point. They recognized that Tyonek strata at the southwestern end of this exposure represented the fill of an incised paleovalley. Bradley and others (1999) also recognized the paleovalley-filling nature of these deposits. Stricker and Flores (1996) suggested a tidal influence on strata above the paleovalley fill succession (east of Seldovia Point), but did not explain the basis for their interpretation. Flores and others (1994, 1997) examined the Tyonek Formation in exposures on the northwest side of the basin, along Chuit Creek and the Chuitna River. In that area they interpreted Tyonek sand bodies as the product of braided streams that were flanked by floodplains and mires. They suggested a tidal influence on floodplain mudstones in this area and subsequently recognized several tide-influenced facies in cores from the Diamond–Chuitna project area (a few miles east of Chuit Creek), including tidal sand flat, tidal marsh, and tidal channel deposits (Flores and others, 1997). Hite (1976) provided a regional interpretation for the Tyonek as the product of alluvial fans, fan deltas, and estuarine processes, but did not discuss the Tyonek in the Seldovia–Coal Cove area.

Hayes and others (1976) examined exposures of the Beluga and Sterling Formations on the Kenai Peninsula. They interpreted the Beluga as the product of alluvial fans and braided fluvial streams that flowed westward from the Kenai–Chugach mountains. They interpreted the Sterling as the product of moderately large meandering streams that flowed south to southeastward in the area of the Kenai Peninsula. These authors noted that the Beluga was composed mainly of metasedimentary rock fragments from the Kenai–Chugach mountains and that Sterling sandstones were composed of quartz, plagioclase, and volcanic rock fragments derived from the Aleutian–Alaska ranges to the north and west.

Boss and others (1976), in a paper describing the Middle Ground Shoal oil field, noted the time-transgressive nature of the Beluga and Sterling Formations, interpreted the Beluga as a "waste basket" stratigraphic unit, and interpreted the Sterling as the product of braided streams possibly similar to present-day streams in the area. These authors described the Tyonek as consisting of massive fluvial sandstones, floodplain shales, and thick coals, but did not provide details on fluvial style (for example, braided or meandering). Interestingly, they claimed to recognize tillites in the Beluga and Sterling Formations that they infer were deposited by glaciers originating in the Kenai Mountains (their fig. 5).

Rawlinson (1984) examined exposures of the Beluga and Sterling Formations along the west shore of Kachemak Bay. He interpreted the Beluga (referred to as Homerian stage beds in his paper) as the product of braided and meandering streams flanked by natural levee, floodplain, and flood-basin deposits. Beluga streams flowed westward and northwestward from the Chugach–Kenai mountains. He interpreted the Sterling (Clamgulchian in his paper) as the product of meandering streams that were flanked by overbank deposits similar to those recognized in the Beluga. Sterling rivers flowed down the regional paleoslope toward the west–northwest. Rawlinson (1984) confirmed the conclusion of Hayes and others (1976) that the abundance of low-rank metamorphic rock fragments in the Beluga and abundant volcanic grains in the Sterling reflected sources in the Kenai–Chugach mountains and Alaska–Aleutian Range, respectively.

A group of geoscientists working for ARCO in the 1980s and 1990s developed a biostratigraphic and depositional systems framework for Cook Inlet basin. Limited elements of this framework have been published (Swenson, 2002) and include alluvial fans along the western and eastern basin margins that grade basinward to an axial fluvial system. By integrating depositional systems information with detailed palynological analyses they were able to demonstrate the time-transgressive nature of Tertiary lithostratigraphic units (Swenson, 2002, his figures 5 and 6).

Flores and Stricker (1992) interpreted the upper part of the Beluga Formation and lower and middle parts of the Sterling Formation along the west shore of Kachemak Bay as the products of suspended-load anastomosed streams and meandering streams, respectively. They attributed coal deposition to raised mires; they also inferred that the thicker coals in the Beluga were the result of vertical accretion typical of the anastomosed system, whereas thinner coals in the Sterling reflect lateral migration of fluvial channels and resulting interruption of peat deposition. Flores and Stricker (1993) interpreted the Sterling Formation exposures at Clam Gulch as the products of braided streams. They suggested that channel style in the Sterling evolved up-section from bedload-dominated low-sinuosity forms to mixed- and suspended-load forms, but did not mention changes in inferred plan-form geometry.

FACIES ANALYSIS

Twenty-one facies are recognized in exposures of the Kenai Group in outcrop on the southern Kenai Peninsula. These are summarized in table 1 and will not be addressed in more detail in this report. The facies occur in nine facies associations (table 2). A brief description and interpretation of each association is presented below.

Facies Association 1 – Valley Margin Apron

DESCRIPTION

Facies association 1 consists largely of matrix-supported conglomerate (Gmm) with subordinate interbedded clast-supported conglomerates of facies Gcm (tables 1 and 2; fig. 4a). Clasts range from granule size to approximately 100 cm, are angular to sub-angular, equant shaped, and are supported by a maroon-colored, argillaceous, silty–sandy matrix (fig. 4b–d). This association is always in contact with underlying Mesozoic bedrock along steeply-dipping surfaces and extends up to 30 m away from this contact (fig. 4a). Clast compositions reflect derivation from nearby Mesozoic lithologies. At Point Naskowhak and Coal Cove clasts were derived from Jurassic volcanigenic rocks of the Talkeetna Formation (Peninsular terrane), whereas at Seldovia Point clasts were derived from sedimentary and volcanic rocks of the McHugh Complex (Chugach terrane).

INTERPRETATION

This association records deposition from cohesive debris flows on small alluvial fans located along steeply sloping margins of paleovalleys incised into underlying bedrock of the Peninsular and Chugach terranes. Angular and sub-angular clast shapes attest to limited transport.

Table 1. Cook Inlet Facies. Facies codes and interpretations significantly modifed from Miall (1996).

Lithofacies	Code	Description	Interpretation
Gravel–Conglomerate			
Matrix-supported conglomerate	Gmm	Very poorly sorted granule to cobble conglomerate, unstratified, clasts angular to sub-round derived from subjacent bedrock and supported by a clayey, silty, sandy matrix	Plastic to pseudoplastic debris flows and hyperconcentrated flows operating in areas of high relief, typically near basin margin
Clast-supported massive conglomerate	Gcm	Poor to moderately sorted, disorganized granule to boulder conglomerate, clasts sub-angular to rounded, bedding up to 3+ m, laterally continuous and discontinuous	Pseudoplastic debris flows and hyperconcentrated flows operating in areas of high relief near basin margin
Clast-supported crudely bedded conglomerate	Gch	Poor to moderately sorted, disorganized to moderately organized granule to boulder conglomerate, clasts sub-angular to well-rounded, crude horizontal bedding up to 1.5 m thick and laterally discontinuous, locally developed clast imbrication	Longitudinal barforms
Clast-supported planar cross-bedded conglomerate	Gcp	Poor to moderately sorted granule to cobble conglomerate, clasts sub-angular to well-rounded, planar-tangential foresets up to 2.5 m thick and laterally discontinuous over tens of meters	Moderate to large two-dimensional transverse bedforms and delta-like growths on downstream ends of composite bars
Clast-supported trough cross-bedded conglomerate	Gct	Poor to moderately sorted granule to cobble conglomerate, trough cross-bedded in sets up to 2.5 m thick; log and large plant fragments present locally	Moderate to large three-dimensional, sinuous-crested to linguoid bedforms
Conglomeratic lag	Gl	Granule and pebble lags up to 20 cm thick overlying scour surfaces at base of sand beds; equant to discoid-shaped extrabasinal clasts and discoid-shaped mudstone ripup clasts, locally consists of only mudstone rip-up clasts	Coarsest grain sizes transported along channel thalwegs; mark bypass surfaces
Sand–Sandstone			
Massive sandstone	Sm	Poorly sorted, very fine to very coarse, beds up to 2 m thick, floating pebbles and cobbles locally	Sediment gravity flows, rapid deposition without tractive transport
Horizontally laminated sandstone	Sh	Very fine to very coarse beds from 0.5 cm to 2 m thick, floating pebbles locally; includes some low-angle lamination	Lower and upper flow-regime plane bed phase; correct choice depends on overall facies context
Ripple cross-laminated sandstone	Sr	Very fine to fine grained, beds to 15 cm thick, locally abundant plant fragments and roots	Lower flow regime, downstream migrating ripples
Planar cross-bedded sandstone	Sp	Very fine to very coarse grained, solitary and grouped sets up to 1.5 m thick, locally pebbly	Lower flow regime two-dimensional bedforms with relatively straight crestline; includes delta-like growths along margins of barforms
Trough cross-bedded sandstone	St	Fine to very coarse grained, in solitary and grouped sets 4 cm to 2 m thick, locally pebbly and pebble line base of some foresets, deformed foresets present locally	Lower flow regime three-dimensional bedforms, sinuous to linguoid crestlines
Convolute bedded sandstone	Scb	Fine- to medium-grained clayey sands, ubiquitous convolute bedding, trough cross-bedding locally visible within convolute beds	Deformation resulting from low permeability and high fluid pressure resulting in fluidization and loss of strength; process may be associated with one or more of the following: high sedimentation rates, frictional drag at interface between larger bedforms and overlying moving fluid, deformation of oversteepened foreset laminae; origin may be a combination of the above factors locally

Table 1. Cook Inlet Facies. Facies codes and interpretations significantly modifed from Miall (1996)—continued.

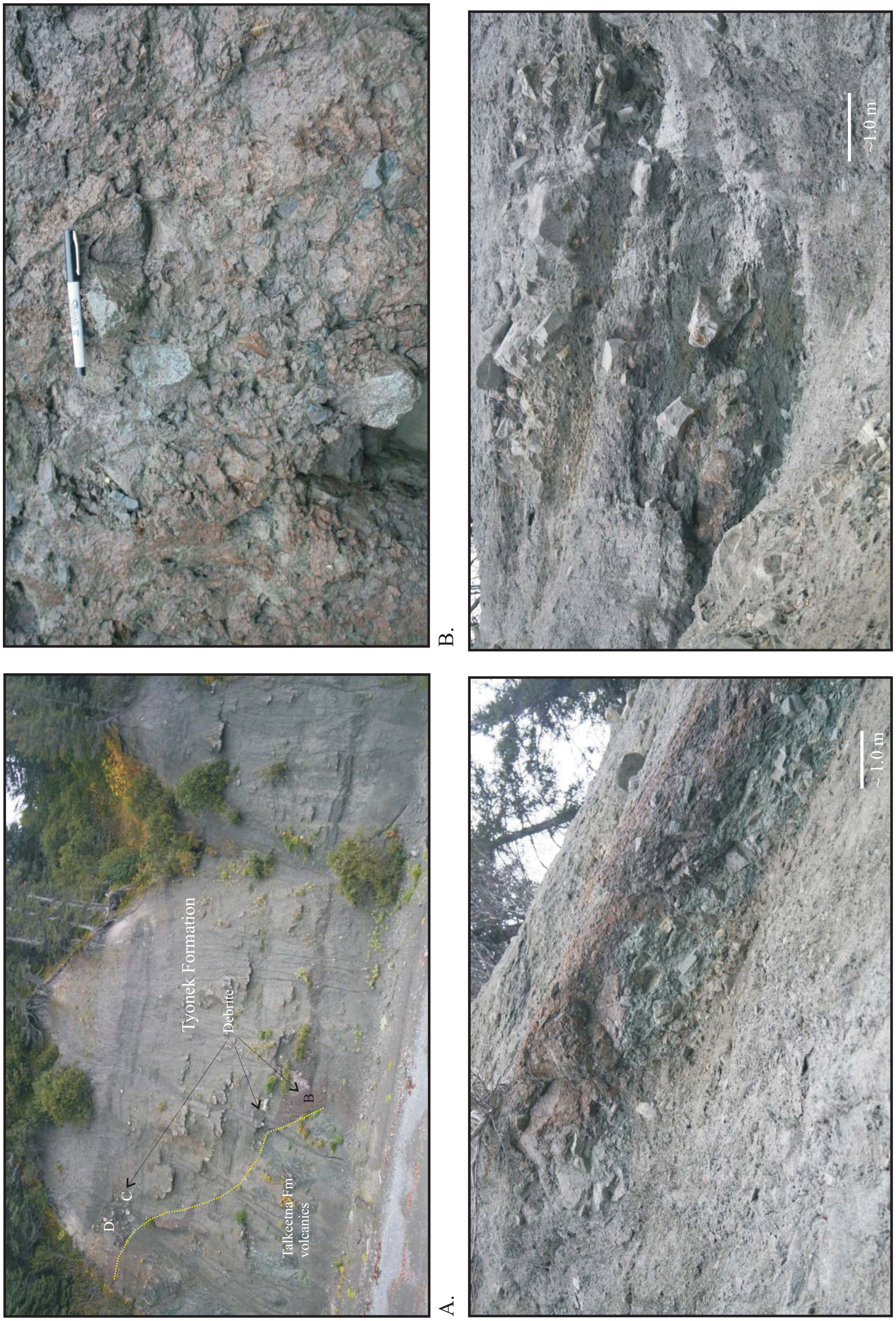
Lithofacies	Code	Description	Interpretation
Scour-fill sandstone	Ssf	Very-fine- to fine-grained sand with interlaminated mudstone, laminae as form-concordant scour drape, plant fragments and roots locally abundant	Concave-up erosion surfaces cut during flood events and subsequently draped by fine-grained sediment during low flow conditions
Clay/Silt/Mud			
Laminated claystone	Fcl	Light gray to dark brown claystone with undisturbed alternating light and dark millimeter-scale lamination	Slow settling from suspension in quiet water setting removed from sources of coarser sediment; deposition in floodplain ponds, lakes, and abandoned fluvial channels; possible seasonal laminae
Massive claystone	Fcm	Light to medium gray claystone, no visible lamination, minor scattered plant fragments, color mottling locally	Rapid deposition during flood events on poorly drained floodplain distal to fluvial channels, poorly developed soils locally; locally developed marshes (paludal)
Laminated mudstone	Fml	Light gray to brown silt and silt-clay mixtures in undisturbed millimeter- to centimeter-scale laminae, darker laminae commonly finer grained; locally ripple cross-laminated	Alternating slow suspension settling and relatively rapid suspension settling during flood event in distal levee and proximal perennially flooded regions of floodplain
Thinly interbedded sandstone and siltstone	Fssl	Interbedded very-fine-grained sandstone and siltstone, bed millimeter to multi-centimeters thick, locally ripple cross-laminated	Upper flow regime plane bed and lower flow regime ripple bed conditions in waning flows depositing sand-silt couplets
Massive mudstone	Fmm	Light gray to brown massive silt, silt-clay, and silt-clay-sand mixtures, commonly micromicaceous, no visible internal structures, sideritic concretions locally abundant and commonly with preserved plant fragments, rooted horizons locally	Rapid deposition during flood events on poorly drained floodplain proximal to fluvial channels, poorly developed soils locally, sparse colonization of depositional surface by land plants
Blocky mudstone	Fmb	Light gray to brown blocky mudstone, common sideritic concretions and rooted horizons; tree stumps in growth position locally	Relatively rapid deposition during flood events in seasonally flooded regions of floodplain, weak to moderate pedogenesis and colonization by land plants and trees
Carbonaceous mudstone	Fcb	Dark brown laminated claystone and mudstone, abundant terrestrial organic material typically preserved as comminuted plant fragments	Alternating suspension settling of clay and fine silt and relatively rapid deposition admixed terrestrial organic material, clay, and silt during flood events affecting perennially flooded region of floodplains
Coal	C	Dark brown to black, blocky lignitic to sub-bituminous coal, dull and alternating bright and dull layers common, original plant material commonly recognizable; dispersed volcanigenic mineral crystals and disrupted ash layers common	Swamp; thick low-ash coals probably originated in raised mires, whereas high-ash coals originated in topographically low swamps that frequently received clastic sediment from nearby fluvial sources

Facies codes and interpretations significantly modifed from Miall (1996)

Table 2. Cook Inlet Facies associations.

	Lithofacies Association	Lithofacies	Geometry	Interpretation
1	Valley margin apron	Gmm, Gcm	Wedge	Colluvial apron and regolith locally at valley margin.
2	Disorganized gravelly braided fluvial	Gcm, Gch, Gct/Gcp, Gmm, Sm, Sh, St., Fsb, and minor coal	Sheet	Paleovalley-fill; hyperconcentrated flow and normal, but flashy stream flow, local sediment sources.
3	Sheetflood-dominated alluvial fan	Gcm, Gch, Sm, Sh, St, and possible Gct or Gcp	Sheet	Basin margin alluvial fans traversed by braided streams flanked by poorly drained floodplains, semi-regional sources.
4	Sandy braided fluvial sheet	Sm/St/Scb, Sh, Sp, Sr, Gl, and minor Fssl	Sheet	Low- to moderate-sinuosity sandy braided streams distal to the basin margin, regional sediment dispersal systems and sources. Abundant Scb at Clam Gulch attributed herein to seismic shaking.
5	Meandering channel fluvial sheet	Sm/St, Sh, Sp, Sr, Ssf, Gl, minor Scb	Broadly lenticular	Moderate- to high-sinuosity meandering streams flanked by prominent poorly drained floodplains.
6	Overbank sheet	Fmm/Fmb, coal; minor Fcm, Fml, Fcl, and Fssl; altered tephra locally	Sheet	Poorly drained floodplains with local ponds and lakes; periodically converted to vast raised mires.
7	Single-thread channel-fill	Sm, St, and Sr	Lenticular	Single-thread, mixed- to suspended-load fluvial channels, limited or no lateral migration.
8	Crevasse channel	Sm, Sh, St, Sr, Ssf	Lenticular	Small single-thread channels. Distinction from association 7 may be artificial.
9	Crevasse splay	Sm, Sh, St, Sr, Fssl, Fmm	Lobate and sheet	Crevasse splay lobes; most likely includes some sheet-like levee deposits.

*Splay assignment unless able to see channel margins.
**Single-thread and crevasse channels division based on arbitrary size cutoff.



A. B. C. D.

Figure 4. Outcrop photos of the Tyonek Formation ~3 km west of Point Naskowhak (see fig. 2).

A. Helicopter view toward the south showing a steeply-dipping depositional contact between the Tyonek Formation and volcanigenic rocks of the Lower Jurassic Talkeetna Formation. Light-colored resistant material in the Tyonek a short distance to the right (west) of the contact is angular boulders of Talkeetna and anomalously cemented Tertiary coarse-grained sandstone and conglomerate. Note the progressive onlap of the underlying bedrock surface by valley-filling strata of the Tyonek. Letters B, C, and D refer to the locations pictured in fig. 4B, 4C, and 4D.

B. Close-up view of matrix-supported conglomerate in the Tyonek a few meters east of the contact with the Talkeetna Formation.

C. Angular blocks of volcanic rock in an argillaceous, sandy, pebbly matrix in the Tyonek Formation.

D. Same as fig. 4C, but at a slightly higher stratigraphic position

Facies Association 2 – Disorganized Gravelly Braided Fluvial

DESCRIPTION

Facies association 2 consists dominantly of clast-supported massive conglomerate (Gcm) and horizontally bedded conglomerate (Gch), with subordinate interbedded trough and planar cross-stratified conglomerate (Gct and Gcp), matrix-supported conglomerate (Gmm), massive sandstone (Sm), horizontally bedded sandstone (Sh), and trough cross-stratified sandstone (St), and minor locally developed blocky mudstone (Fmb) and coal (tables 1 and 2). Facies Gcm is most abundant, followed by Gch; both are present as tabular to broadly lenticular lithosomes up to 3 m thick (fig. 5a–b and 6a). Conglomerate beds extend laterally from a few meters to many tens of meters. Thin, laterally discontinuous channel fills of facies Gcm, Gch, and Sm are present locally (fig. 6b). Clast size ranges from 0.3–15 cm, clast shapes are equant to slightly discoidal, and sorting is very poor to poor (fig. 5c–d). Where enough disc-shaped clasts are present, weakly developed imbrication is recognizable locally, but clast fabric in most beds is disorganized. Low-angle sigmoidally cross-bedded gravel (Gcp) and low-angle planar bedded gravel are present locally and grade laterally to facies Gcm and Gch. Interbedded sandy facies are commonly well cemented and project out from outcrop surfaces (figs. 5b and 6a). Sandy facies are present as thin (few centimeters) discontinuous drapes separating conglomerate beds, as thin discontinuous beds up to 1 m thick blanketing conglomerate beds and filling depositional topography on conglomerate beds (fig. 5a, top right) and, less commonly, as laterally continuous sheets separating conglomerate beds (fig. 5a, at geologist's knee level). Amalgamated conglomerate beds are also common (fig. 5a, conglomerate body above thick sand). Poorly preserved plant material is common and well-preserved leaf fossils are present locally as are petrified logs and carbonized plant roots (fig. 5e). Mudstones are locally preserved as discontinuous drapes (fig. 5f).

INTERPRETATION

This association records deposition in low-sinuosity fluvial channels separated by low-relief longitudinal bar forms. Locally developed low-angle cross-bedded conglomerate (Gcp) records lateral or downstream accretion along the margins of larger bars. The disorganized appearance of many conglomerate beds (Gcm) suggests deposition from sediment-laden hyperconcentrated flows (Pierson, 2005) generated during flood events. At Point Naskowhak conglomerates of this association interfinger along the margin of an incised paleovalley with debrites of the valley margin apron association. Minor coal indicates plant colonization or deposition of allochthonous plant matter in low-lying areas (topogenous mires) between active channels or in abandoned channels.

Facies Association 3 – Sheetflood-dominated Alluvial Fan

DESCRIPTION

Facies association 3 consists dominantly of facies Gcm, Gch, Sm, Sh, and St. Possible cross-bedded conglomerates belonging to Gct or Gcp were observed in beds at least 2 m thick, but were inaccessible for further analysis. Individual conglomerate beds range from 2 m to at least 6 m thick and erosive bases are common (fig. 7a); thicker conglomerate bodies up to 15+ m probably represent amalgamated successions (fig. 7a). Conglomerate is clast supported, poorly to moderately sorted, with tightly packed poorly sorted sandy matrix. Clast sizes range from granule to 30 cm (fig. 7b). Imbricate clast fabrics are developed only locally (fig. 7c). Conglomerate is typically compact, but weakly cemented to uncemented; well-cemented masses occur widely scattered in most exposures and accumulate as float near the base of steep outcrops of this association. Sandstones are present as lenses up to 2 m thick that extend along local strike for many meters to many tens of meters (fig. 7a) and consist dominantly of facies Sm and Sh, with St locally developed. Sand lenses commonly include scattered floating pebbles and concentrated pebble accumulations 1–2 clasts thick above scour surfaces or along low-angle dipping laminae. In the study area addressed in this report, facies association 3 has only been recognized along the upper reaches of the Fox River (fig. 2), a short distance west of exposures of the Chugach terrane (McHugh Complex).

INTERPRETATION

This association is interpreted as the product of high-gradient, low-sinuosity gravelly braided streams and sheetflood processes. Crudely developed horizontal stratification resembles stratification associated with longitudinal and diagonal gravel bars in modern braided streams (Hein and Walker, 1977) and in gravelly sheetflood deposits (Blair and McPherson, 1994). Disorganized clast fabrics suggest relatively rapid deposition from flows with high sediment concentrations, and possibly from hyperconcentrated flows locally (for example, Pierson, 2005). The geometry of these deposits is unclear and hyperconcentrated flows may have been associated with channelized or un-channelized sheetfloods. Possible Gct or Gcp suggest the presence of large gravel bedforms that represent either in-channel structures or deposition along the slip face (downstream end or lateral margin) of large bar forms.

Figure 5. Outcrop photos of the Tyonek Formation at ~1 km east of Seldovia Point, Point Naskowhak, and Coal Cove (see fig. 2).

A. View toward the south showing tabular amalgamated conglomerate (above geologist's head) and tabular sand body (top of measuring staff, which is 1.5 m long, is resting against sand body). Note the irregularly shaped base of the sandstone body and the thin sandstone lenses and drapes in the overlying amalgamated conglomerate.

B. View toward the south showing interbedded poorly-sorted pebble conglomerate, sandstone, and minor mudstone. Conglomerates form tabular to broadly lenticular bodies; sandstones form tabular and lenticular bodies, whereas mudstones are only present as thin drapes and lenticular bodies of limited lateral extent.

C. Poorly-sorted pebble conglomerate in the conglomerate bed near the geologist's right foot in figure 5b.

D. Poorly-sorted, clast-supported pebble conglomerate at Coal Cove.

E. Rooted, poorly-sorted granule conglomerate, coarse-grained sandstone, and sandy mudstone in the dark-brown layer near the base of the slope at the far left edge of the photo in figure 5a.

F. Blue-green colored, rusty weathering mudstone at Coal Cove.

A.

B.

Figure 6. Outcrop photos of the Tyonek Formation east of Seldovia Point (see fig. 2). Facies exposed near Seldovia Point fill a paleovalley incised into the underlying McHugh Complex.

A. Interbedded poorly-sorted pebble conglomerate and sandstone similar to the succession at Point Naskowhak (fig. 4a, right side of photo, and fig. 5a). This photograph was taken a few hundred meters east of the photo in figure 5b.

B. Pebble conglomerate and sandstone channel fills separated by thin tabular mudstones and sandstones east of Seldovia Point. The red lines show shallow channel scour surfaces. This photo was taken east of the location shown in figure 6a.

A. B. C.

Figure 7. Outcrop photos of the lower Pliocene strata in the Sterling Formation along the west side of the Fox River (see fig. 2). Facies exposed at this location are interpreted as part of a streamflow/sheetflood-dominated alluvial fan complex that was deposited along the eastern basin margin.

A. Massive (Gcm) and crude horizontally stratified (Gch) poorly-sorted pebble conglomerate. Note the erosive base to the amalgamated conglomerate package overlying the sandstone lens.

B. Poorly organized clast fabric in conglomerate below the sandstone lens in figure 7a.

C. Locally developed imbricate clast fabric immediately below the sandstone lens in figure 7a.

Facies Gcp/Gct demonstrates that some channels were relatively deep (>>2m). Sandstone lenses represent deposition during the waning stage of flood events as drapes in bar top positions and as minor channel fills (Miall, 1977; Rust, 1972, 1978). Characteristics of facies association 3 and its close proximity (within 0.5 km) to exposures of the Chugach terrane and significant mountainous topography (at least present-day mountainous topography) suggest it represents part of a wet alluvial fan or fan complex.

Facies Association 4 – Sandy, Braided Fluvial Sheet

DESCRIPTION

Facies association 4 consists dominantly of facies Sm, St, and Scb, followed in abundance by Sh, Sp, and Sr. Facies Gl is common and occurs in beds up to 30 cm thick. The facies composition of this association appears to differ across the study area. Along the west shore of Kachemak Bay, this association consists largely of subequal amounts of Sm and St, with subordinate Sp, Sh, and minor Scb (fig. 8a–d). In this area the association commonly weathers to form sheet-like sand bodies with a monotonous appearance. Along the east shore of Cook Inlet at Clam Gulch, the association consists predominantly of Scb (fig. 8e) followed in abundance by St, Sh, and Sp, all interbedded to form a complex facies mosaic of sheet-like sand bodies. Between Kachemak Bay and the east shore of Cook Inlet (Clam Gulch), along Deep Creek, the facies makeup of this association appears similar to that noted for Kachemak Bay except that convolute bedding appears more distinctive (greater abundance?; fig. 8d and 8f). In all of these areas facies Scb is made up of deformed versions of St, Sh, and Sp.

Internal low-relief scour surfaces are common and, in outcrops oriented at high angles to paleoflow, they create a complex series of intersecting surfaces, making the internal organization appear complex (fig. 9a). The presence of these surfaces allows sand bodies of this association to be distinguished from sand bodies of association 5 (meandering fluvial channel fill). Extrabasinal clasts from pebble to boulder size (up to 45 cm along the apparent long dimension) are widely scattered throughout this association and appear to “float” in a sandy matrix (fig. 8b). Mudstone rip-up clasts are locally abundant near the base of sand bodies assigned to this association.

Clear fining-upward grain size trends are typically only present in the uppermost few meters of the sandy braided fluvial association where they grade up-section to mudstones and coal of the overbank association. Scour at the base of sand bodies commonly resulted in sand-on-coal contacts. Prominent fining-upward successions are present only locally within some sand bodies where facies Sh, St, Sr, and Fssl overlie concave-upward scour surfaces (fig. 9b).

INTERPRETATION

This association is interpreted as the depositional record of low- to moderate-sinuosity sandy braided streams. The suite of facies recognized is similar to facies described along braided reaches of the modern sandy South Saskatchewan River (Cant and Walker, 1978). Complex internal scour surfaces recognized in some outcrops of this association are similar to surfaces recognized in sandy braided alluvium by Adams and Bhattacharya (2005) and Bristow (1993), and are discussed further in the section addressing stacking patterns and depositional systems. Association with coal and fine-grained overbank facies demonstrates that active channel tracts were flanked by aggrading floodplains. The occurrence of facies Sh, St, Sr, and Fssl above concave-upward scour surfaces are interpreted as the fill of abandoned channels.

Convolute bedding in this association warrants further discussion. Many fluvial systems documented in the literature include examples of soft-sediment deformation. In most systems these features are minor components of the total facies composition. Many examples are attributed to a combination of frictional drag at the sediment–water interface and liquefaction of over-steepened foresets. At Clam Gulch soft-sediment deformation features are ubiquitous and their abundance is not likely attributable to fluvial processes alone. We tentatively suggest that these features are related to liquefaction of clay-rich sands resulting from an external forcing mechanism. Given the Holocene record of repeated major earthquakes (Combellick, 1994), we favor a seismogenic origin for this fabric (for example, Ettensohn and others, 2002), but more work is required to test this hypothesis.

Facies Association 5 – Meandering Channel Fluvial Sheet

DESCRIPTION

Facies association 5 consists of a suite of facies similar to those recognized in association 4 (Sm, St, Sh, with subordinate Sr, Ssf, Scb, and Fssl). This association is bounded below by an erosional contact with underlying overbank mudstones and above by a gradational contact with overlying overbank mudstones. The presence of lateral accretion surfaces within this association is the main characteristic that distinguishes it from the otherwise similar sandy braided fluvial association (fig. 9c).

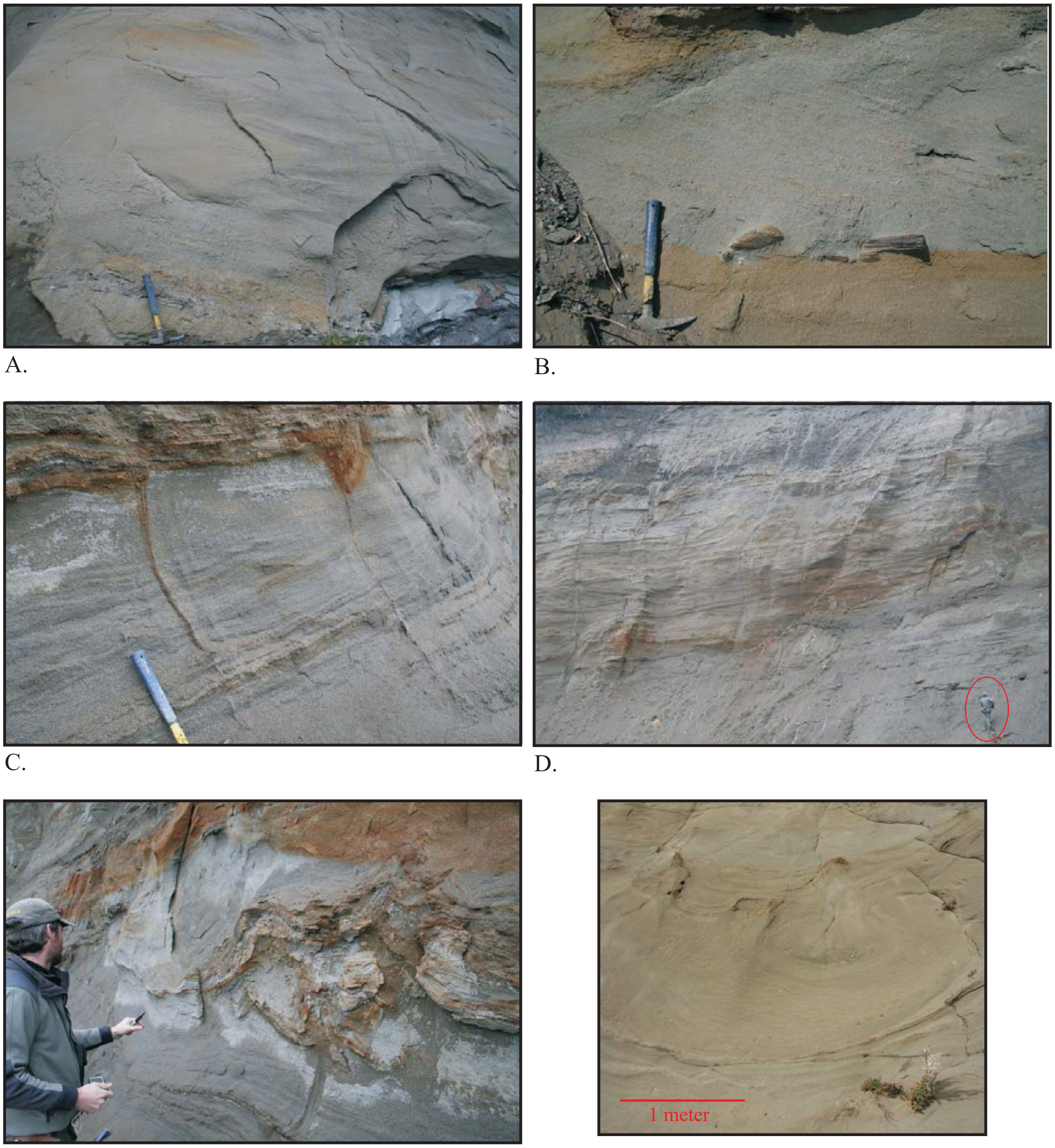


Figure 8. Outcrop photos of the Sterling Formation along Deep Creek at location 07MAW03 and near Falls Creek (see fig. 2).

A. Trough cross-stratified sandstone (St) above thin, discontinuous lag of mudstone rip-up clasts (visible near top of hammer handle) near Falls Creek.

B. Trough cross-stratified sandstone (St) near the base of a tabular channel sand body near Falls Creek. Note the cobble of granitic/dioritic material and small log to the right of the hammer and immediately above the red-stained sandstone. The contact between the red-stained sandstone and the overlying sandstone corresponds to an erosion surface at the base of an amalgamated sand body.

C. Horizontally laminated sandstone (Sh) cut by thin, rusty-stained sand-filled dikes at 07MAW03 (fig. 2).

D. Approximately 12 m of sandstone below an overbank mudstone package. Note the geologist in the lower right for scale. Also note several through-going surfaces that bound prominent sets of planar-tangential foresets (Sp, or St along a trough axis-parallel cut) and horizontally bedded sandstone.

E. Convolute bedded sandstone (Scb) along Deep Creek (07MAW03).

F. Convolute bedded sandstone (Scb) at Clam Gulch.

A.

B.

C.

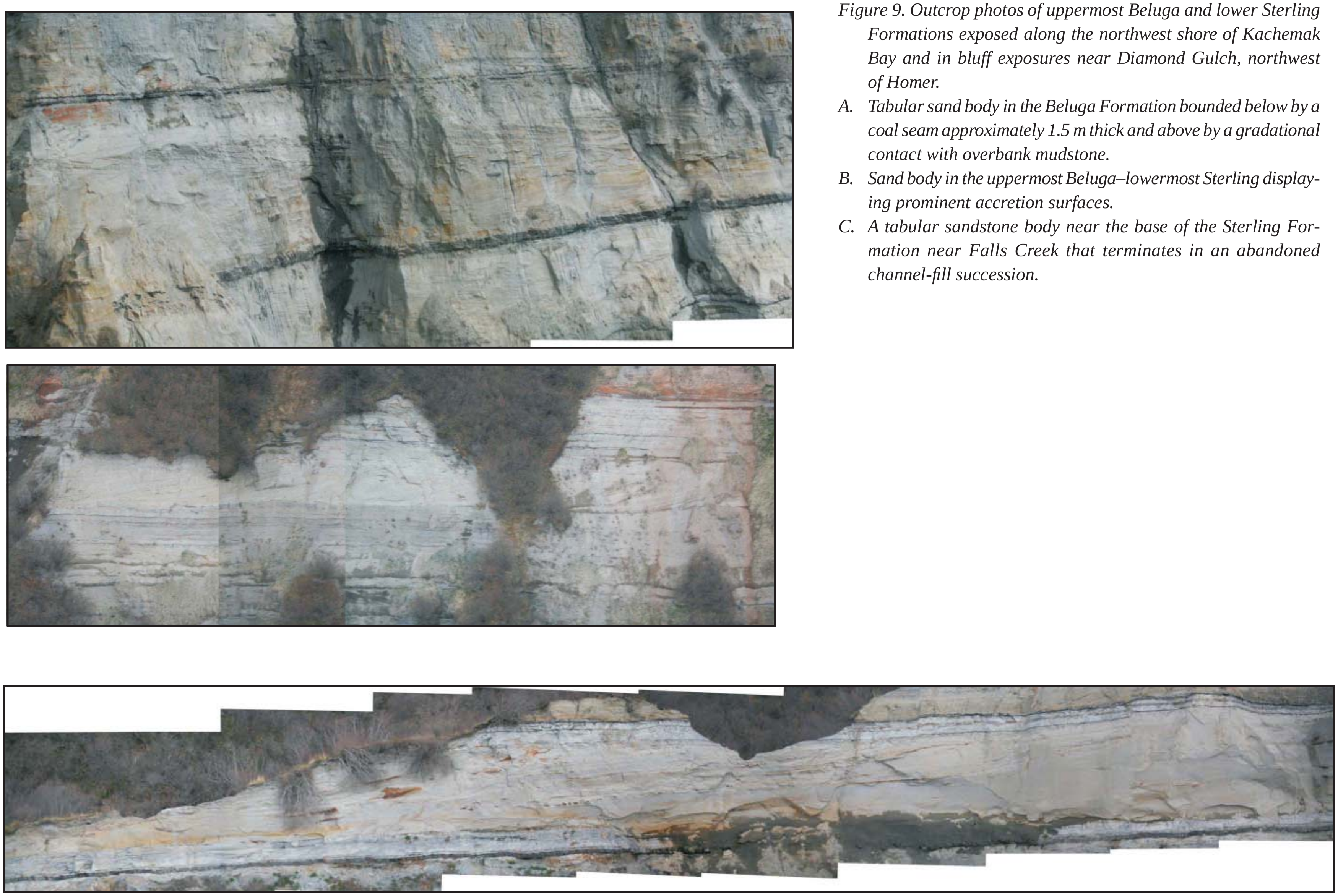


Figure 9. Outcrop photos of uppermost Beluga and lower Sterling Formations exposed along the northwest shore of Kachemak Bay and in bluff exposures near Diamond Gulch, northwest of Homer.

A. Tabular sand body in the Beluga Formation bounded below by a coal seam approximately 1.5 m thick and above by a gradational contact with overbank mudstone.

B. Sand body in the uppermost Beluga–lowermost Sterling displaying prominent accretion surfaces.

C. A tabular sandstone body near the base of the Sterling Formation near Falls Creek that terminates in an abandoned channel-fill succession.

INTERPRETATION

This association is interpreted as the record of moderate- to high-sinuosity mixed-load meandering rivers. The close association with mudstones of the overbank association (above, below, and lateral to sand bodies) demonstrates that active channels were flanked by aggrading poorly-drained floodplains. Our interpretation of this facies association is tentative and based on only one location; this location also includes sand bodies assigned to facies association 4. The component facies and lateral accretion surfaces recognized in facies association 5 are not unique to meandering stream deposits, but are also common in sandy braided stream deposits. More work is required to determine if this association is truly different from facies association 4 (for example, includes point bar successions) and whether or not it is the record of high sinuosity streams.

Facies Association 6 – Overbank Sheet

DESCRIPTION

Facies association 6 is prominent in most outcrops in the Kachemak Bay area, where it consists predominantly of facies Fmm, Fmb, and coal (fig. 10a–b), with locally important Fcm, Fml, Fcl, Fssl, and altered tephra (fig. 10c). Locally Fml, Fcl, and Fssl comprise facies successions up to a few meters thick in which millimeter-scale laminae are undisturbed by plant roots. The overbank association comprises tabular bodies that envelop several other facies associations, including the fluvial channel fill, crevasse channel fill, and crevasse splay associations.

Lignitic coal seams are a prominent component of this association and range from centimeters to several meters in thickness. Coals commonly include scattered yellow–white crystal clusters up to a few millimeters diameter. Coals appear to be laterally continuous over significant outcrop distances (many hundreds of meters).

INTERPRETATION

This association is interpreted to record deposition during floods beyond the confines of active fluvial channels. Deposition was largely from suspension and over time floodplains aggraded vertically. Facies Fmm and Fmb suggest a poorly-drained floodplain characterized by localized weak pedogenesis. Progradation/lateral migration and vertical accretion of related associations during flood events give the overbank association a more complex appearance. The occurrence of tephras indicates relatively common volcanic eruptions in the arc to the west. Thick, laterally continuous coal seams indicate that vast areas of the floodplain were colonized by dense vegetation, that a delicate balance between peat accumulation and subsidence was maintained for significant periods of time, and that these areas were isolated from clastic input. Scattered yellow–white crystal clusters represent fragments of tephras that were disrupted and dispersed by plant roots (Reinink-Smith, 1990; Dallegge and Layer, 2004).

The lateral continuity of coal seams bounding occurrences of the sandy braided fluvial and meandering fluvial associations suggest that catastrophic subsidence led to establishment of widespread floodplain mires. Alternatively, the lateral continuity of coals below most tabular sand bodies suggests that catastrophic and widespread subsidence shut down peat deposition, resulting in abrupt channel re-establishment (avulsion). We favor the latter interpretation.

Locally important occurrences of Fcl, Fml, and Fssl suggest deposition in floodplain ponds and lakes. Undisturbed millimeter-thick laminae typical of these occurrences suggest deposition from suspension in a low-energy environment in water deep enough to eliminate colonization from terrestrial vegetation. Local intercalations of Fssl and Fcm suggest transport in turbulent suspensions and traction transport of coarser material, possibly associated with small lacustrine deltas located near the margin of floodplain lakes.

Facies Association 7 – Single Thread Channel Fill

DESCRIPTION

Facies association 7 consists of a suite of facies similar to those recognized in associations 4 and 5, but Sm, St, and Sr are most abundant (tables 1 and 2). The primary characteristic of this association is its lenticular ribbon to narrow sheet geometry; channel margins are commonly visible in outcrop. Many sand bodies preserve the cross-sectional shape of the original channel (ribbon-like geometry), whereas other bodies record limited lateral channel migration (narrow sheet geometry). Sand bodies are up to 7 m thick and encased in mudstones of the overbank association. Examples of this association in laterally continuous exposures of the overbank association typically show overlapping channel fills at different stratigraphic levels (fig. 11).

Figure 10. Outcrop of an overbank succession exposed along the east shore of the Fox River (fig. 2). The age of this succession is unknown, but its location near exposures of the Sterling Formation suggest it is part of this unit.

A.

A. View toward the south showing approximately 12 m of overbank mudstone and thin lignitic coal.

B.

B. Contact between a lignitic coal (even with geologist's head) and an underlying mudstone.

C.

C. Laminated argillaceous mudstone (Fml) shale from the Beluga Formation near Fritz Creek (06PJM04 at 9m).

Figure 11. Outcrop photomosaics showing stratigraphic details in the Beluga Formation near Fritz Creek (see fig. 2). The right side of the top panel joins to the left side of the lower panel. The Beluga at this location is dominated by overbank mudstone that encases broadly lenticular, single-thread sand-filled channels. The yellow lines show the trace of measured sections through the lower part of the bluff and red lines show channel fill sandstone bodies.

INTERPRETATION

Association 7 resembles anastomosed fluvial sand bodies described by Kirschbaum and McCabe (1992), Nadon (1994), and Rygel and Gibling (2006) in that it forms ribbon- and narrow sheet-like sand bodies. It differs from these published examples in that multiple sand bodies have not yet been recognized at the same stratigraphic level in the study area; outcrop examples of this association include overlapping channel sands at different stratigraphic levels. We interpret association 7 as the record of single-thread mixed- to suspended-load channels that experienced limited lateral migration. Our interpretation differs from Flores and Stricker (1992), who interpreted the same exposures as the record of anastomosed fluvial channel fills.

Facies Association 8 – Crevasse Channel

DESCRIPTION

Facies association 8 consists of facies Sm, Sh, St, Sr, and minor Ssf. These facies comprise the fill of narrow channels that range from 1 to 3 m thick and 5 m to many tens of meters wide. Channels are encased in the tabular mudstone association. Channel fills of association 8 resemble association 7, but are significantly smaller.

INTERPRETATION

This association is interpreted as a crevasse channel-fill succession. Crevasse channels formed when levees bounding larger meandering(?) trunk channels were breached during flood events (high flow stage). Preliminary data suggest that crevasse channels are more common in overbank deposits that include larger channels of association 7.

Facies Association 9 – Crevasse Splay

DESCRIPTION

Facies association 9 occurs encased within mudstones of the overbank association and consists of Sm, Sh, St, Sr, Fssl, and Fm. This association forms sheet-like bodies composed of sandstone–mudstone couplets that range from decimeters to approximately 2 m thick; locally this association consists of amalgamated sand beds, each up to a few decimeters thick. Facies Sm, Sh, and/or St form the base of these couplets; individual sheets can consist of a single couplet or multiple couplets. Plant roots are locally common.

INTERPRETATION

This association is interpreted to record deposition as channel levees and as crevasse splay sheets. Available data do not allow differentiation between splay sheets and levee deposits. We infer that splay sheets probably account for the bulk of this association. Single sand–mud couplets, stacked sand–mud couplets, and amalgamated multi-decimeter-thick sand-on-sand beds likely record distal to proximal variations in crevasse splay deposition.

STACKING PATTERNS AND DEPOSITIONAL SYSTEMS

In this section the facies associations presented above are placed in a depositional systems context. Associations in late Oligocene(?) to early Miocene strata between Barabara Point and Coal Cove are discussed first, followed by middle to upper Miocene strata near Homer, and ending with Pliocene strata along the northwest shore of Kachemak Bay, Deep Creek and Clam Gulch, and the Fox River. Facies and facies associations are identified on the measured sections at the end of this report. Figure 12 is a schematic representation of fluvial style interpreted for formations of the Kenai Group exposed in the study area and will be referred to throughout this section.

Tyonek Formation—Barabara Point to Coal Cove

Late Oligocene to early Miocene strata assigned to the Tyonek Formation fill paleotopographic depressions developed on Mesozoic rocks of the Talkeetna Formation and McHugh Complex between Barabara Point and Coal Cove (fig. 2). This is most clearly demonstrated at Coal Cove and Point Naskowhak, where the accumulations are interpreted as paleovalley fills (fig. 12). At the latter location the valley margin apron association (table 2) rests abruptly with angular discordance above dark green- and maroon-weathering volcanic rocks of the Lower Jurassic Talkeetna Formation (fig. 4a). Debrites of this association interfinger laterally over short distances (5–30 m) with conglomerates of the disorganized gravelly braided fluvial association. Stratigraphically higher debrites clearly backstep (shift away from the paleovalley axis) up the margin of the paleovalley and show an unequivocal onlap relation (fig. 4a). Clast and matrix compositions closely reflect the parent material in the subjacent Talkeetna Formation and were obviously locally sourced. The valley margin apron association represents talus aprons that

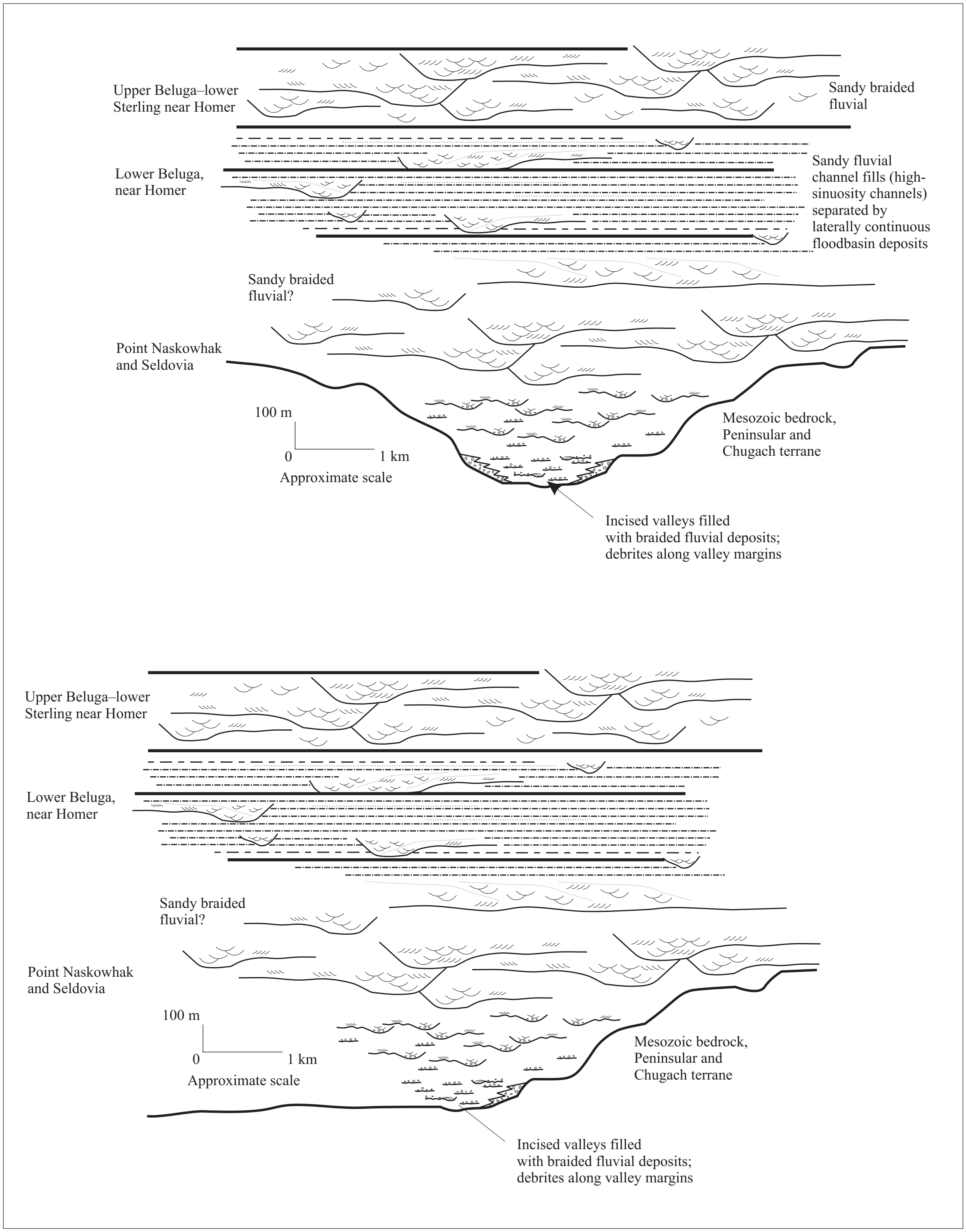


Figure. 12. Line drawing illustrating the evolution of fluvial style from late Oligocene through early Pliocene time in the Homer–Kachemak Bay area. Scale is approximate only.

accumulated at the toe of exposed bedrock slopes. Angular clasts and clast-supported fabrics typical of these debrites suggest an origin whereby hill slope colluvium was mobilized during high rainfall events (or seasonal snowmelt) and transported downslope as debris flows. Debrites grade toward valley axes into the deposits of low-sinuosity braided streams responsible for depositing the disorganized gravelly braided fluvial association. The disorganized nature of these conglomerates suggests flashy streams that were prone toward hyperconcentrated flows (for example, Pierson, 2005). Sand lenses and sand drapes were deposited during waning flow stage and during low-flow periods. The paleovalley near Point Naskowhak has an apparent width parallel to the shoreline of 1.7 km. Minimum estimates of the depth of incision are provided by the thickness of Tertiary strata preserved in these exposures: 15 m at Coal Cove (and Point Pogibshi) and at least 30 m at Point Naskowhak.

The succession at Coal Cove is similarly interpreted as a paleovalley-fill succession, but the actual valley walls are poorly exposed. At this location, an interfluve of Talkeetna volcanics separates what are thought to be two narrow paleovalleys, each probably less than 0.5 km in apparent width parallel to the shoreline.

A much thicker Tertiary succession is exposed between Seldovia Point and Barabara Point, east of Seldovia Bay, which is addressed in more detail by Finzel and others (this volume). The Tertiary succession at this location dips gently toward the east and the base is exposed near Seldovia Point where the entire bluff height of approximately 14 m consists of pebble conglomerate and lenticular sandstone of the disorganized gravelly braided fluvial association (fig. 6a). Lithologies present in nearby exposures of the Mesozoic McHugh Complex are recognized as clasts in conglomerate of this association. The contact between Tertiary deposits and underlying Mesozoic rocks is not exposed, but progressive overlap of Mesozoic rocks by Tertiary conglomerate and sandstone is apparent (fig.13a) and supports interpretation of this succession as the fill of an incised paleovalley. Valley margin alluvial apron deposits have not been recognized at this location. The gravelly braided fluvial deposits grade up-section to better organized sandstones and mudstones interpreted as distal sandy braided fluvial (association 4) and floodplain deposits (association 6) that reflect deposition beyond the confines of the paleovalley (Finzel and others, this volume).

In summary, Tertiary rocks mapped as Tyonek Formation include gravelly braided fluvial deposits that filled the axial region of incised paleovalleys that were cut into Mesozoic bedrock of the Peninsular and Chugach terranes. Debrites formed a discontinuous alluvial apron along the valley margin and represent slope colluvium. Between Barabara Point and Seldovia Point locally sourced incised paleovalley fill deposits grade up-section to mixed-load distal braided fluvial deposits that likely extended beyond the confines of incised paleovalleys. Distal braided alluvium near Barabara Point megascopically appears to record sediment derived from more regional sources. Flores and others (2004) reported the occurrence of tidally influenced deposits in the Tyonek between Barabara and Seldovia points but did elaborate. We did not find tide-influenced facies in Tyonek outcrops in this area.

Lower Beluga Formation—Bluff Point to McNeil Creek

Exposures of late Miocene strata in coastal bluffs northwest and northeast of Homer are thought to represent stratigraphic positions relatively low in the Beluga Formation (Adkison and others, 1975). These exposures consist largely of associations 6, 7, 8, and 9 (table 2). The overbank association envelops the fluvial channel fill, crevasse channel, and crevasse splay associations (associations 7, 8, and 9, respectively). Overbank deposits of association 6 dominate these exposures. Figure 11 shows a photomosaic of bluff exposures east of Fritz Creek, on the west shore of Kachemak Bay, that illustrates sand body geometry and the relative abundance of sandy versus muddy associations. Measured section 07JRM01 and 02 intersect relatively thick overbank successions (association 6) with thin crevasse splay sand sheets (association 9). Measured sections 06PM003 and 004 also intersect relatively thick overbank deposits with numerous crevasse splay sheets (association 9) and possible crevasse channel fills (association 8). The fluvial channel-fill association forms broad ribbons to narrow sheet sand bodies that cut into underlying mudstones of the overbank association (figs. 11 and 12). These sand bodies are interpreted as the product of single thread rivers that traversed poorly drained floodplains and did not migrate significant distances laterally. Our interpretations contrast with those of Flores and Stricker (1992), who interpreted the succession near McNeil Creek as the product of suspended-load anastomosed streams.

Bluff exposures northwest of Bluff Point closely resemble exposures of the lower Beluga Formation near Fritz Creek (fig. 14). Measured section 07MAW204 intersects a thick overbank succession (association 6) with numerous crevasse splay and probable crevasse channel sand bodies (associations 8 and 9). The lower Beluga at this location is similar to the succession exposed near Fritz Creek in that overbank deposits represent a prominent part of the depositional system.

In summary, the lower Beluga Formation in the vicinity of Homer and Kachemak Bay is characterized by broad ribbon-like and narrow sheet-like sand bodies bounded by thick, laterally continuous overbank mudstone

A.

B.

Figure 13. Outcrop photos of Tertiary strata near Seldovia Point and along the upper Fox River (see fig. 2).

A. Exposures of the McHugh Complex at beach level overlain by poorly exposed valley-fill strata of the Tyonek Formation.

B. Helicopter view toward the west showing early Pliocene alluvial fan deposits of the Sterling Formation very close to the eastern basin margin.

Figure 14. Outcrop photomosaic illustrating the facies organization of the Beluga Formation west of Diamond Gulch (see fig. 2). The yellow line shows the trace of measured section 07MAW204. The yellow oval encloses two geologists for scale.

successions. These sand bodies are interpreted as the products of single-thread streams that carried a significant percentage of their total load in suspension. Frequent flood events led to accretion of significant thicknesses of overbank mudstones. Locally, numerous small channel fills and thin sheet-like sand bodies suggest that flow in the larger streams frequently broke through their levees to deposit crevasse channel and splay sand bodies. Thick, laterally continuous overbank deposits record deposition in a high accommodation setting.

Upper Beluga Formation to Lower Sterling Formation—Falls Creek

Exposures of latest Miocene to Pliocene strata near Falls Creek on the west shore of Kachemak Bay straddle the Beluga–Sterling formational boundary as placed by Adkison and others (1975). These workers placed the formation contact at the base of a channel sand body exposed just above the beach a short distance northeast of the mouth of Falls Creek (their measured section L5) and noted, "The position of the contact is broadly determined by an upward change in the heavy mineral suites…." Their measured sections are generalized and do not show a gross change in stratigraphy (for example, sand:mudstone) across the position of their contact. This is consistent with our observation that the Beluga–Sterling contact in this region appears gradational based on a gradual change in fluvial style. Related to this gradual change in fluvial style is a gradual up-section decline in the thickness of coal seams.

Exposures of the uppermost Beluga and lowermost Sterling near Falls Creek are characterized by laterally continuous sand bodies up to 12 m thick consisting of the sandy braided fluvial and meandering fluvial sheet associations (association 4 and 5). Overbank mudstones and lignitic coal seams of association 6 form laterally continuous caps (up to 5 m thick) to many sheet sand bodies. Although prominent in these bluff exposures, the overbank association is thinner than exposed in the lower Beluga. Many sand bodies of the sandy braided fluvial association are internally monotonous and consist largely of massive sandstone and trough cross-bedded sandstone (fig. 15). Some sand bodies assigned to association 4 include numerous large, overlapping concave-upward surfaces suggestive of multi-lateral scours typical of sandy braided fluvial deposits (fig. 9a). Sand bodies of the meandering fluvial sheet association include uniformly dipping surfaces indicative of lateral accretion (fig. 9c). The range of internal organization noted here suggests that upper Beluga–lower Sterling rivers included both braided and meandering channel geometries. Although thinner than in the lower Beluga, the presence of laterally continuous overbank deposits (association 6) suggests that rivers were still flanked by prominent floodplains. The reduced thickness of overbank deposits is probably the result of increased erosion from laterally migrating and avulsing river channels. Many thick sand bodies rest in erosional contact on lignite seams, demonstrating that channels scoured down to the level of underlying peat mats, but could not cut through them. Increased erosion and reduced thickness of overbank deposits are attributed to deposition in lower accommodation settings.

Sterling Formation—Deep Creek

Outcrops assigned to the Sterling Formation occur discontinuously along the valley of Deep Creek, west of the Fox River. The stratigraphic position of these exposures in the Sterling is unclear. Flores and Stricker (1993) note that exposures at Clam Gulch represent the upper Sterling Formation, but do not explain the basis for this interpretation. The exposures along Deep Creek are separated from Clam Gulch by at least one major northeast-trending fold and from exposures along the Fox River by at least two major folds (fig. 2; see Magoon and others, 1976). These structures complicate determination of the stratigraphic position of the Deep Creek exposures within the Sterling Formation.

Many exposures consist predominantly of sandstone of association 4 (figs. 15 and 16a) or a combination of association 4 (sandy braided fluvial) and mudstones of association 6 (fig. 16b). The laterally discontinuous nature of these exposures makes classifying sand body geometry and evaluating the lateral continuity of overbank deposits particularly difficult; we infer sheet-like geometries based on comparison with similar sand bodies in the lower Sterling along the west shore of Kachemak Bay.

Intersecting outcrop faces illustrate the internal organization of an amalgamated sand body at location 07MAW03 (fig. 2) and provide insights on fluvial channel style. The outcrop faces shown in figure 16a intersect at a high angle to provide nearly orthogonal views through a multistory and multilateral sand body at least 20 m thick. Three surfaces of different order are visible in both (fig. 16a). One class of surface can be traced across the exposure and correlated between the two faces; these surfaces bound individual stories. The second class of surface is internal to the individual stories and probably bounds bar and channel architectural elements (fig. 16a, left of bend; for example, Miall, 1995). The other class of surface is internal to these elements, cannot be traced significant distances, and probably records slipfaces with smaller-scale dunes that comprise the large bars and channel elements

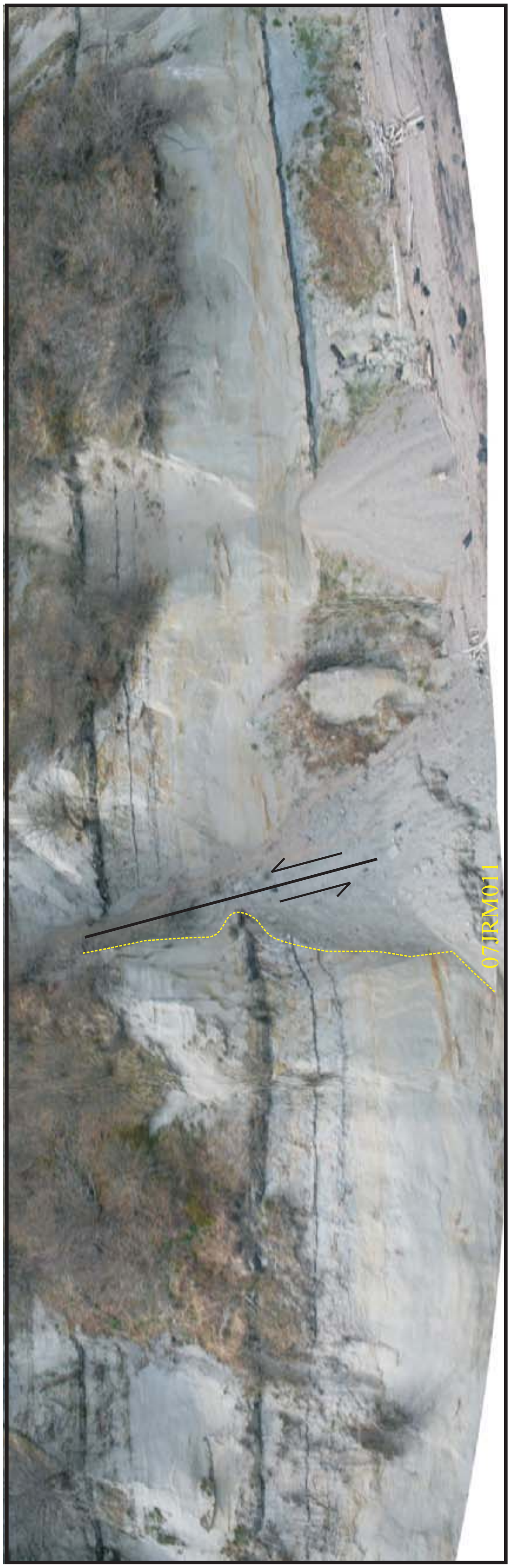


Figure 15. Tabular sand body and deceptively continuous coal seams in the lower Sterling Formation near Falls Creek. A high-angle fault runs down the axis of the ravine and offsets coal seams by approximately 10 m.

A.

B.

C.

Figure. 16. Outcrop photos of the Sterling Formation along Deep Creek.

A. Photomosaic at 07MAW03 showing two intersecting outcrop faces. The left face is oriented at a high angle to paleoflow and the right face is oriented nearly parallel to paleoflow. Note the contrasting organization of facies along these two cuts. Cross-sections perpendicular to paleoflow in sandy braided alluvium typically appear more complex and less organized (left face) than along cuts parallel to paleoflow (right face).

B. Channel-fill succession overlain by overbank mudstones along Deep Creek at 06PD244.

C. Trough cross-stratified sandstone (St) at 06PD244.

(fig. 16a, right of bend). The latter two classes of surfaces are characterized by significant complexity: changes in concavity and dip direction over short distances make each story appear internally disorganized. In contrast, the intersecting outcrop face (fig. 16a, right of bend) includes the through-going surfaces that bound stories and surfaces internal to each story. These internal surfaces include relatively few concave-up scours and well-defined dune slip faces that dip consistently toward the right, imparting a more orderly, organized appearance for each story. Although this exposure is of limited extent, the complex surfaces seen on the left half of figure 16a suggest this orientation is close to depositional strike (perpendicular to paleoflow) for this river in this area, and that the right side of image is oriented close to depositional dip (nearly parallel to westerly paleoflow). Strike-oriented exposures through sandy braided alluvium are typically characterized by complex internal surfaces that dip in various directions and lack preferred orientations as expected in meandering streams (Bristow, 1993; Adams and Bhattacharya, 2005).

Sterling Formation—Fox River

Previously unmapped and undated (Cieutat and others, 1992) deposits along the Fox River in the Kenai National Wildlife Refuge consist of conglomerates and lenticular sandstones of association 3 (fig. 13b; wet alluvial fan association). Palynological samples collected during the 2006 field season yielded pollen of early Pliocene age that do not appear to be reworked (Pierre Zippi, unpublished report). These coarse-grained units represent very proximal deposits broadly correlative with the Sterling Formation. Facies recognized in this association (Gcm, Gch, Gcp/Gct, Sm, and Sh) are common in gravelly braided stream environments (tables 1 and 2). The proximity of this association to exposures of deformed and uplifted rocks of the McHugh Complex a few kilometers away suggest these braided streams were associated with a large alluvial fan, or complex of fans, deposited along the Kenai–Chugach Mountain front during Pliocene time. Though not recognized in outcrop in the study area, alluvial fans were probably present along this mountain front in Miocene time and possibly earlier. Clast composition reflects derivation from greywackes, argillites, and bedded cherts in the McHugh Complex to the east. $^{40}Ar/^{39}Ar$ dates from volumetrically minor, but conspicuous, white and black diorite clasts obtained during the present study indicate they were derived from near-trench plutons in the accretionary prism (e.g. Bradley and others, 2003).

DISCUSSION

Outcrop data gathered during the 2006 and 2007 seasons provide insights on the nature of nonmarine depositional systems along the eastern margin of Cook Inlet basin. Late Oligocene to early Miocene strata exposed in coastal bluffs between Seldovia Point and Coal Cove, previously mapped as Tyonek Formation (Magoon and others, 1976; Bradley and others, 1999), record deposition in paleovalleys incised into deformed Mesozoic rocks of the McHugh Complex and Talkeetna Formation. These occurrences of the Tyonek are drastically different than the type Tyonek in the subsurface, or from the Tyonek in outcrop on the northwest side of the basin (see Calderwood and Fackler, 1972, and Flores and others, 1994). Braided streams occupying these valleys transported detritus derived from relatively small, locally sourced catchment areas, were prone to flashy discharge and hyperconcentrated flows, and graded to colluvial aprons comprised of debrites at valley margins. Valley-filling braided alluvium near Seldovia Point grades up-section to sandy braided alluvium attributed to a dispersal system of more regional extent, reflecting deposition more distal to the basin margin (Finzel and others, this volume).

Late Miocene strata exposed in coastal bluff exposures northwest of Homer and along the west shore of Kachemak Bay near Fritz Creek, mapped by Kirschner and Lyon (1973) and Magoon and others (1976) as Beluga Formation, record deposition from suspended-load to mixed-load, high-sinuosity single-thread (anastomosed) rivers. Sand bodies associated with these rivers are narrow sheets to broad ribbons up to 8 m thick encased in overbank mudstones. The high percentage of mudstone and coal in these exposures suggests deposition in high-accommodation settings.

Beluga exposures near Fritz Creek grade up-section over several kilometers of bluff exposures and several hundred meters of section to sheet-like sand bodies up to 15 m thick in the uppermost Beluga and lower Sterling Formations in the vicinity of Falls Creek. Overbank mudstones still form laterally continuous deposits in this area, but are significantly thinner than in the lower Beluga. Sheet-like sand bodies are attributed to low-sinuosity sandy braided rivers; locally visible, well-developed lateral accretion surfaces suggest that meandering streams were also present during this time or, alternatively, that some braid bars also migrated laterally or obliquely. The reduced thickness of overbank deposits is attributed to deposition in low accommodation settings during latest Miocene to Pliocene time in this part of the basin.

Exposures of the Sterling Formation along Deep Creek appear similar to the upper Beluga and lower Sterling Formations along the west shore of Kachemak Bay, but their laterally discontinuous nature precludes more rigorous comparison. One exposure includes two outcrop faces that intersect at a high angle to provide nearly orthogonal cuts through an amalgamated sand body, the details of which suggest deposition in a sandy low-sinuosity fluvial system.

Previously unmapped exposures of conglomerate along the upper reaches of the Fox River contain un-reworked Pliocene palynomorphs. Facies suggest deposition from braided streams that are inferred to have flowed radially down the axis of large wet alluvial fans situated at the basin margin. Within the coarse constraints provided by limited age control, it is reasonable to suggest these fans represent the proximal equivalents to sandy braided alluvium recognized in Sterling Formation exposures along Kachemak Bay and Deep Creek.

ACKNOWLEDGMENT

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APPENDIX A

Table A1. Locations of measured sections illustrated in Appendix A.

No.	Section Name	Location Name	Formation	Latitude	Longitude
1	06PM001	Coal Cove, Port Graham	Tyonek	N59.3942	W151.8925
2	06DL024	Point Pogibshi, Kachemak Bay	Tyonek	N59.41695	W151.88352
3	06PM004	Fritz Creek, Kachemak Bay	Beluga	N59.69571	W151.30385
4	07MAW004	Bluff Point	Beluga	N59.67557	W151.71409
5	07DL002	Bluff Point	Beluga	N59.65911	W151.66521
6	07DL003	Bluff Point	Beluga	N59.65944	W151.66624
7	07DL004	Diamond Gulch	Beluga	N59.65964	W151.66736
8	07JRM001	Fritz Creek, Kachemak Bay	Beluga	N59.69343	W151.31347
9	07JRM002	Fritz Creek, Kachemak Bay	Beluga	N55.69365	W151.3128
10	07JRM003	Fritz Creek, Kachemak Bay	Beluga	N59.6938	W151.31266
11	07JRM005	Fritz Creek, Kachemak Bay	Beluga	N59.69517	W151.30707
12	07JRM006	Fritz Creek, Kachemak Bay	Beluga	N59.69522	W151.30672
13	07JRM008	Fritz Creek, Kachemak Bay	Beluga	N59.6962	W151.30368
14	07JRM009	Fritz Creek, Kachemak Bay	Beluga	N59.70012	W151.29219
15	07JRM010	Falls Creek, Kachemak Bay	Beluga–Sterling	N59.69879	W151.29545
16	07JRM011	Falls Creek, Kachemak Bay	Sterling	N59.77309	W151.12128
17	07JRM012	Falls Creek, Kachemak Bay	Sterling	N59.78246	W151.10204
18	07JRM013	Falls Creek, Kachemak Bay	Sterling	N59.77343	W151.12043
19	07JRM014	Falls Creek, Kachemak Bay	Sterling	N59.77366	W151.12004
20	06PD213	Fox River, Kenai NWR	Sterling?	N59.91270	W150.82426
21	06MAW203	Fox River, Kenai NWR	Sterling	N59.98066	W150.79642
22	06PD244	Deep Creek, southern Kenai Peninsula	Sterling	N59.98250	W151.54721
23	06PD220	Clam Gulch, Cook Inlet	Sterling	N60.24970	W151.39291

Datum is NAD27 Alaska.

FIGURE A1

06PM001
Coal Cove, Port Graham
N59.3942 W151.8925
Tyonek Formation

Page 1 of 2

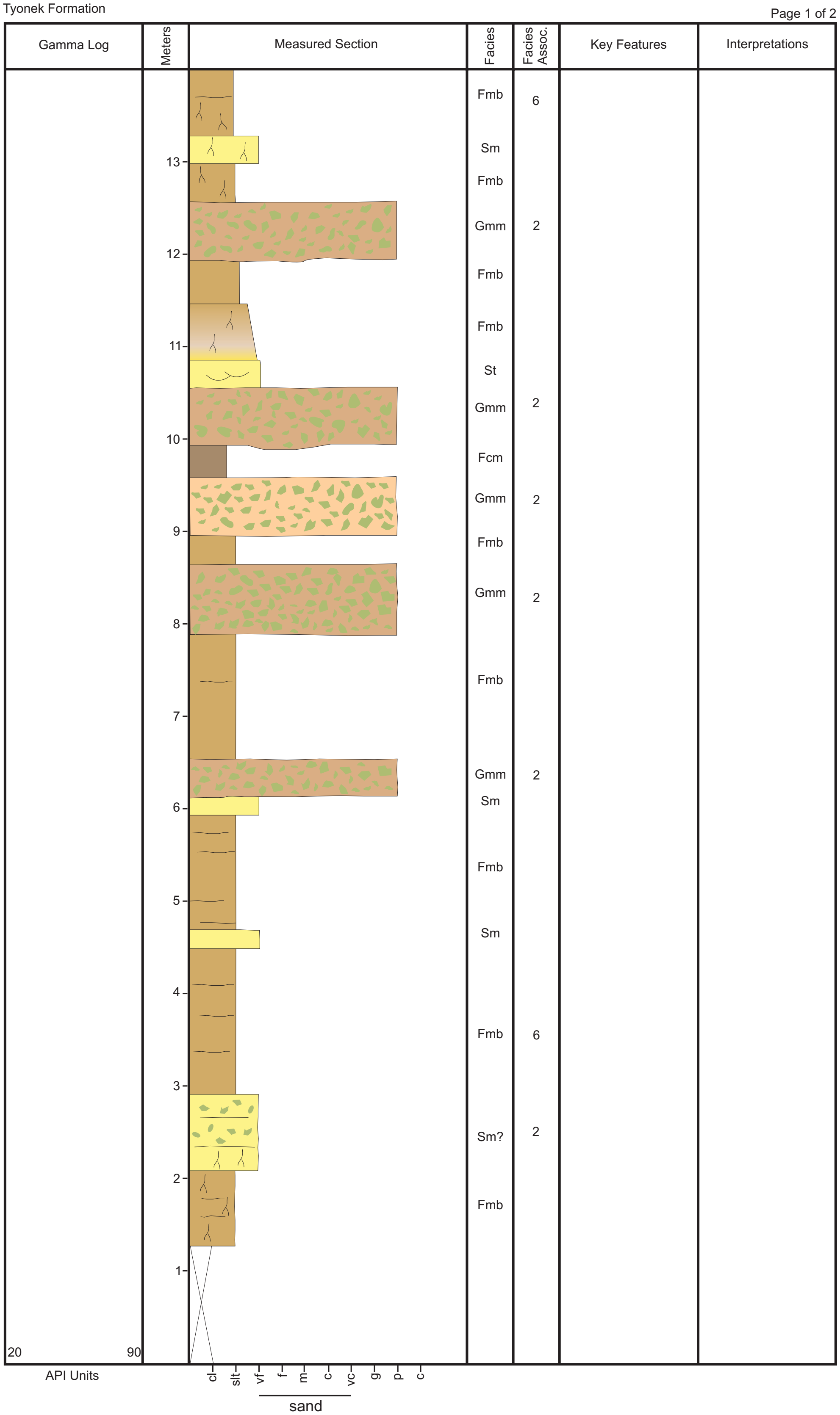


FIGURE A1

06PM001
Coal Cove, Port Graham
N59.3942 W151.8925
Tyonek Formation

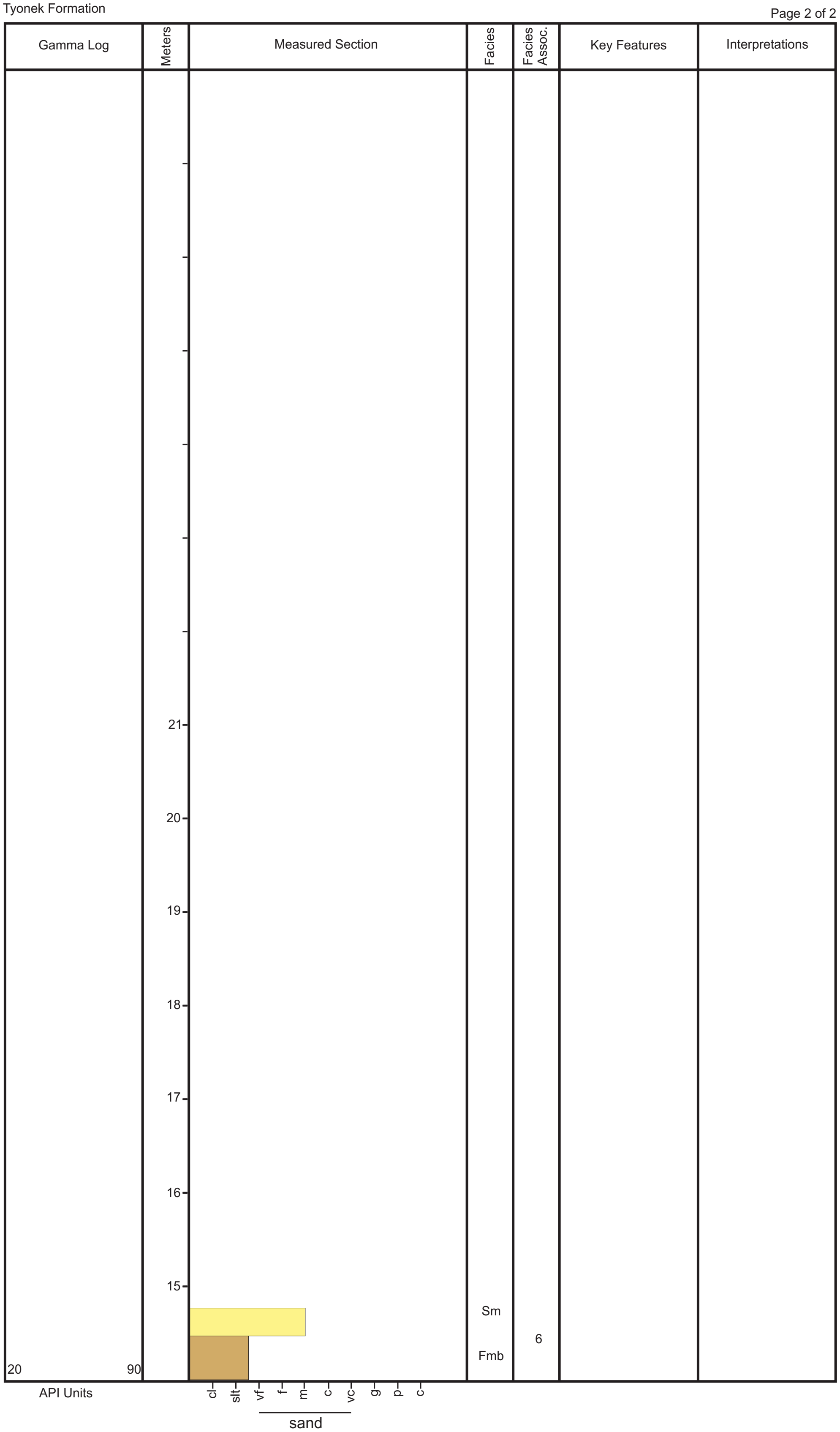


FIGURE A2

06DL024
Point Pogibshi, Kachemak Bay
N59.43726 W151.80049
Tyonek(?) Formation

Page 1 of 2

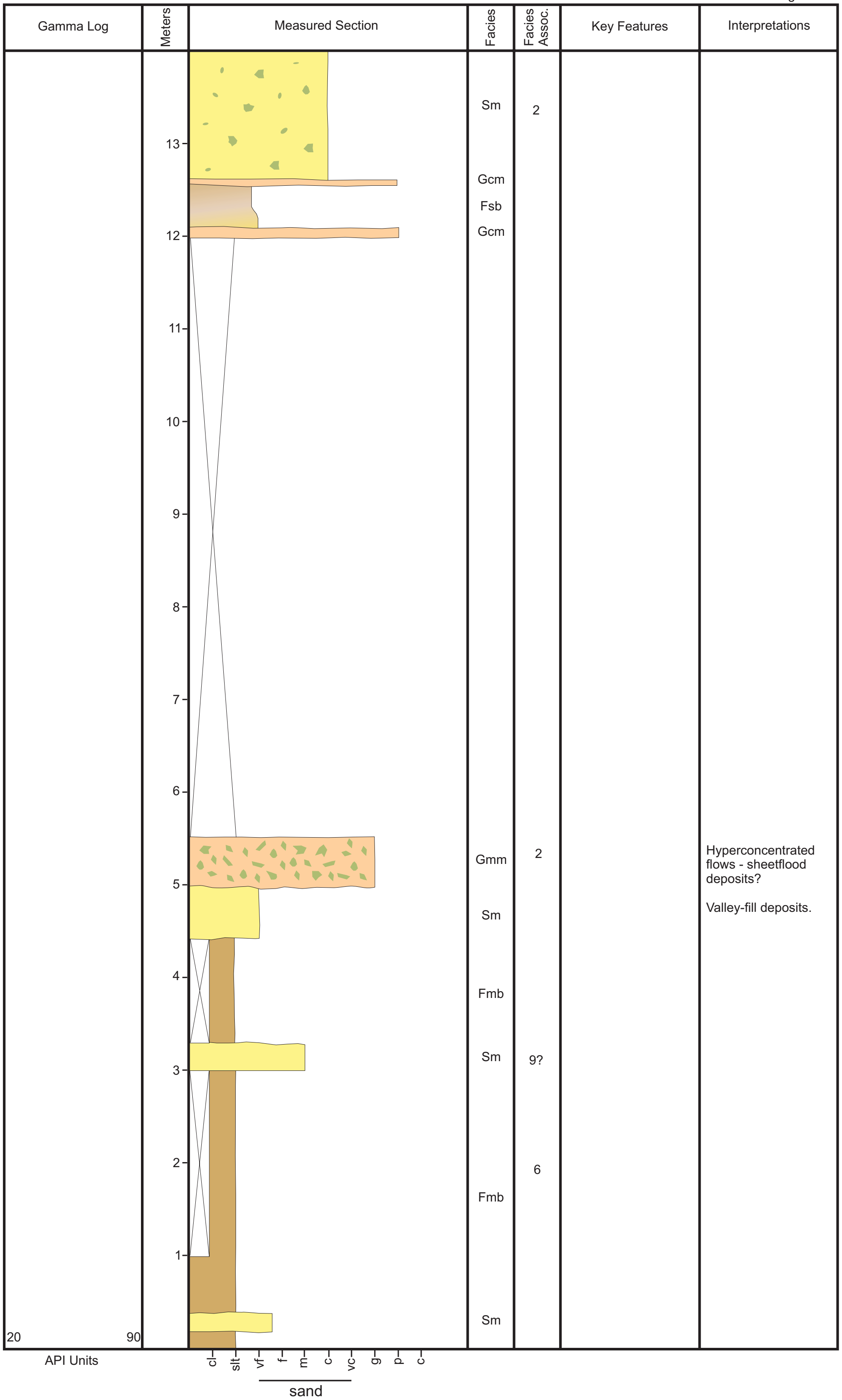


FIGURE A2

06DL024
Point Pogibshi, Kachemak Bay
N59.43726 W151.80049
Tyonek(?) Formation

Page 2 of 2

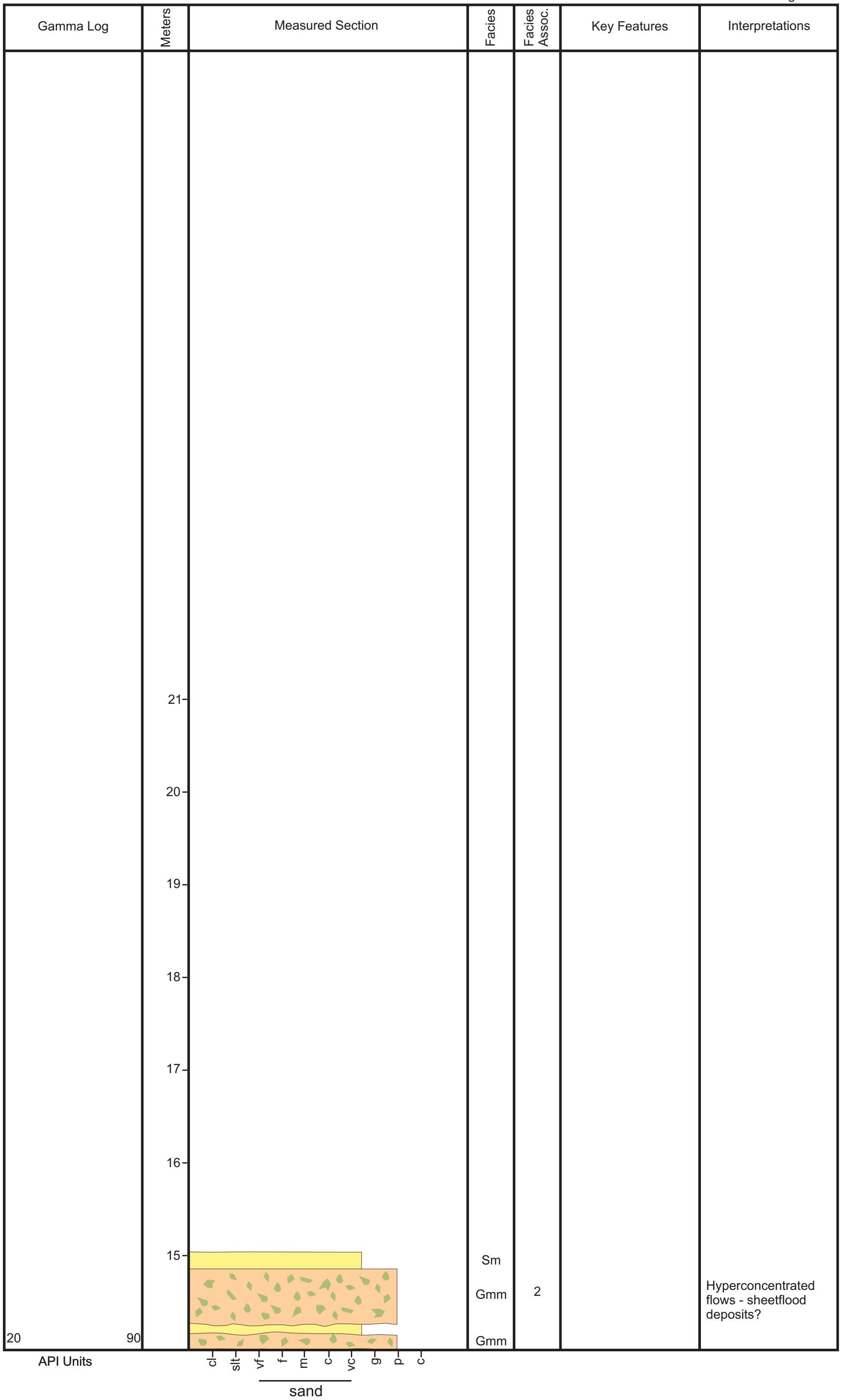
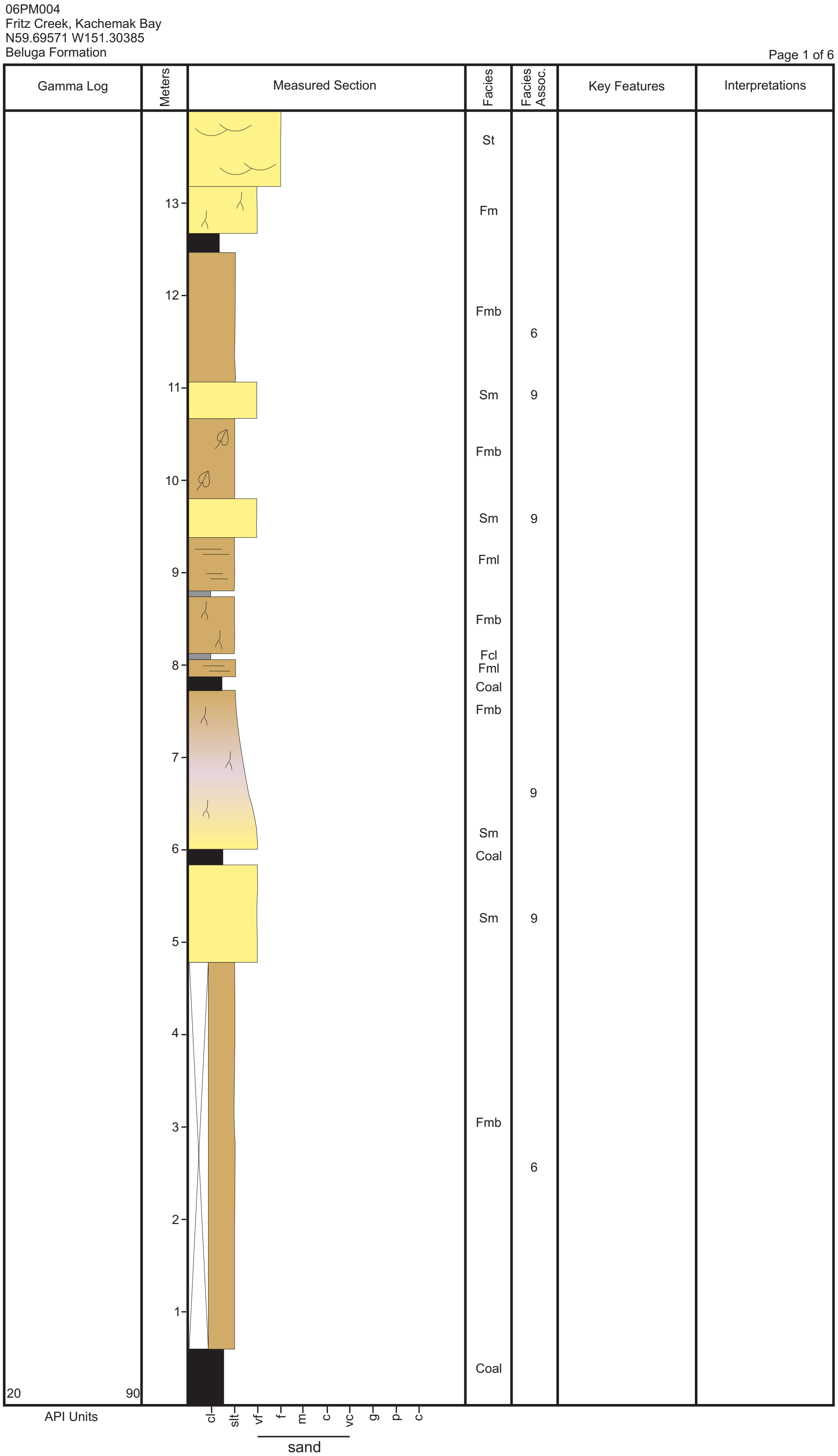


FIGURE A3


06PM004
Fritz Creek, Kachemak Bay
N59.69571 W151.30385
Beluga Formation
Page 1 of 6
Gamma Log
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Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
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Fmb
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Sm
9
Fmb
Sm
9
Fml
Fmb
Fcl
Fml
Coal
Fmb
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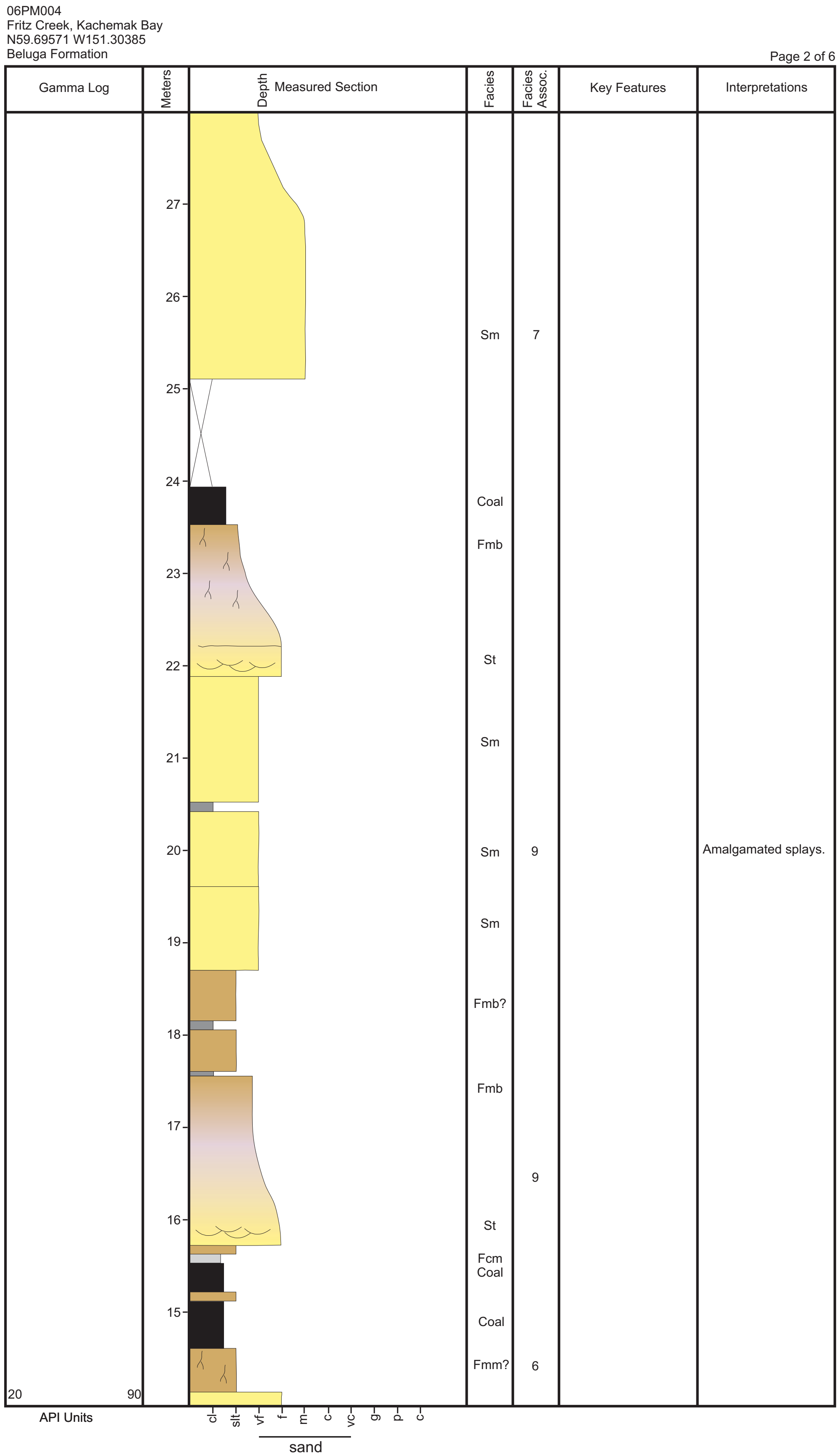
FIGURE A3


06PM004
Fritz Creek, Kachemak Bay
N59.69571 W151.30385
Beluga Formation
Page 2 of 6
Gamma Log
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Depth
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
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Coal
Fmb
St
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Sm
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Amalgamated splays.
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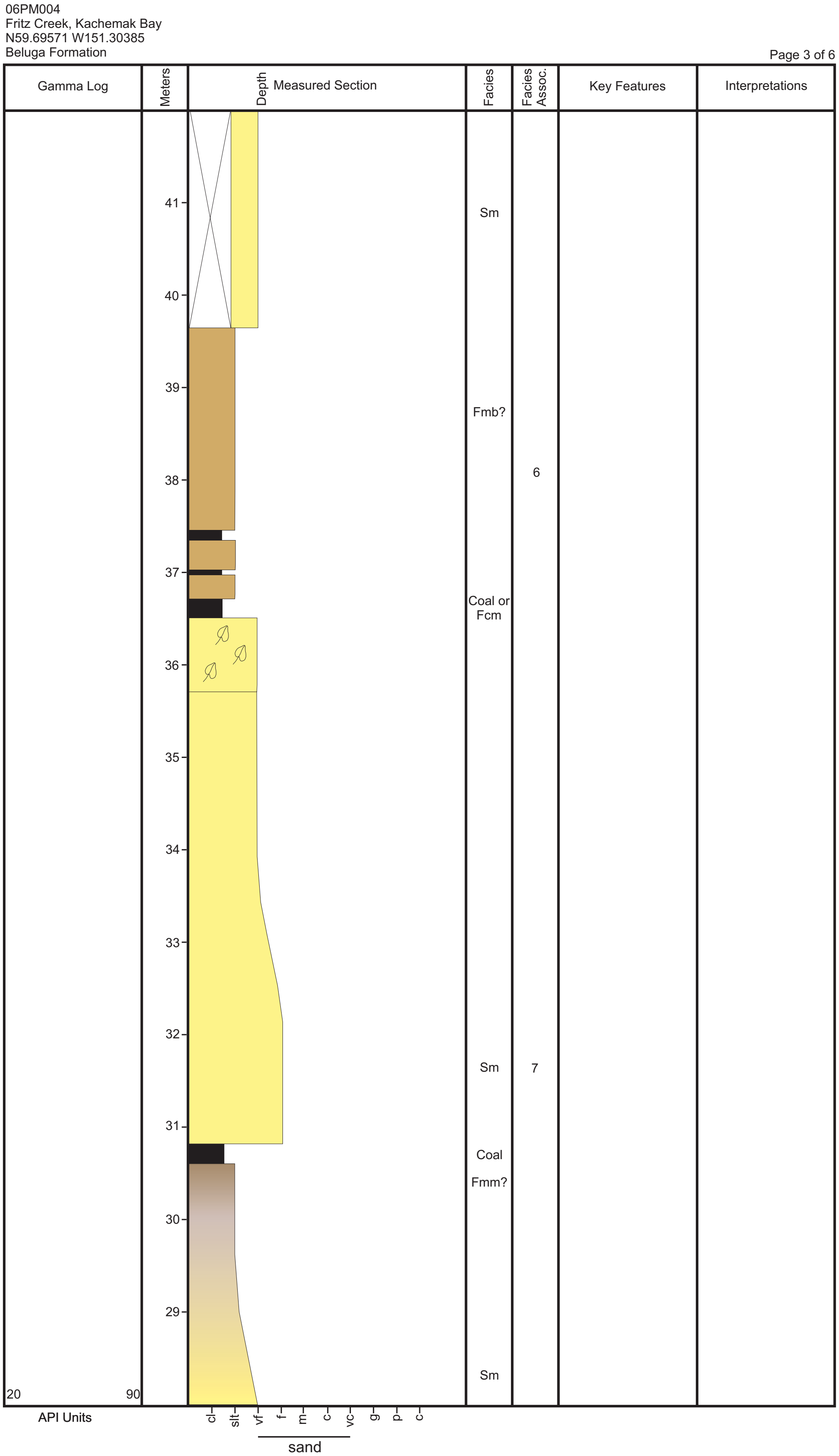
FIGURE A3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Fritz Creek, Kachemak Bay
N59.69571 W151.30385
Beluga Formation
Page 3 of 6
Gamma Log
Meters
Depth
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
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Sm
Fmb?
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Coal or Fcm
Sm
7
Coal
Fmm?
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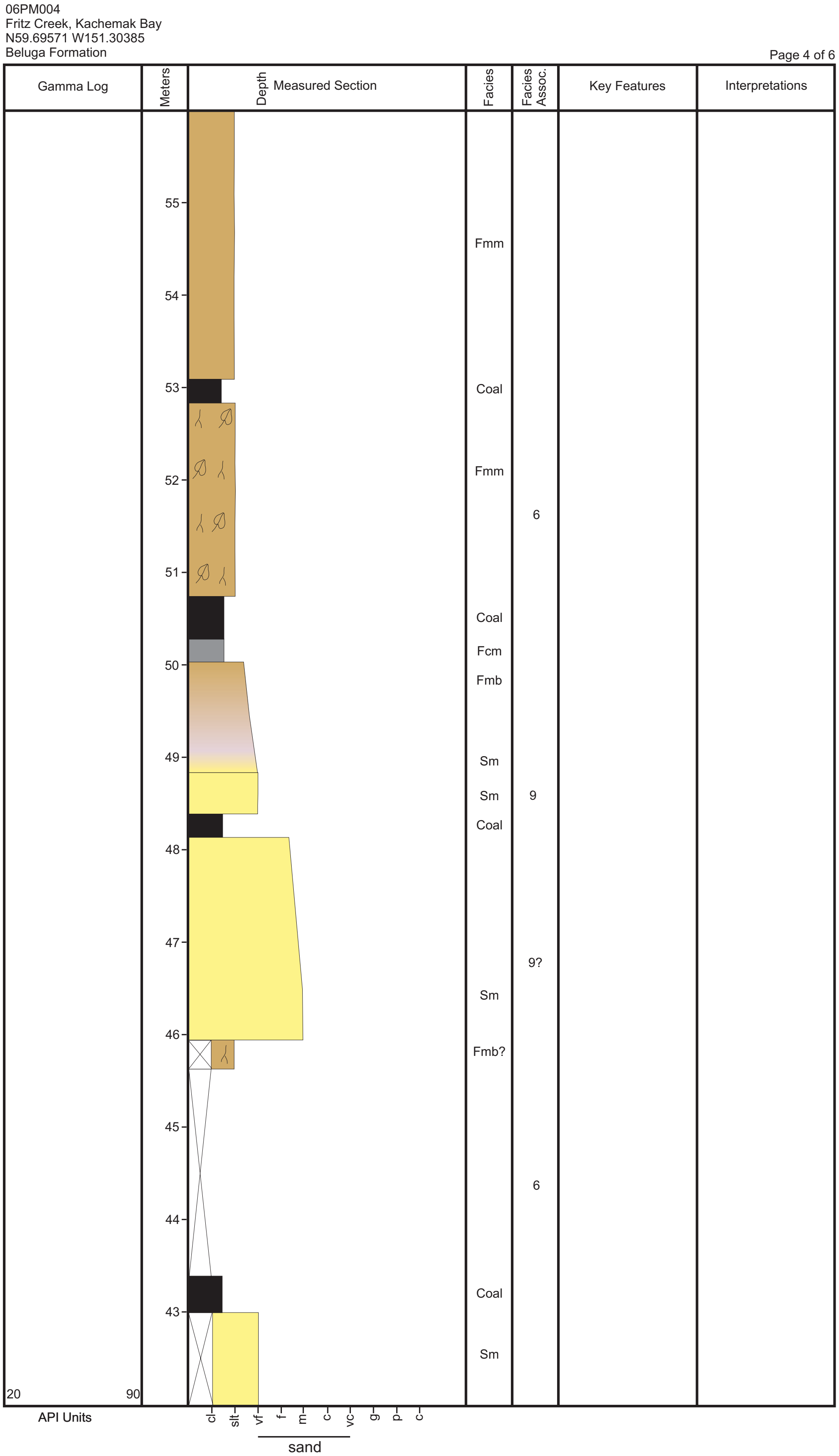
FIGURE A3


06PM004
Fritz Creek, Kachemak Bay
N59.69571 W151.30385
Beluga Formation
Page 4 of 6
Gamma Log
Meters
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Facies Assoc.
Key Features
Interpretations
55
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48
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46
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44
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Fmm
Coal
Fmm
6
Coal
Fcm
Fmb
Sm
Sm
9
Coal
9?
Sm
Fmb?
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Coal
Sm
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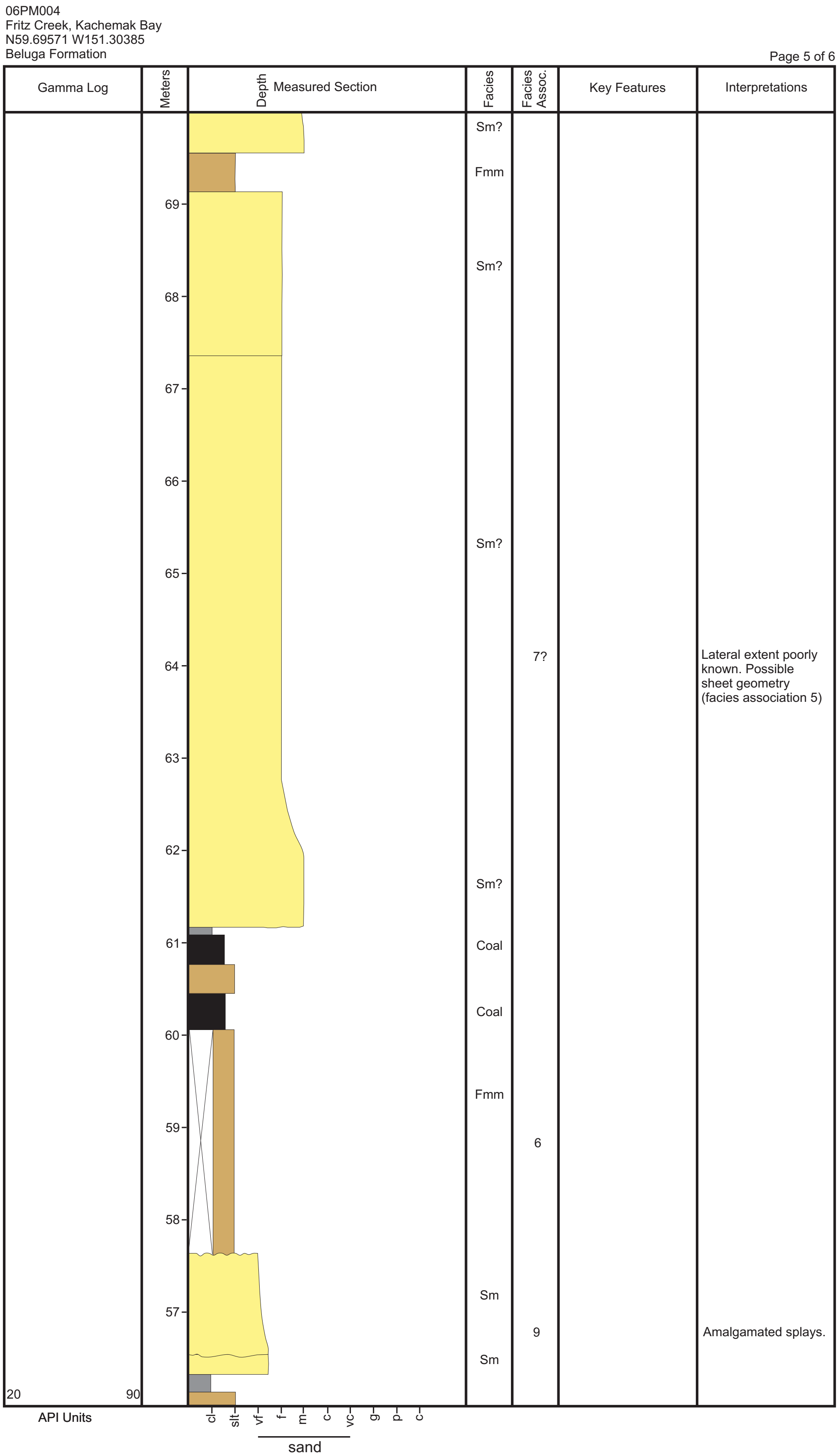
FIGURE A3


06PM004
Fritz Creek, Kachemak Bay
N59.69571 W151.30385
Beluga Formation
Page 5 of 6
Gamma Log
Meters
Depth
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
Sm?
Fmm
69
Sm?
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67
66
Sm?
65
7?
64
Lateral extent poorly known. Possible sheet geometry (facies association 5)
63
62
Sm?
61
Coal
Coal
60
Fmm
59
6
58
Sm
57
9
Amalgamated splays.
Sm
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90
API Units
cl
slt
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vc
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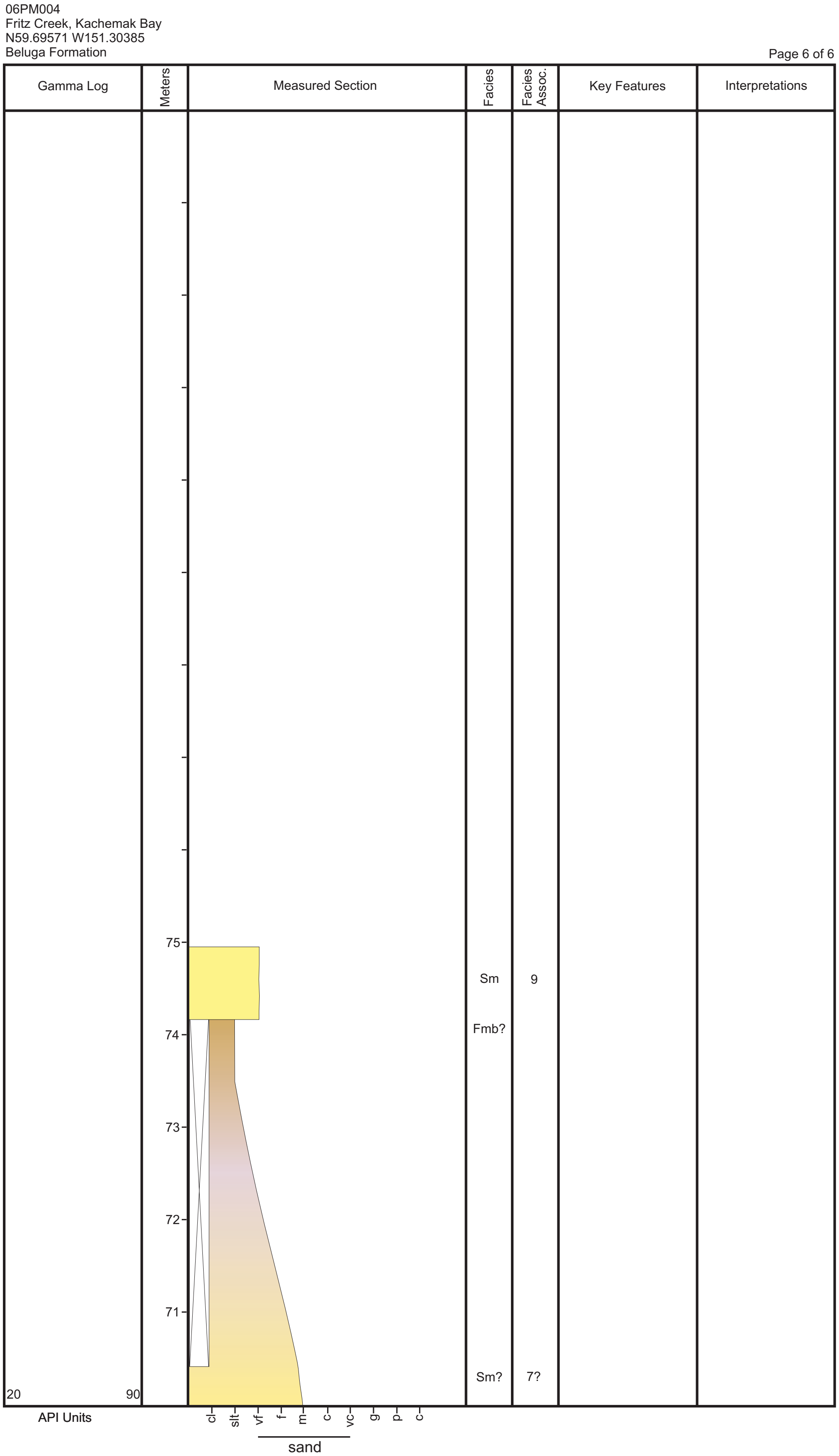
sand

FIGURE A3


06PM004
Fritz Creek, Kachemak Bay
N59.69571 W151.30385
Beluga Formation
Page 6 of 6
Gamma Log
Meters
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Facies
Facies Assoc.
Key Features
Interpretations
75
74
73
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71
Sm
9
Fmb?
Sm?
7?
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API Units
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sand

FIGURE A4

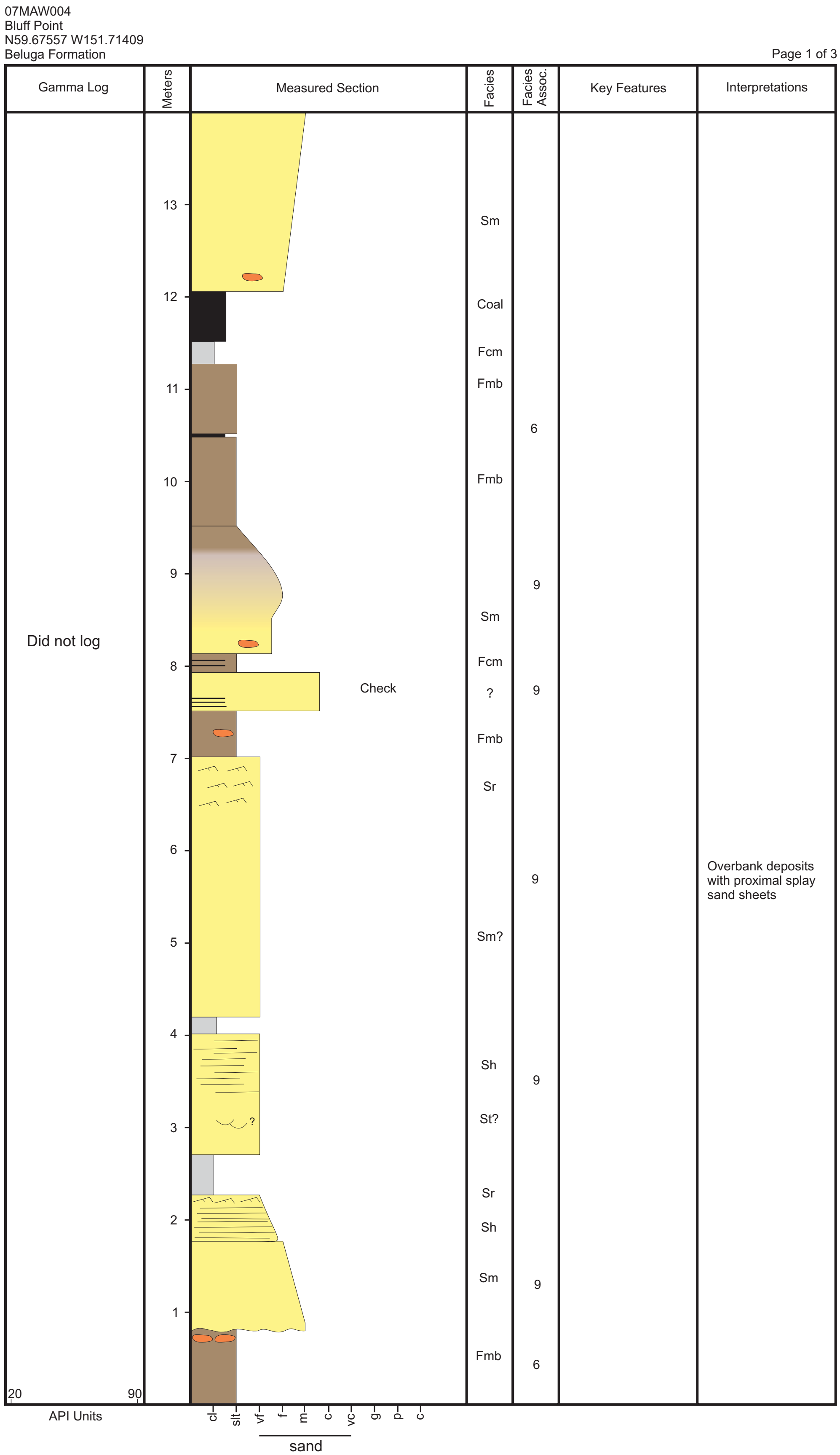

07MAW004
Bluff Point
N59.67557 W151.71409
Beluga Formation
Page 1 of 3
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
Did not log
20
90
API Units
13
12
11
10
9
8
7
6
5
4
3
2
1
Check
Sm
Coal
Fcm
Fmb
Fmb
Sm
Fcm
?
Fmb
Sr
Sm?
Sh
St?
Sr
Sh
Sm
Fmb
6
9
9
9
9
9
6
Overbank deposits with proximal splay sand sheets
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A4

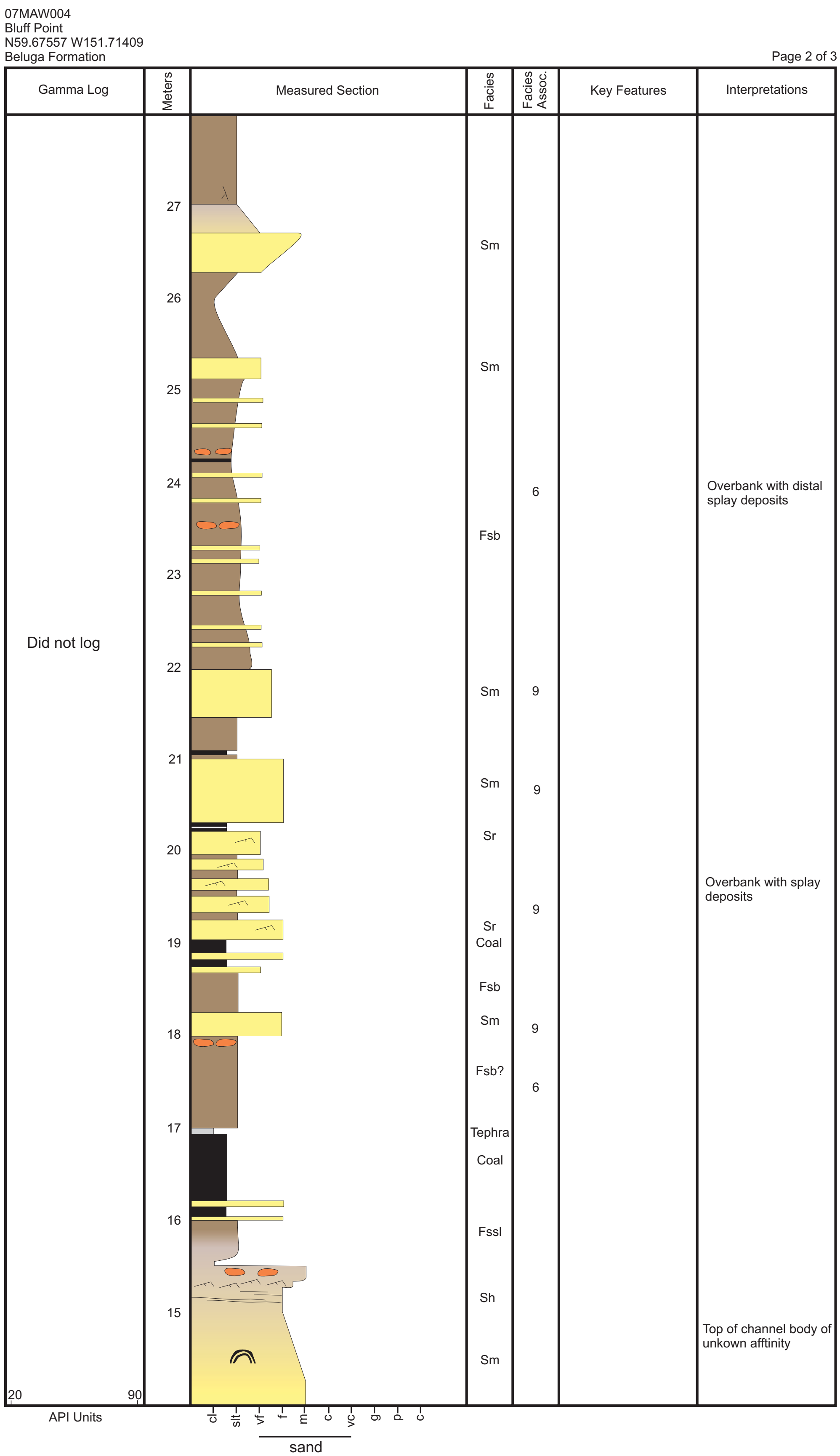

07MAW004
Bluff Point
N59.67557 W151.71409
Beluga Formation
Page 2 of 3
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
Did not log
20
90
API Units
27
26
25
24
23
22
21
20
19
18
17
16
15
Sm
Sm
Fsb
Sm
Sm
Sr
Sr
Coal
Fsb
Sm
Fsb?
Tephra
Coal
Fssl
Sh
Sm
6
9
9
9
9
6
Overbank with distal splay deposits
Overbank with splay deposits
Top of channel body of unkown afftinity
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A4

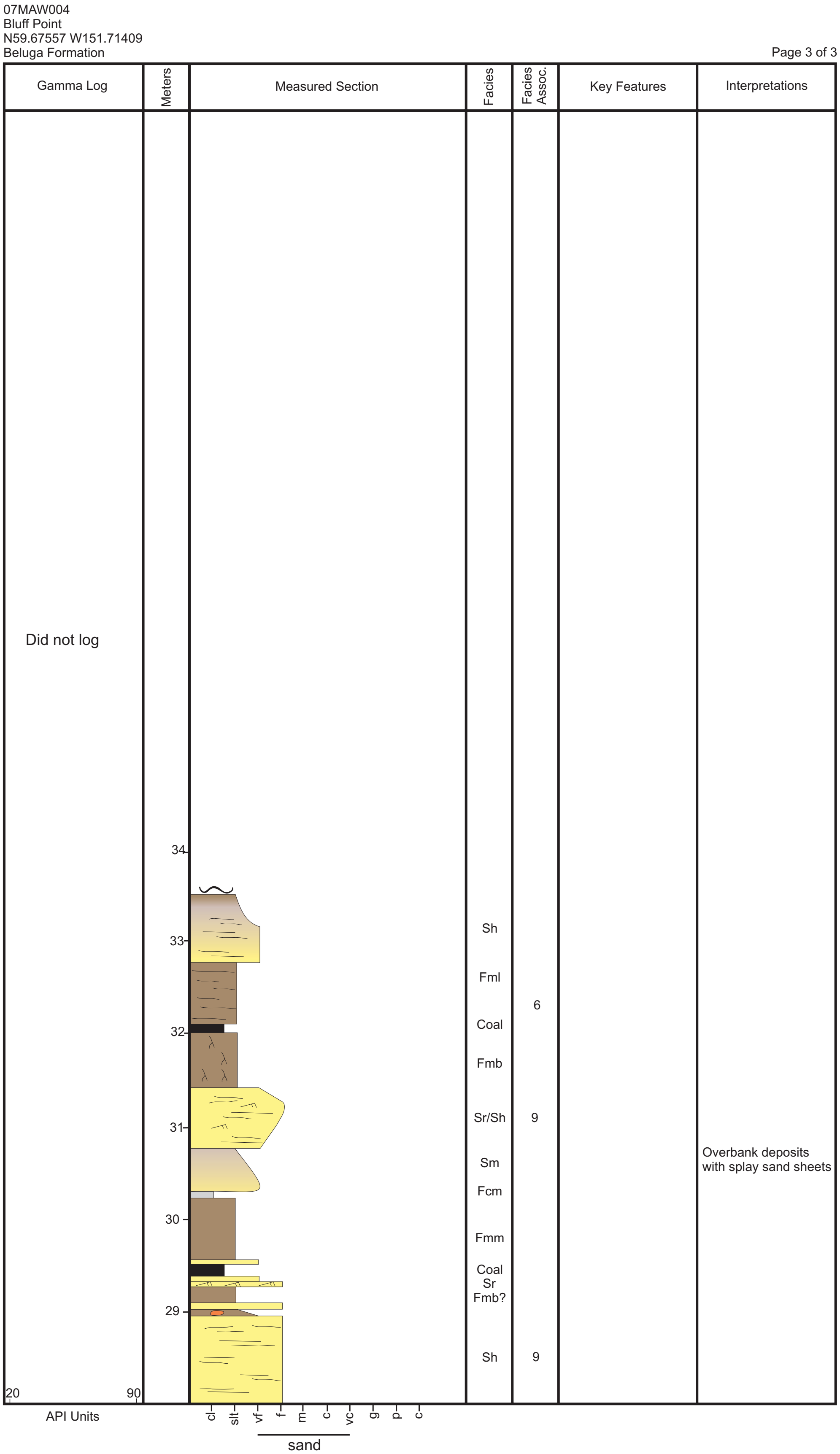

07MAW004
Bluff Point
N59.67557 W151.71409
Beluga Formation
Page 3 of 3
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
Did not log
34
33
32
31
30
29
Sh
Fml
Coal
Fmb
Sr/Sh
Sm
Fcm
Fmm
Coal
Sr
Fmb?
Sh
6
9
9
Overbank deposits with splay sand sheets
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A5

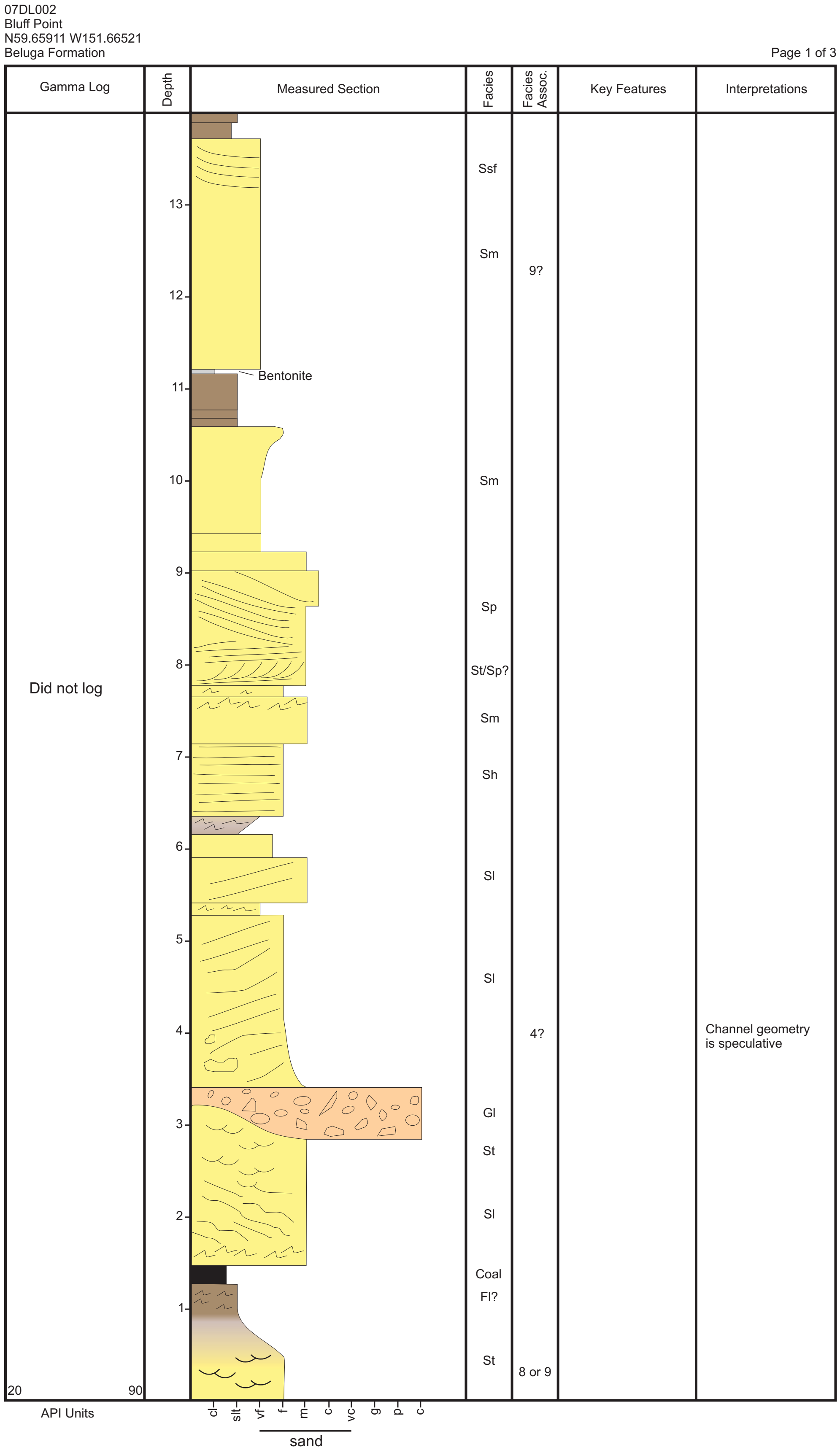

07DL002
Bluff Point
N59.65911 W151.66521
Beluga Formation
Page 1 of 3
Gamma Log
Depth
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
Did not log
20
90
API Units
13
12
11
10
9
8
7
6
5
4
3
2
1
Bentonite
Ssf
Sm
Sm
Sp
St/Sp?
Sm
Sh
Sl
Sl
Gl
St
Sl
Coal
Fl?
St
9?
4?
8 or 9
Channel geometry is speculative
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A5

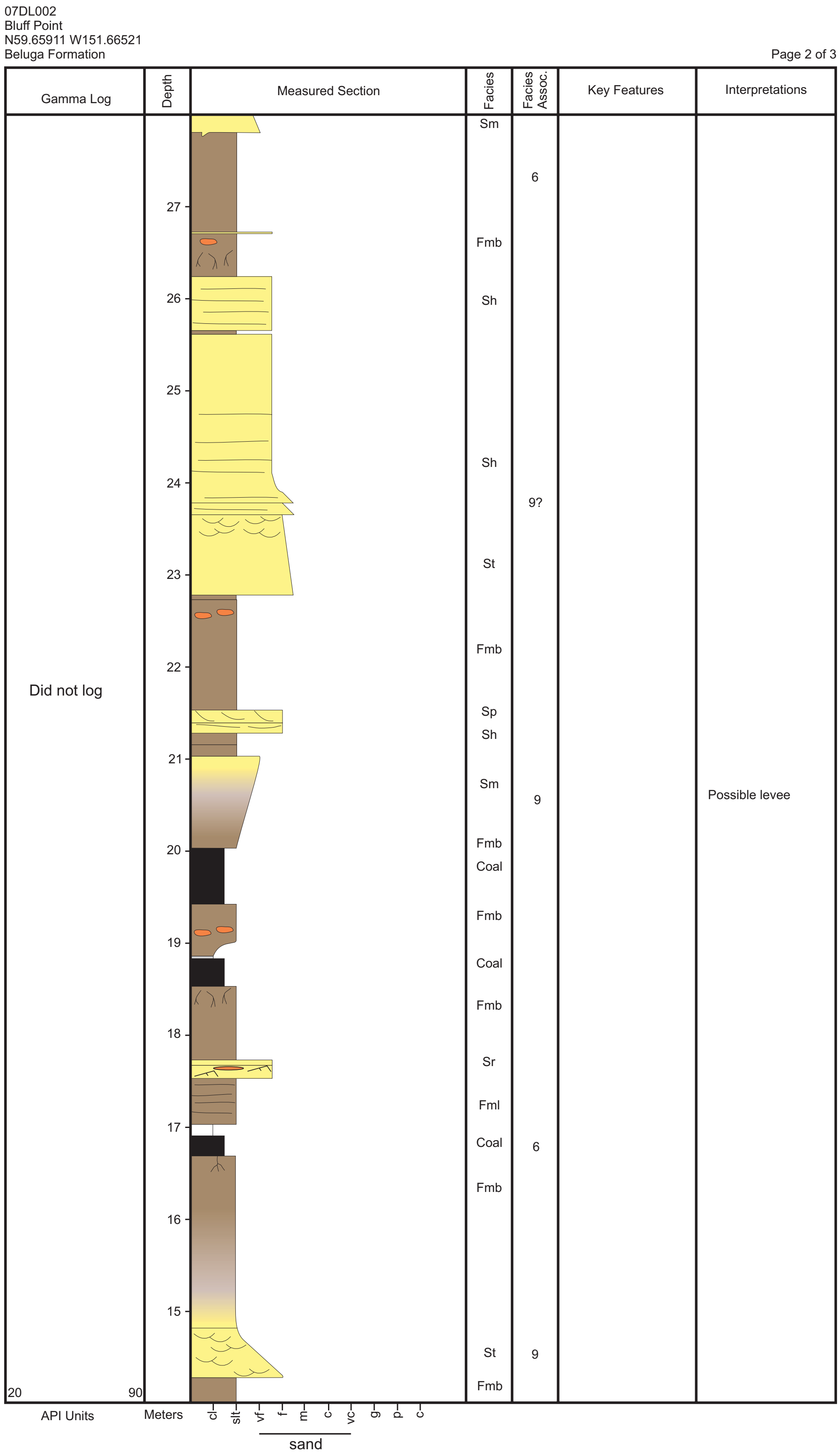

07DL002
Bluff Point
N59.65911 W151.66521
Beluga Formation
Page 2 of 3
Gamma Log
Depth
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
Did not log
20
90
API Units
Meters
27
26
25
24
23
22
21
20
19
18
17
16
15
cl
slt
vf
f
m
c
vc
g
p
c
sand
Sm
Fmb
Sh
Sh
St
Fmb
Sp
Sh
Sm
Fmb
Coal
Fmb
Coal
Fmb
Sr
Fml
Coal
Fmb
St
Fmb
6
9?
9
6
9
Possible levee

FIGURE A5

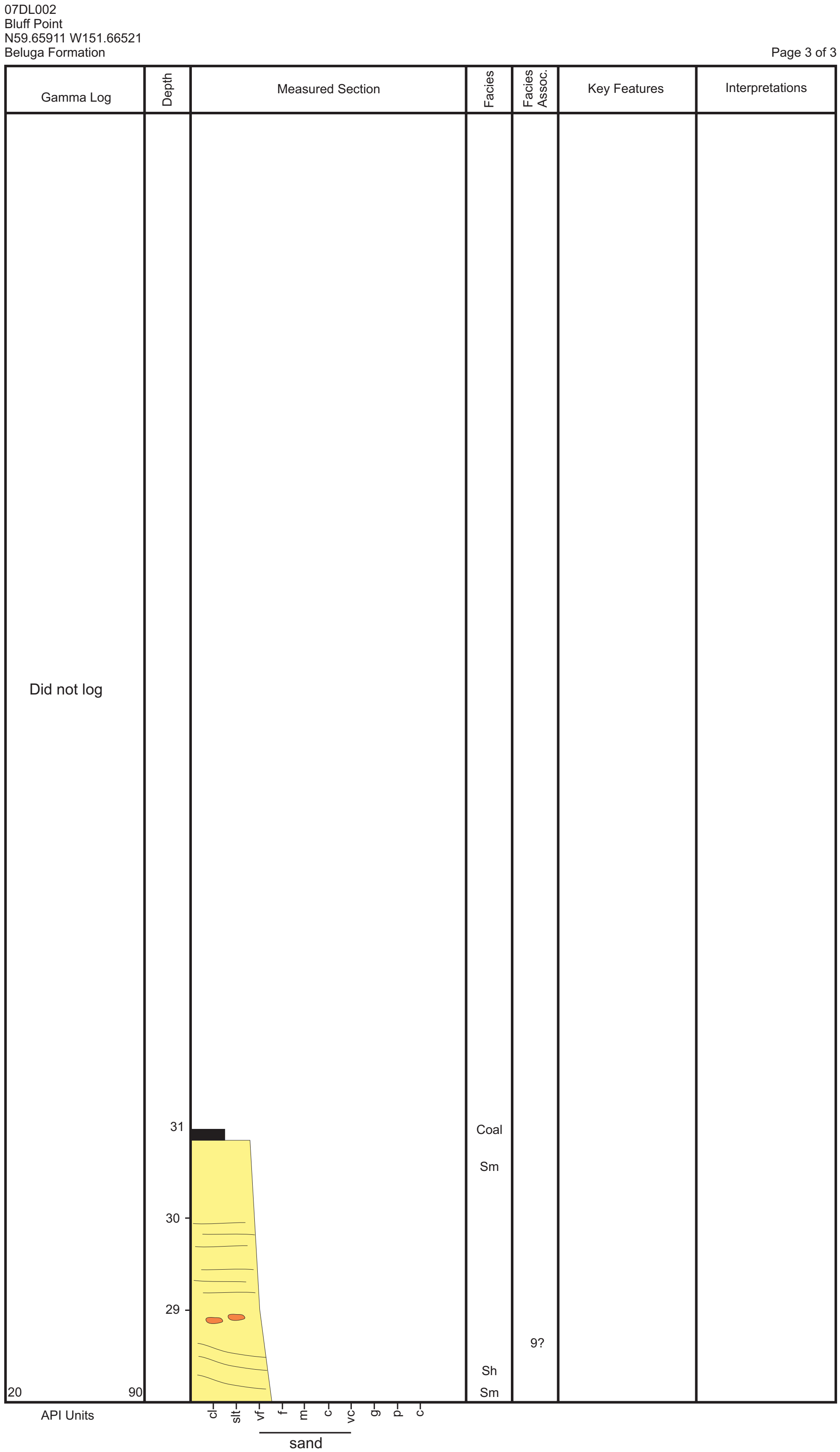

07DL002
Bluff Point
N59.65911 W151.66521
Beluga Formation
Page 3 of 3
Gamma Log
Depth
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
Did not log
31
30
29
Coal
Sm
Sh
Sm
9?
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A6

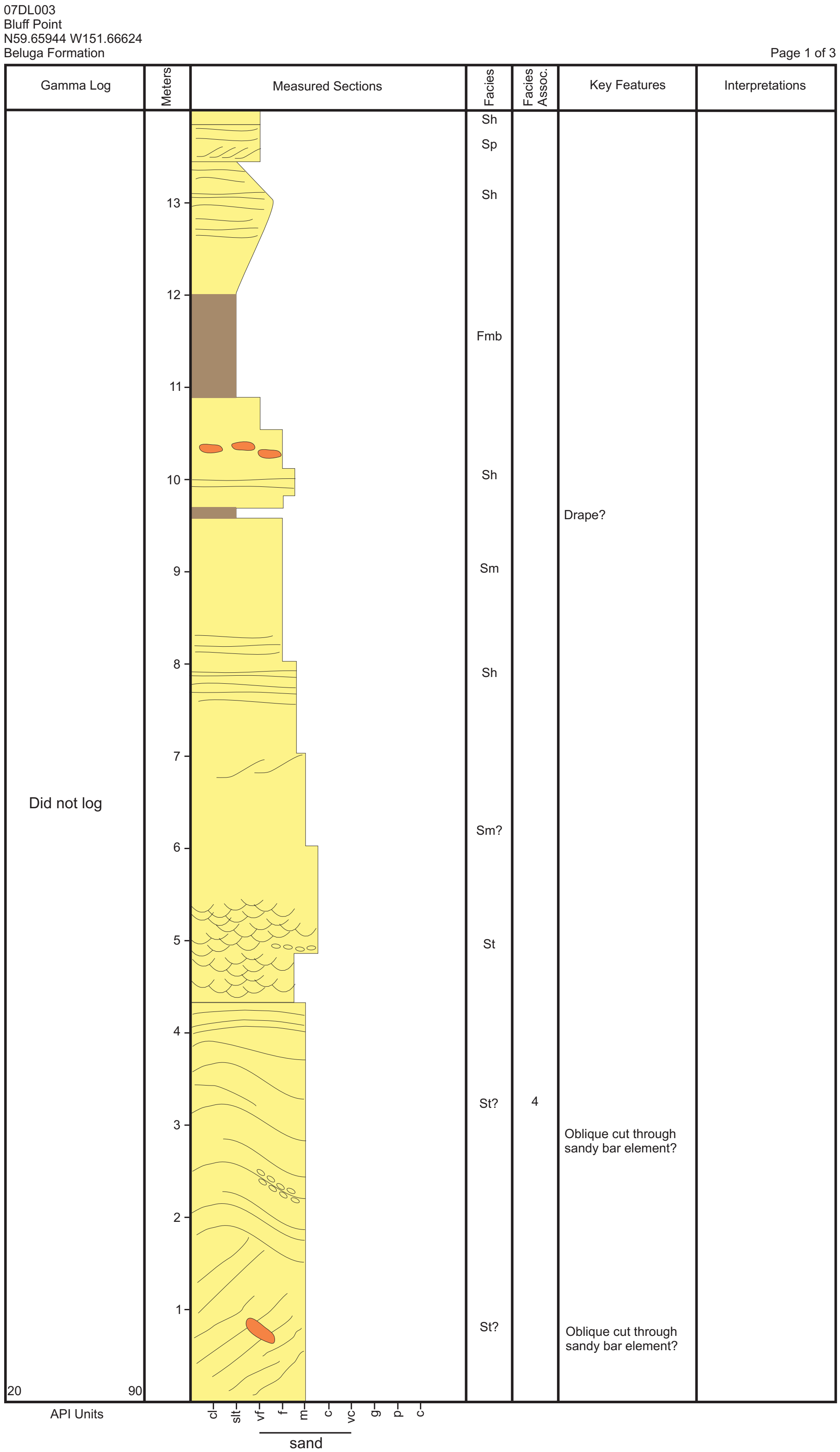

07DL003
Bluff Point
N59.65944 W151.66624
Beluga Formation
Page 1 of 3
Gamma Log
Meters
Measured Sections
Facies
Facies Assoc.
Key Features
Interpretations
Sh
Sp
Sh
13
12
Fmb
11
Sh
10
Drape?
Sm
9
8
Sh
7
Did not log
Sm?
6
St
5
4
St?
4
3
Oblique cut through sandy bar element?
2
1
St?
Oblique cut through sandy bar element?
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A6

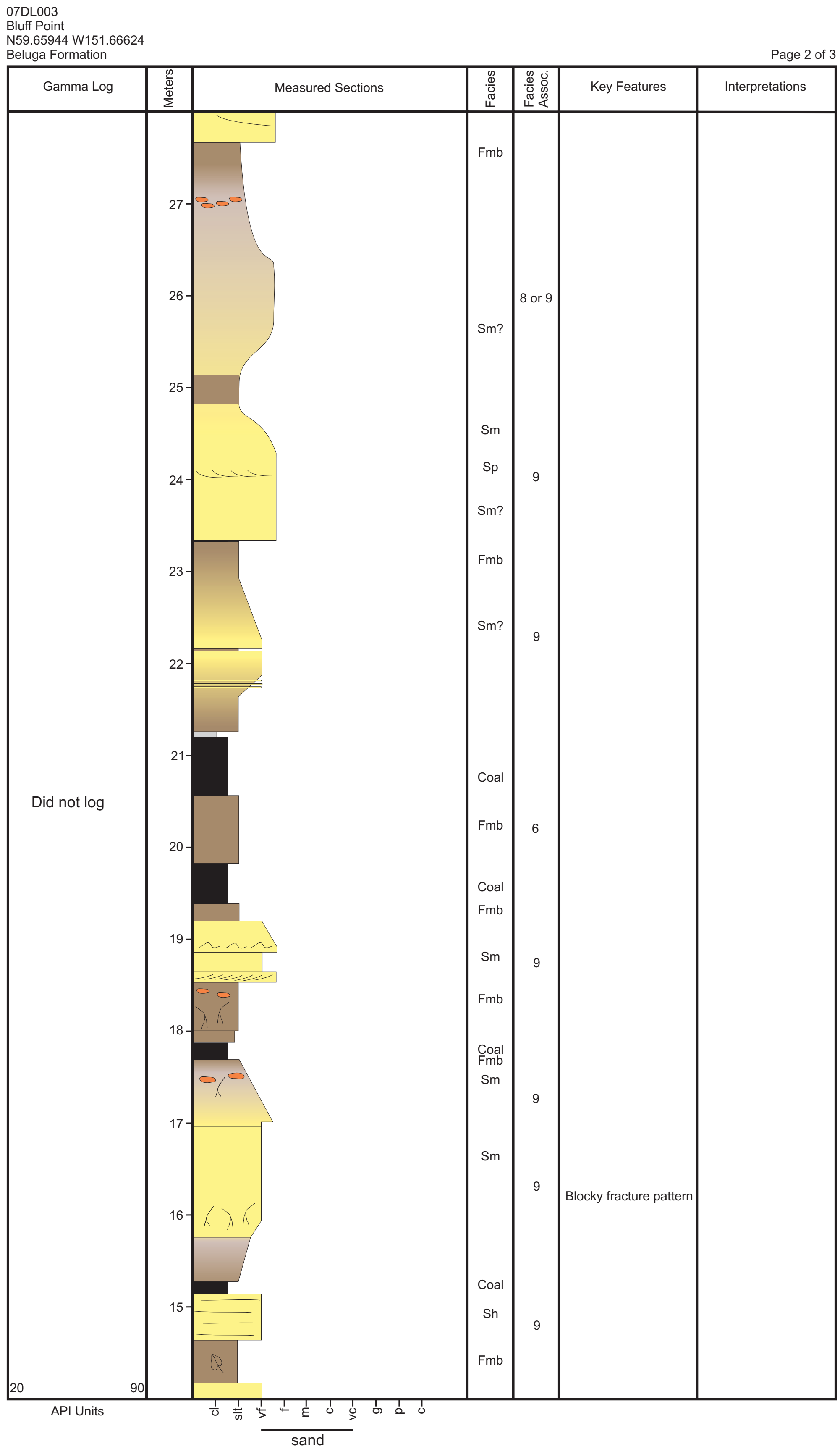

07DL003
Bluff Point
N59.65944 W151.66624
Beluga Formation
Page 2 of 3
Gamma Log
Meters
Measured Sections
Facies
Facies Assoc.
Key Features
Interpretations
Did not log
20
90
API Units
27
26
25
24
23
22
21
20
19
18
17
16
15
Fmb
Sm?
Sm
Sp
Sm?
Fmb
Sm?
Coal
Fmb
Coal
Fmb
Sm
Fmb
Coal
Fmb
Sm
Sm
Coal
Sh
Fmb
8 or 9
9
9
6
9
9
9
9
Blocky fracture pattern
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A6

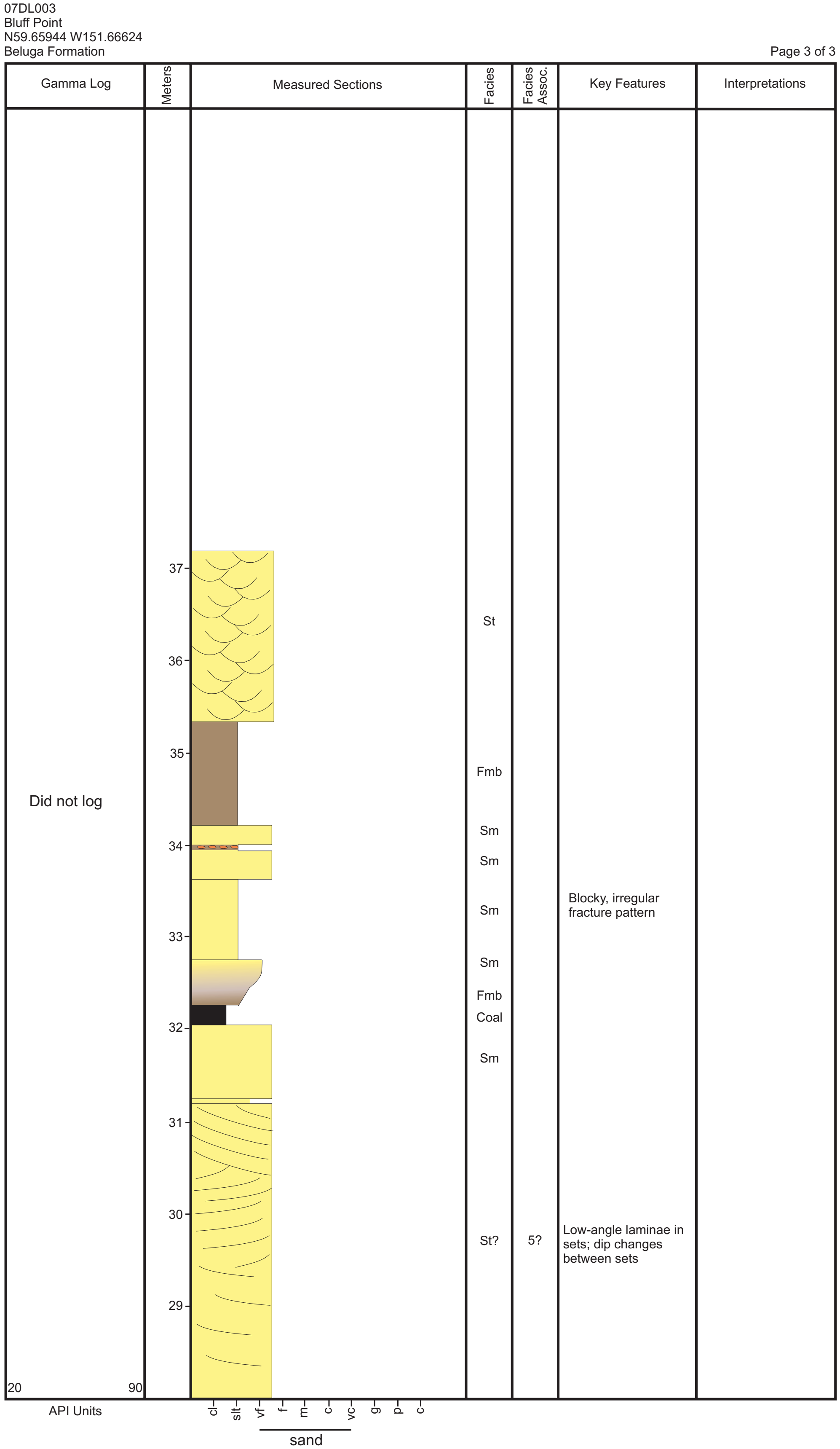
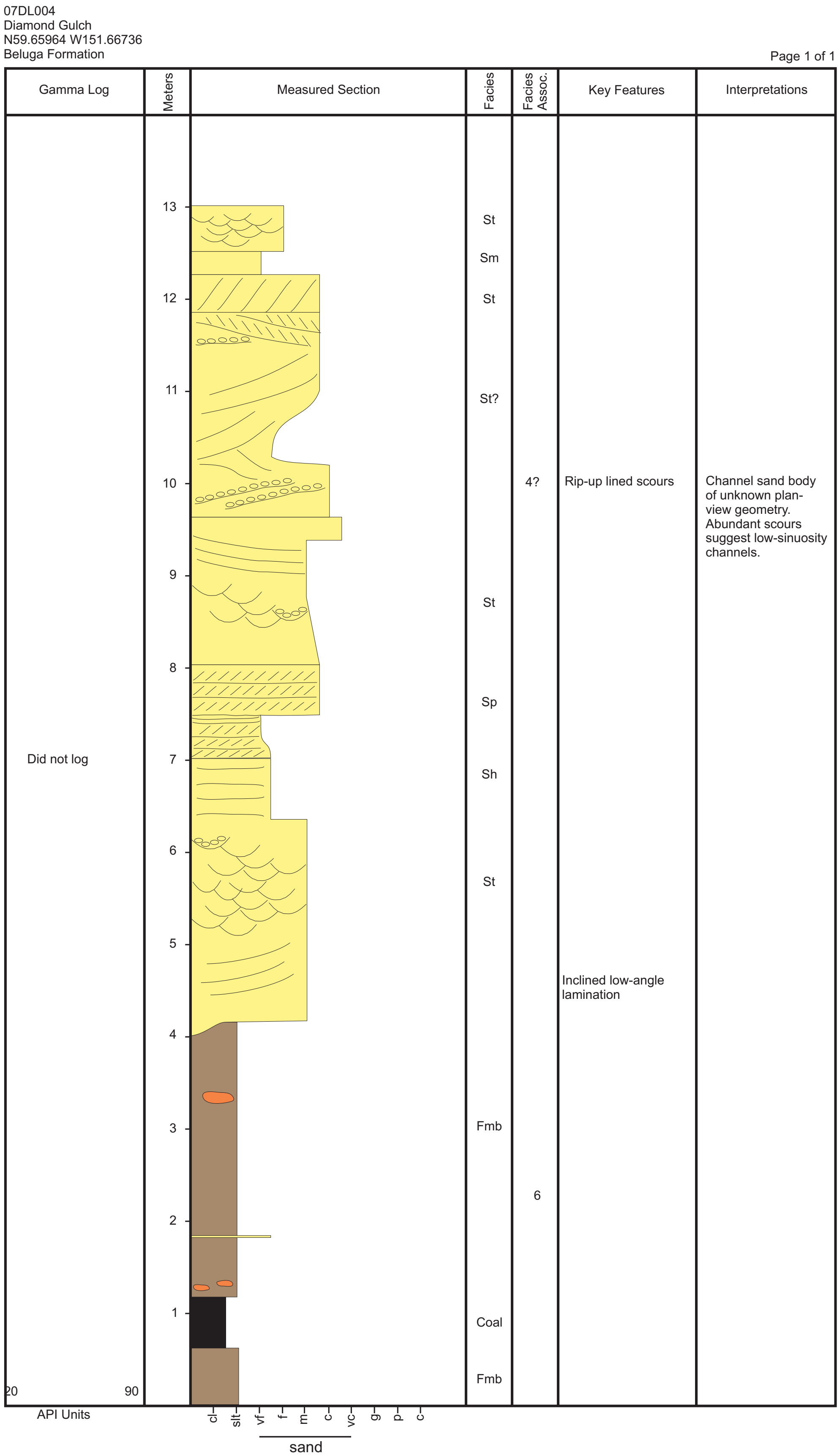

07DL003
Bluff Point
N59.65944 W151.66624
Beluga Formation
Page 3 of 3
Gamma Log
Meters
Measured Sections
Facies
Facies Assoc.
Key Features
Interpretations
Did not log
37
36
35
34
33
32
31
30
29
St
Fmb
Sm
Sm
Sm
Sm
Fmb
Coal
Sm
St?
5?
Blocky, irregular fracture pattern
Low-angle laminae in sets; dip changes between sets
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A7



07DL004
Diamond Gulch
N59.65964 W151.66736
Beluga Formation
Page 1 of 1
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
St
Sm
St
St?
4?
Rip-up lined scours
Channel sand body of unknown plan-view geometry. Abundant scours suggest low-sinuosity channels.
St
Sp
Did not log
Sh
St
Inclined low-angle lamination
Fmb
6
Coal
Fmb
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A8

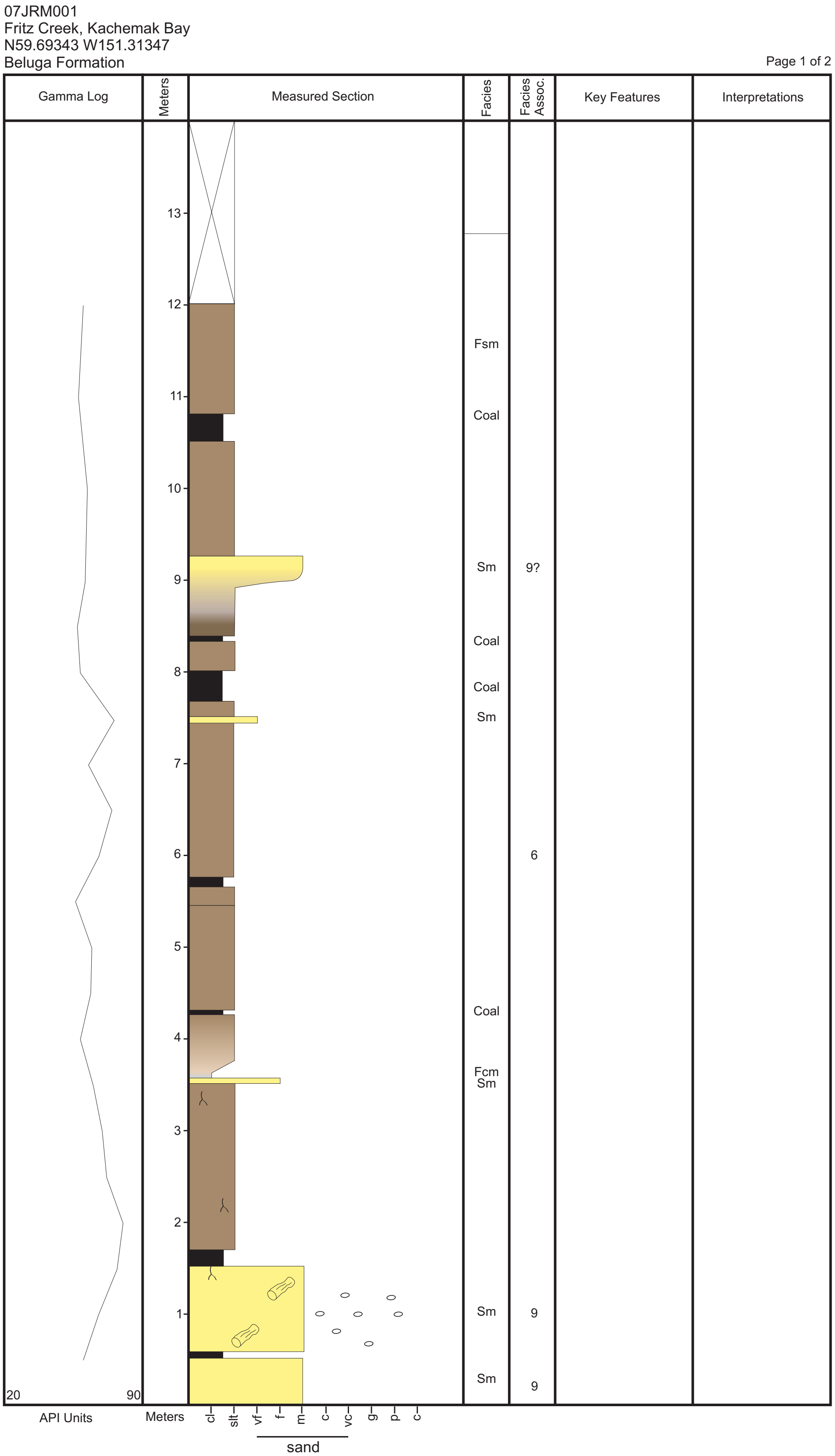

07JRM001
Fritz Creek, Kachemak Bay
N59.69343 W151.31347
Beluga Formation
Page 1 of 2
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
13
12
11
10
9
8
7
6
5
4
3
2
1
Fsm
Coal
Sm
9?
Coal
Coal
Sm
6
Coal
Fcm
Sm
Sm
9
Sm
9
20
90
API Units
Meters
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A8

07JRM001
Fritz Creek, Kachemak Bay
N59.69343 W151.31347
Beluga Formation

Page 2 of 2

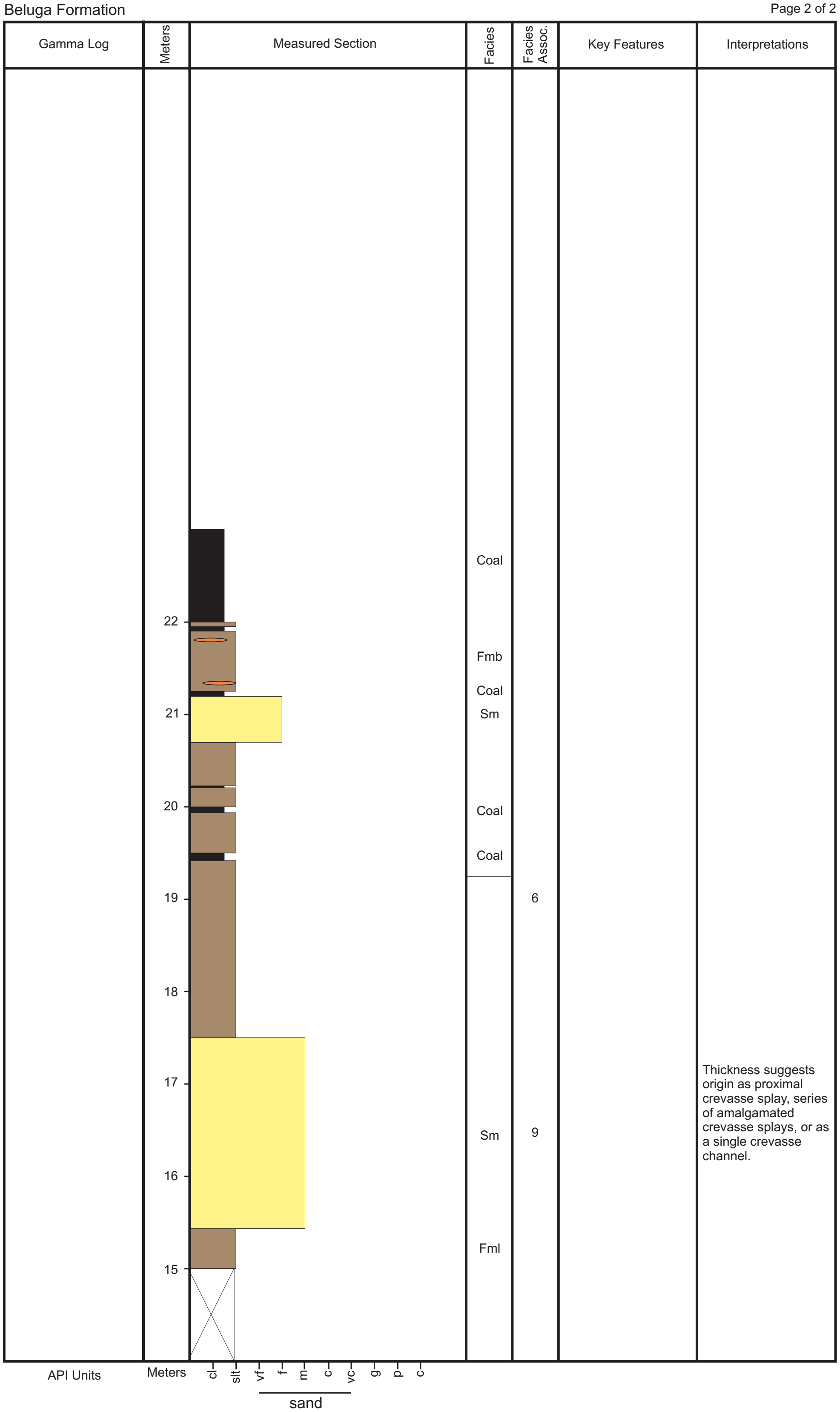


FIGURE A9

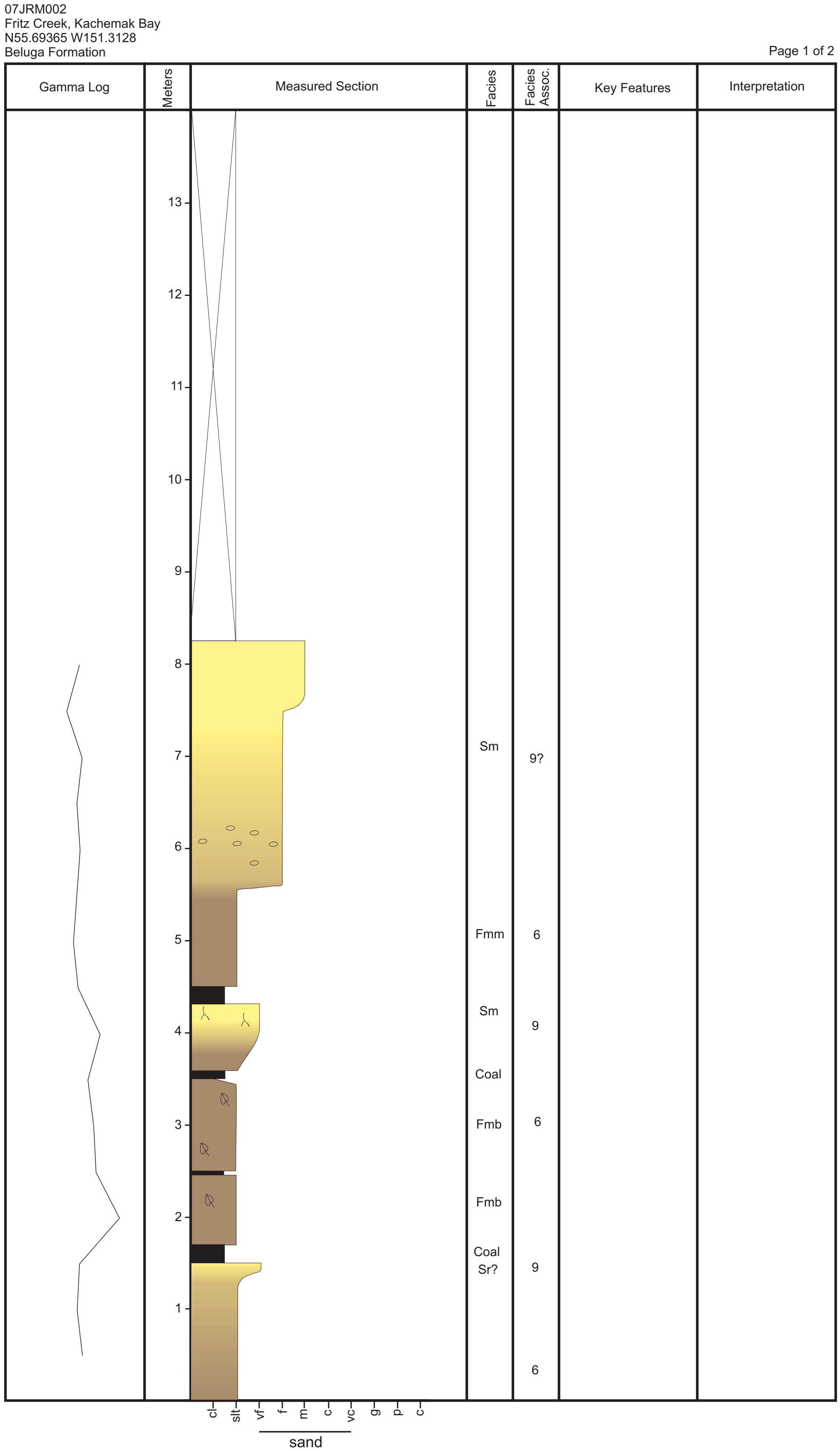

07JRM002
Fritz Creek, Kachemak Bay
N55.69365 W151.3128
Beluga Formation
Page 1 of 2
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretation
13
12
11
10
9
8
7
6
5
4
3
2
1
Sm
9?
Fmm
6
Sm
9
Coal
Fmb
6
Fmb
Coal
Sr?
9
6
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A9

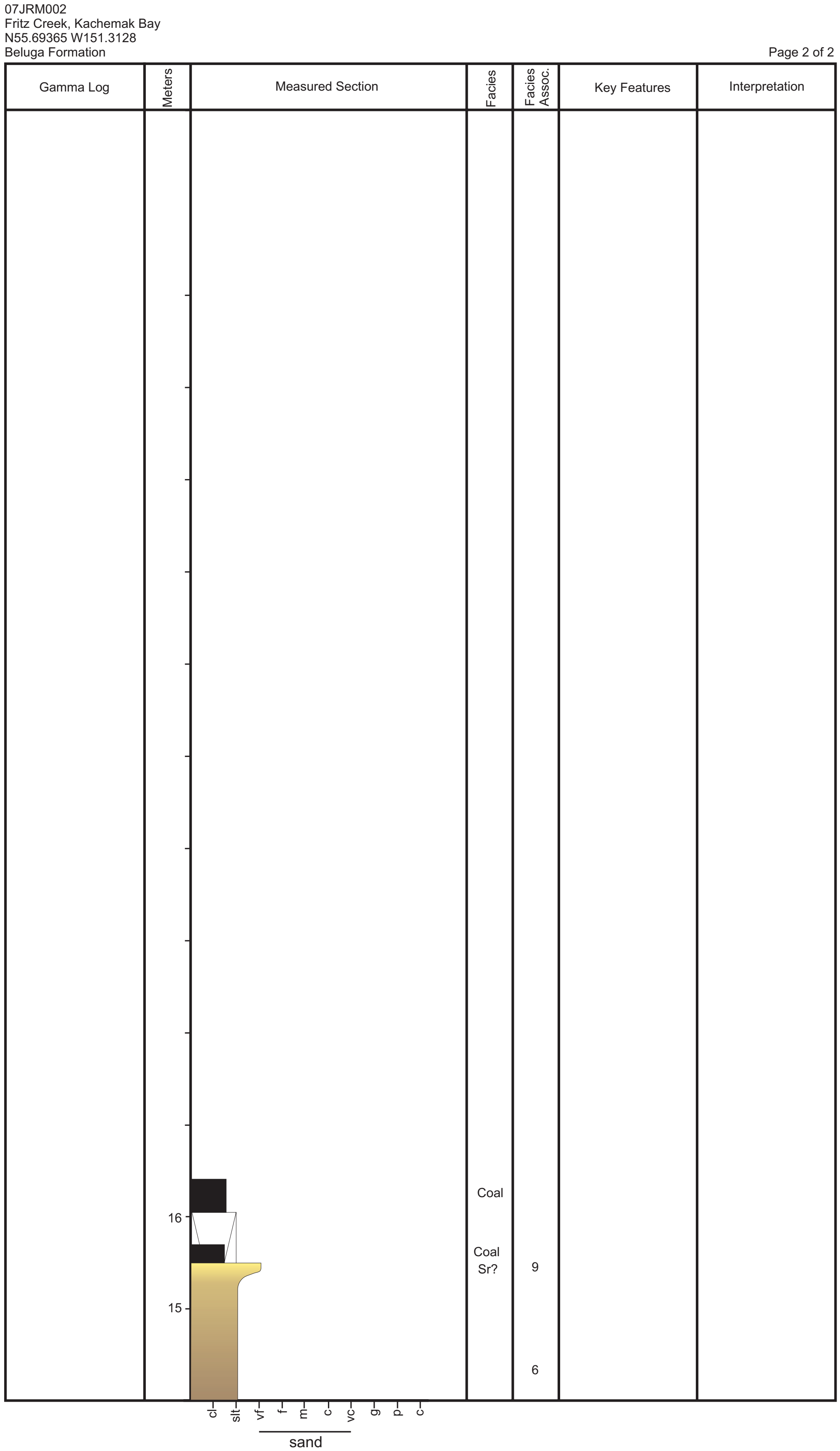

07JRM002
Fritz Creek, Kachemak Bay
N55.69365 W151.3128
Beluga Formation
Page 2 of 2
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretation
16
15
Coal
Coal
Sr?
9
6
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A10

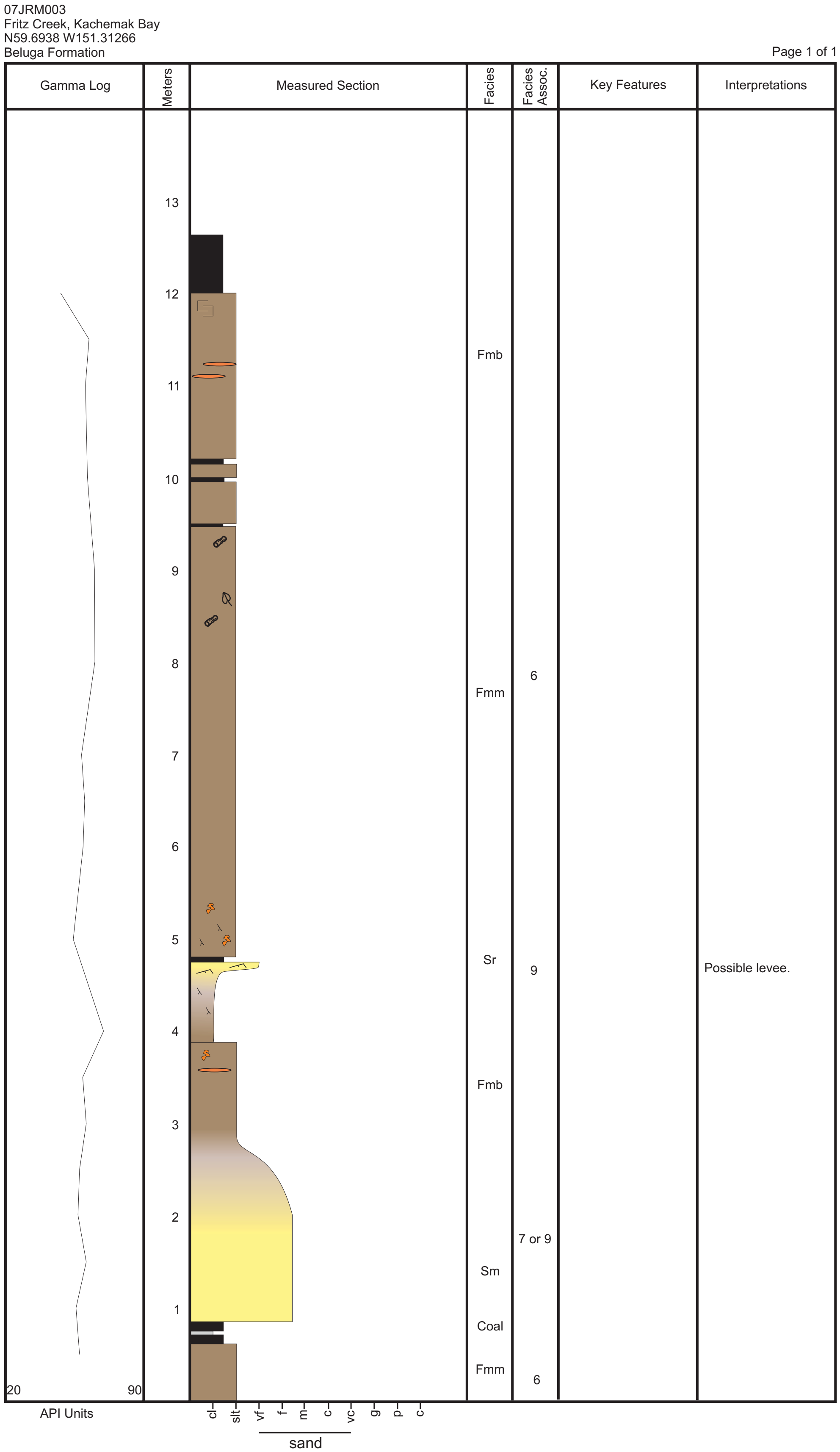

07JRM003
Fritz Creek, Kachemak Bay
N59.6938 W151.31266
Beluga Formation
Page 1 of 1
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
13
12
11
10
9
8
7
6
5
4
3
2
1
Fmb
Fmm
6
Sr
9
Possible levee.
Fmb
7 or 9
Sm
Coal
Fmm
6
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A11

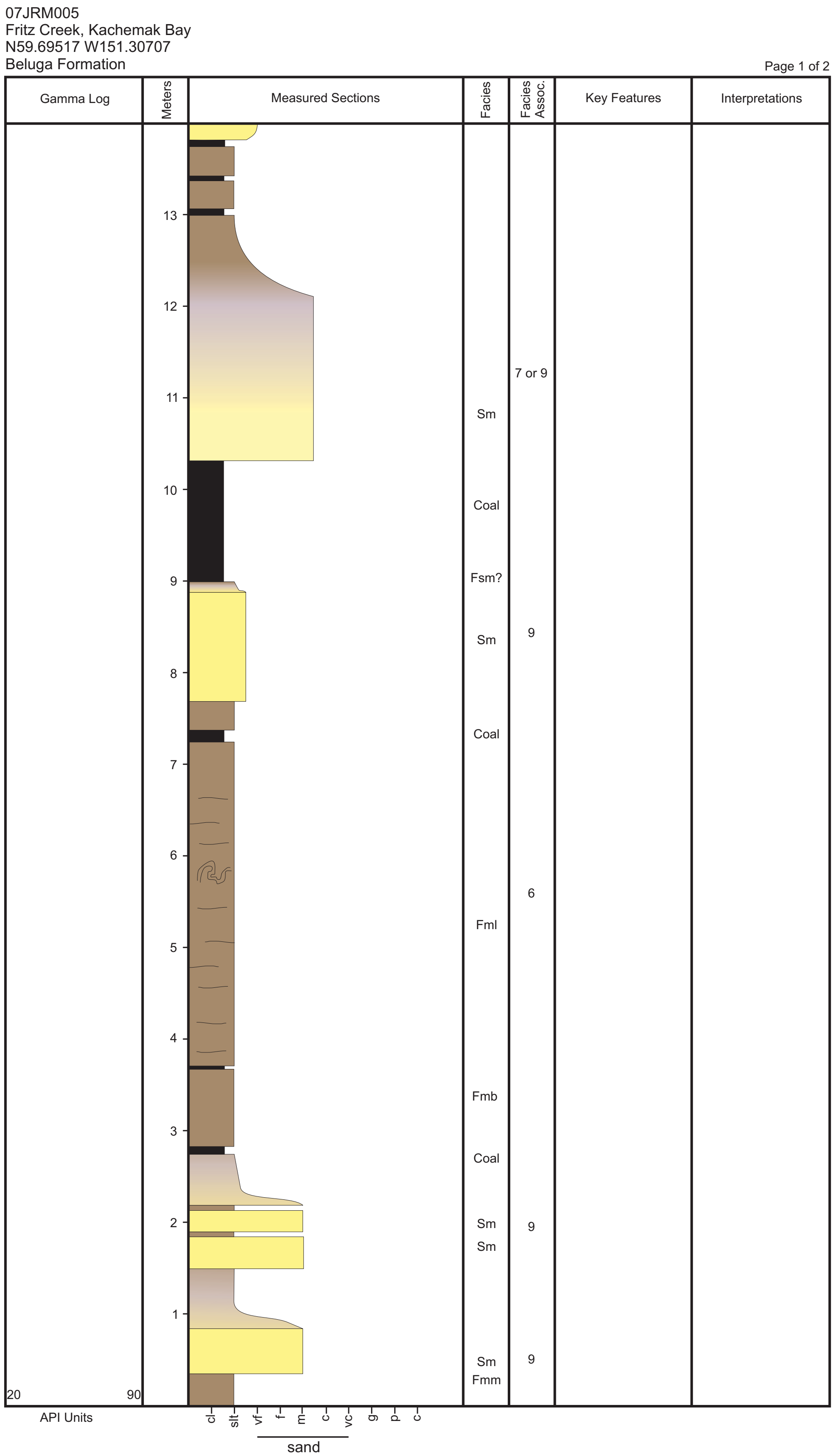

07JRM005
Fritz Creek, Kachemak Bay
N59.69517 W151.30707
Beluga Formation
Page 1 of 2
Gamma Log
Meters
Measured Sections
Facies
Facies Assoc.
Key Features
Interpretations
13
12
11
10
9
8
7
6
5
4
3
2
1
7 or 9
Sm
Coal
Fsm?
9
Sm
Coal
6
Fml
Fmb
Coal
Sm
9
Sm
Sm
9
Fmm
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A11

07JRM005
Fritz Creek, Kachemak Bay
N59.69517 W151.30707
Beluga Formation

Page 2 of 2

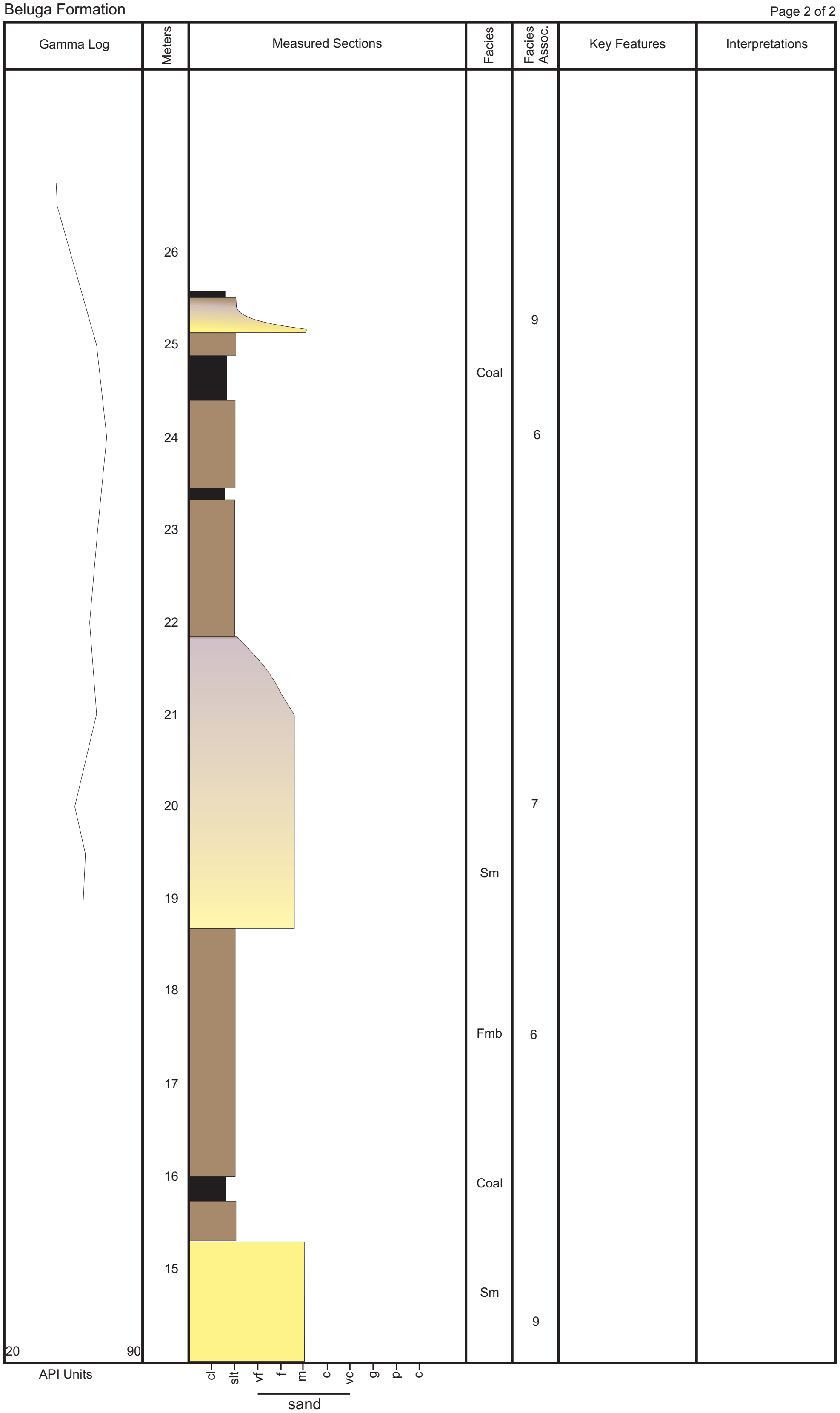


FIGURE A12

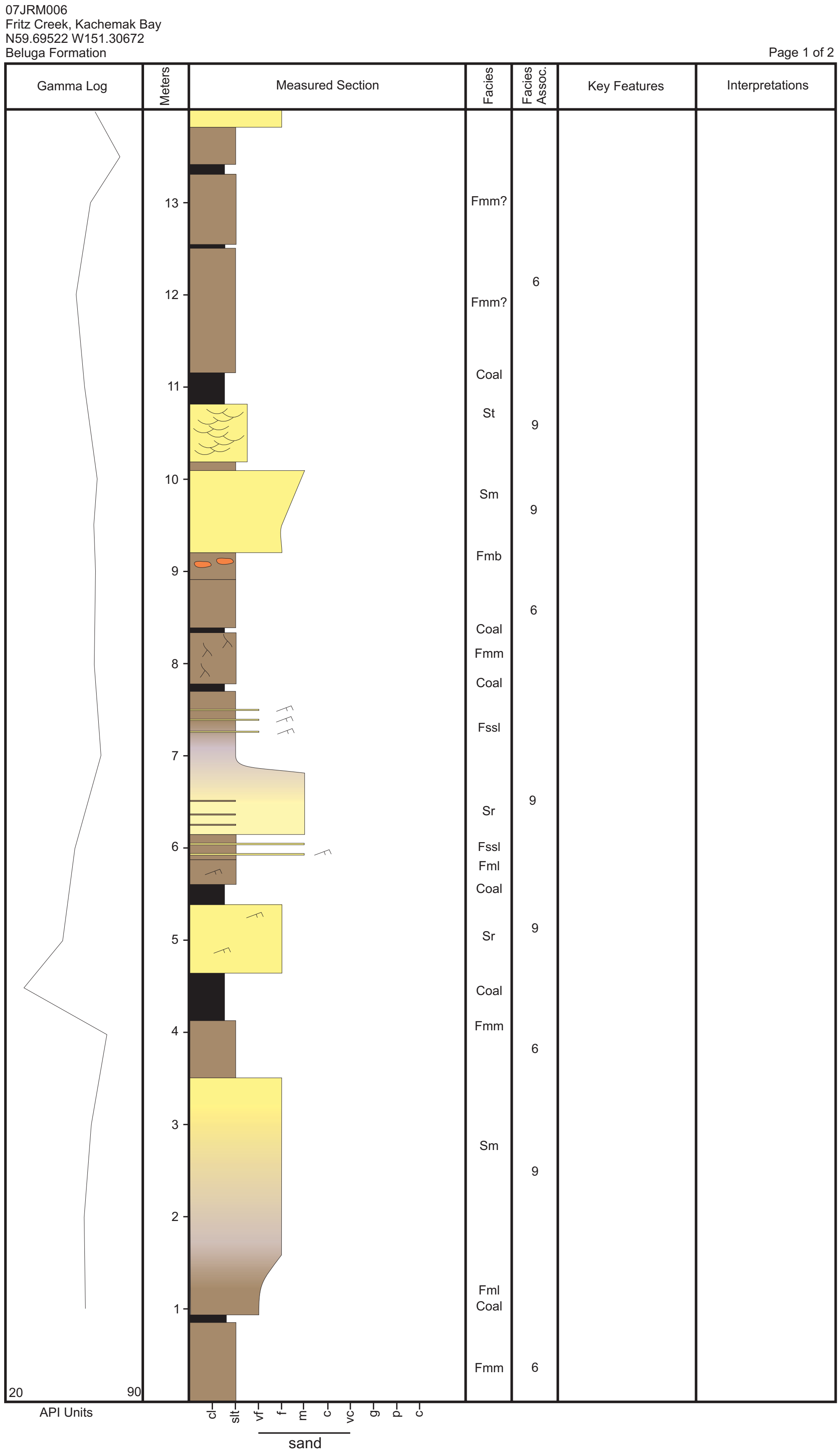

07JRM006
Fritz Creek, Kachemak Bay
N59.69522 W151.30672
Beluga Formation
Page 1 of 2
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
Fmm?
Fmm?
Coal
St
Sm
Fmb
Coal
Fmm
Coal
Fssl
Sr
Fssl
Fml
Coal
Sr
Coal
Fmm
Sm
Fml
Coal
Fmm
6
9
9
6
9
9
6
9
6
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A12

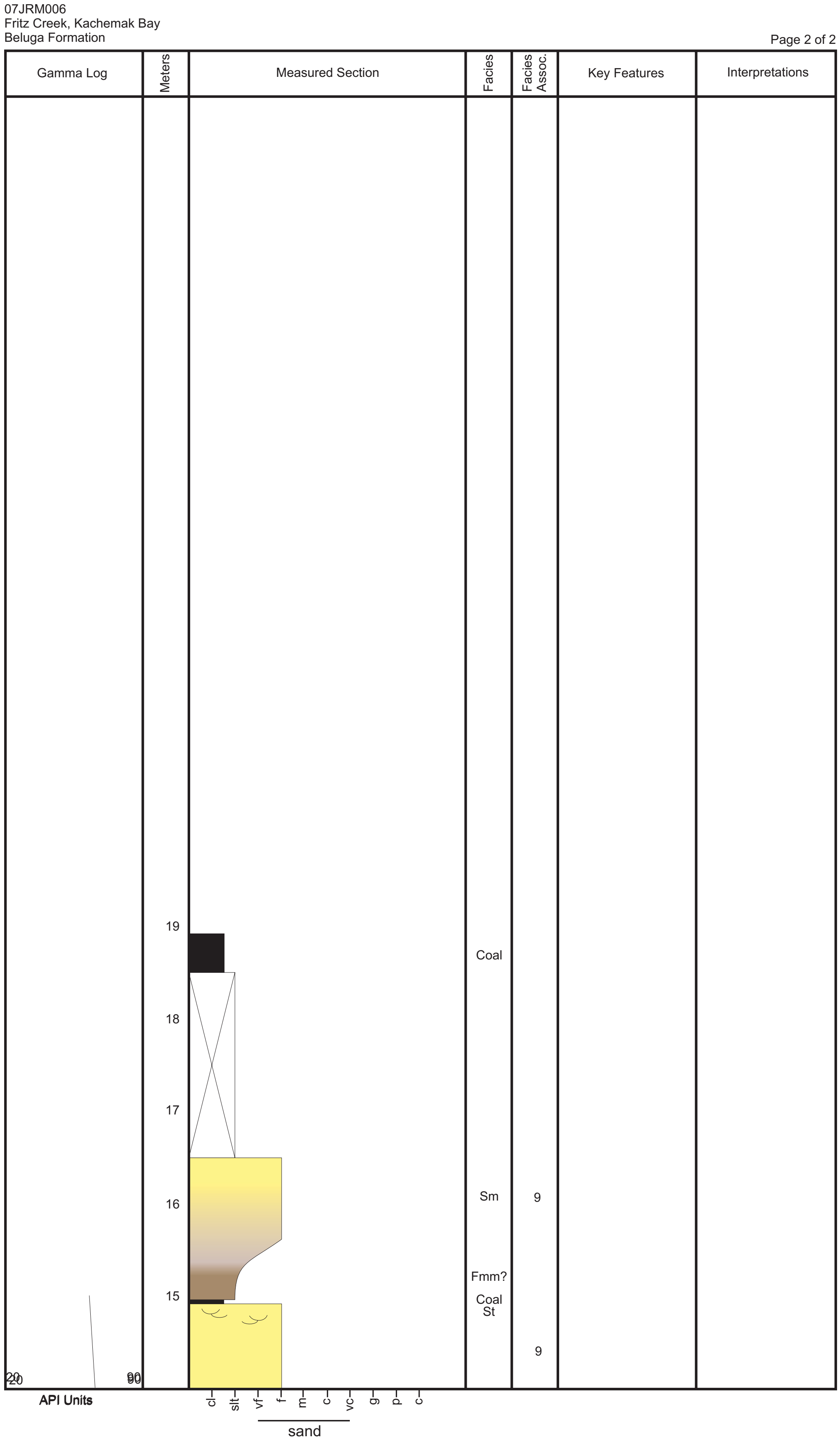

07JRM006
Fritz Creek, Kachemak Bay
Beluga Formation
Page 2 of 2
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
19
18
17
16
15
Coal
Sm
9
Fmm?
Coal
St
9
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A13

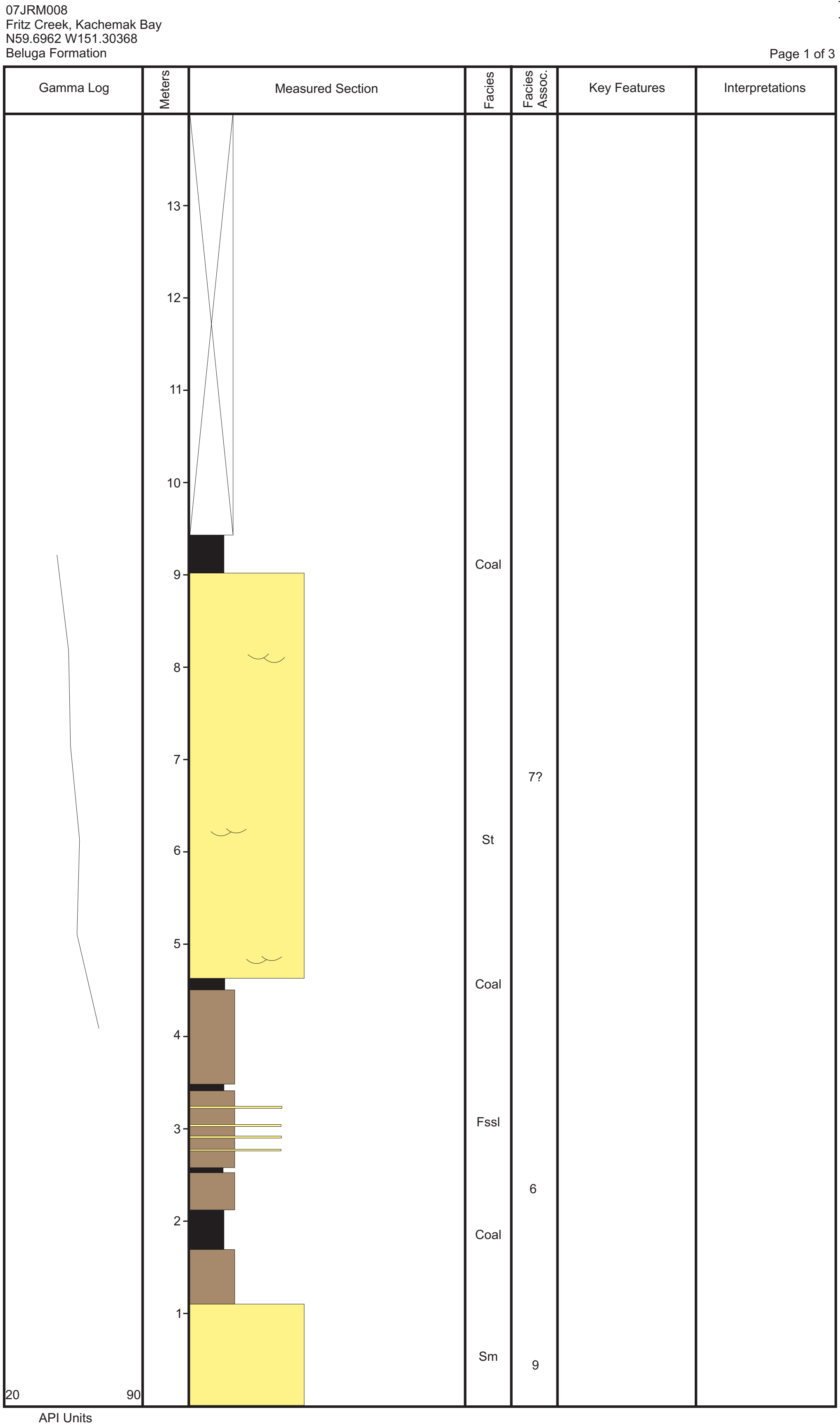

07JRM008
Fritz Creek, Kachemak Bay
N59.6962 W151.30368
Beluga Formation
Page 1 of 3
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
13
12
11
10
9
8
7
6
5
4
3
2
1
Coal
St
Coal
Fssl
Coal
Sm
7?
6
9
20
90
API Units

FIGURE A13

07JRM008
Fritz Creek, Kachemak Bay
N59.6962 W151.30368
Beluga Formation

Page 2 of 3

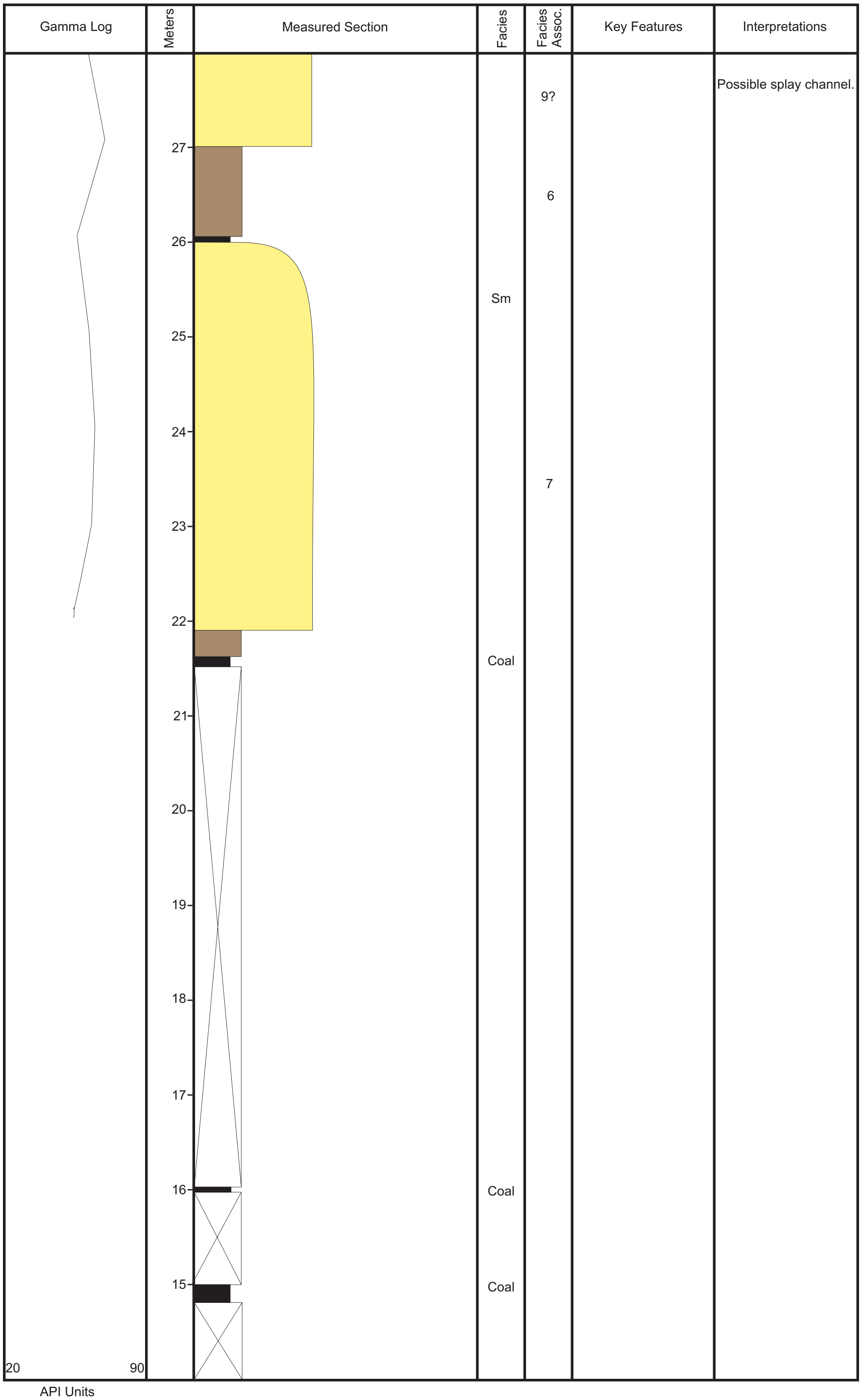


FIGURE A13

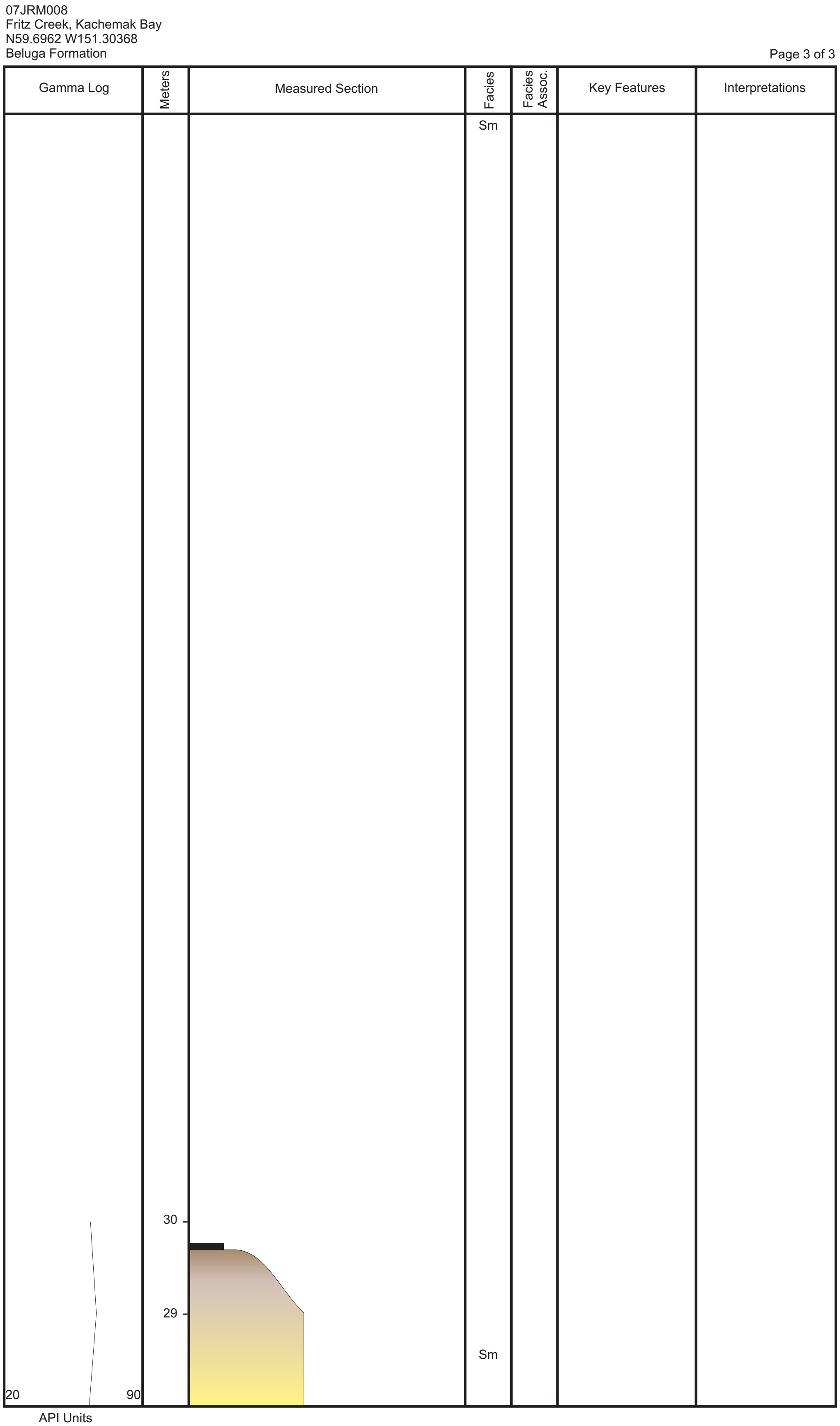

07JRM008
Fritz Creek, Kachemak Bay
N59.6962 W151.30368
Beluga Formation
Page 3 of 3
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
Sm
30
29
Sm
20
90
API Units

FIGURE A14

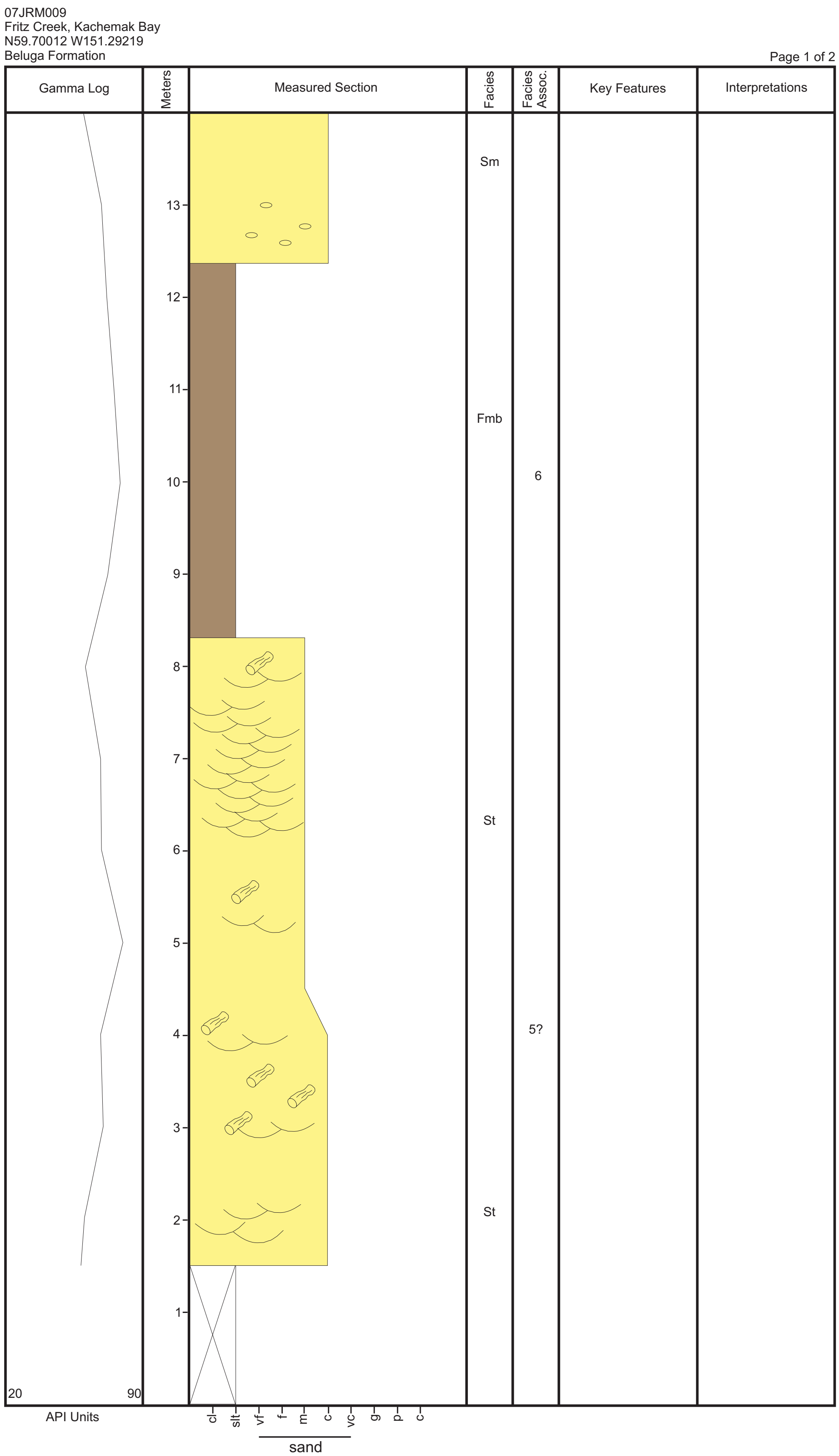
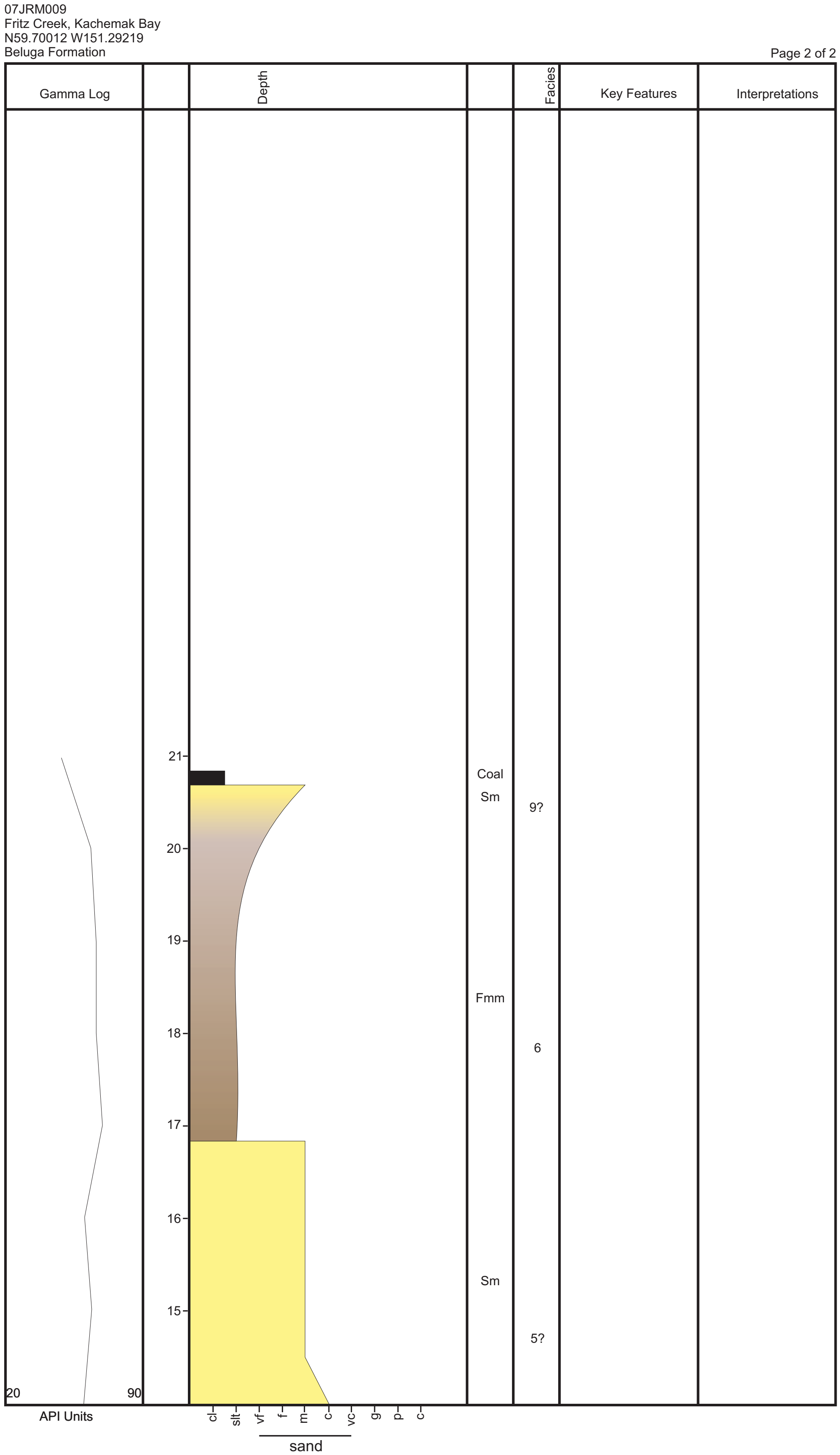

07JRM009
Fritz Creek, Kachemak Bay
N59.70012 W151.29219
Beluga Formation
Page 1 of 2
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
13
12
11
10
9
8
7
6
5
4
3
2
1
Sm
Fmb
6
St
5?
St
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A14



07JRM009
Fritz Creek, Kachemak Bay
N59.70012 W151.29219
Beluga Formation
Page 2 of 2
Gamma Log
Depth
Facies
Key Features
Interpretations
21
20
19
18
17
16
15
Coal
Sm
9?
Fmm
6
Sm
5?
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A15

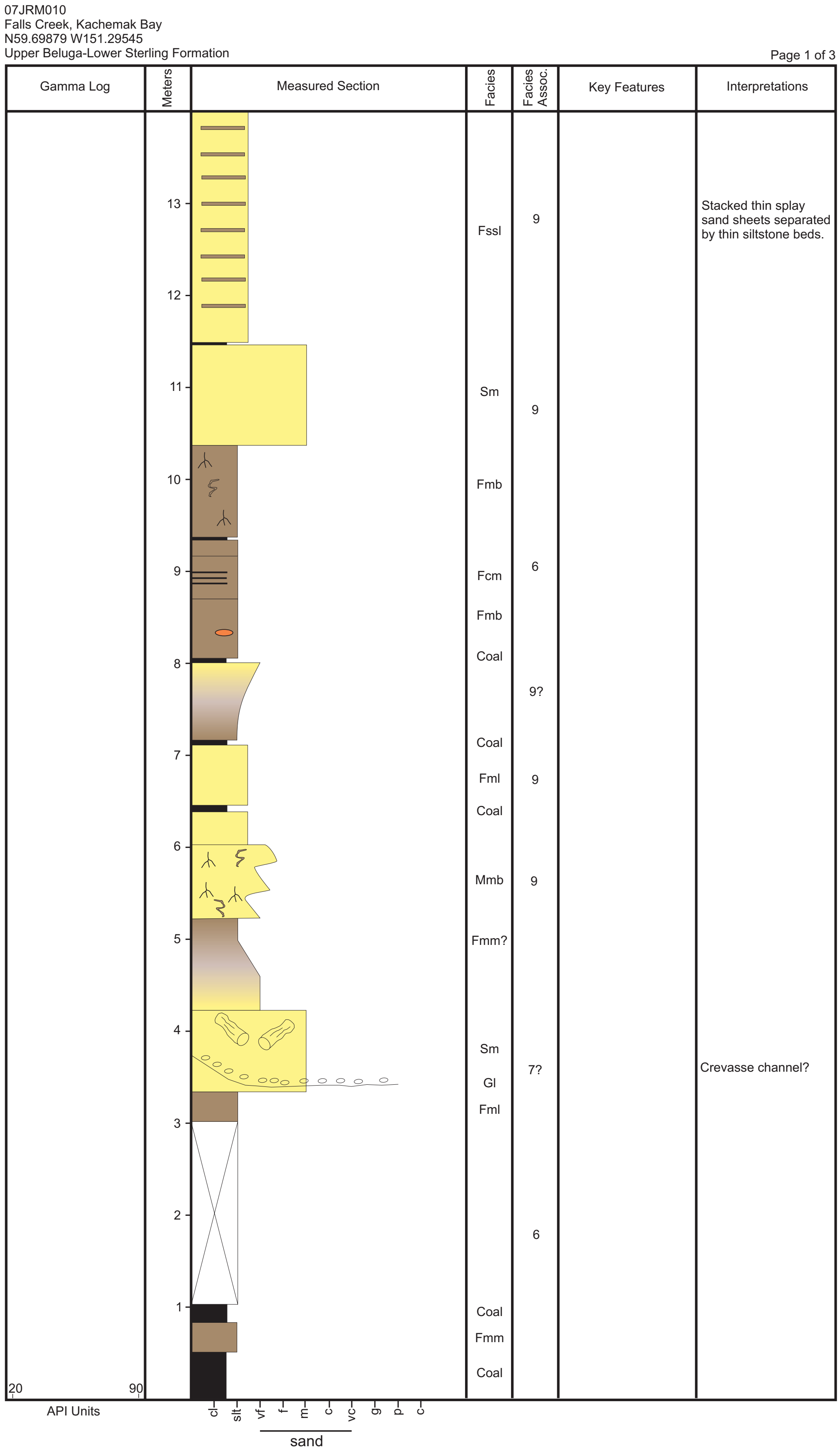

07JRM010
Falls Creek, Kachemak Bay
N59.69879 W151.29545
Upper Beluga-Lower Sterling Formation
Page 1 of 3
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
13
12
11
10
9
8
7
6
5
4
3
2
1
Fssl
9
Stacked thin splay sand sheets separated by thin siltstone beds.
Sm
9
Fmb
6
Fcm
Fmb
Coal
9?
Coal
Fml
9
Coal
Mmb
9
Fmm?
Sm
7?
Crevasse channel?
Gl
Fml
6
Coal
Fmm
Coal
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A15

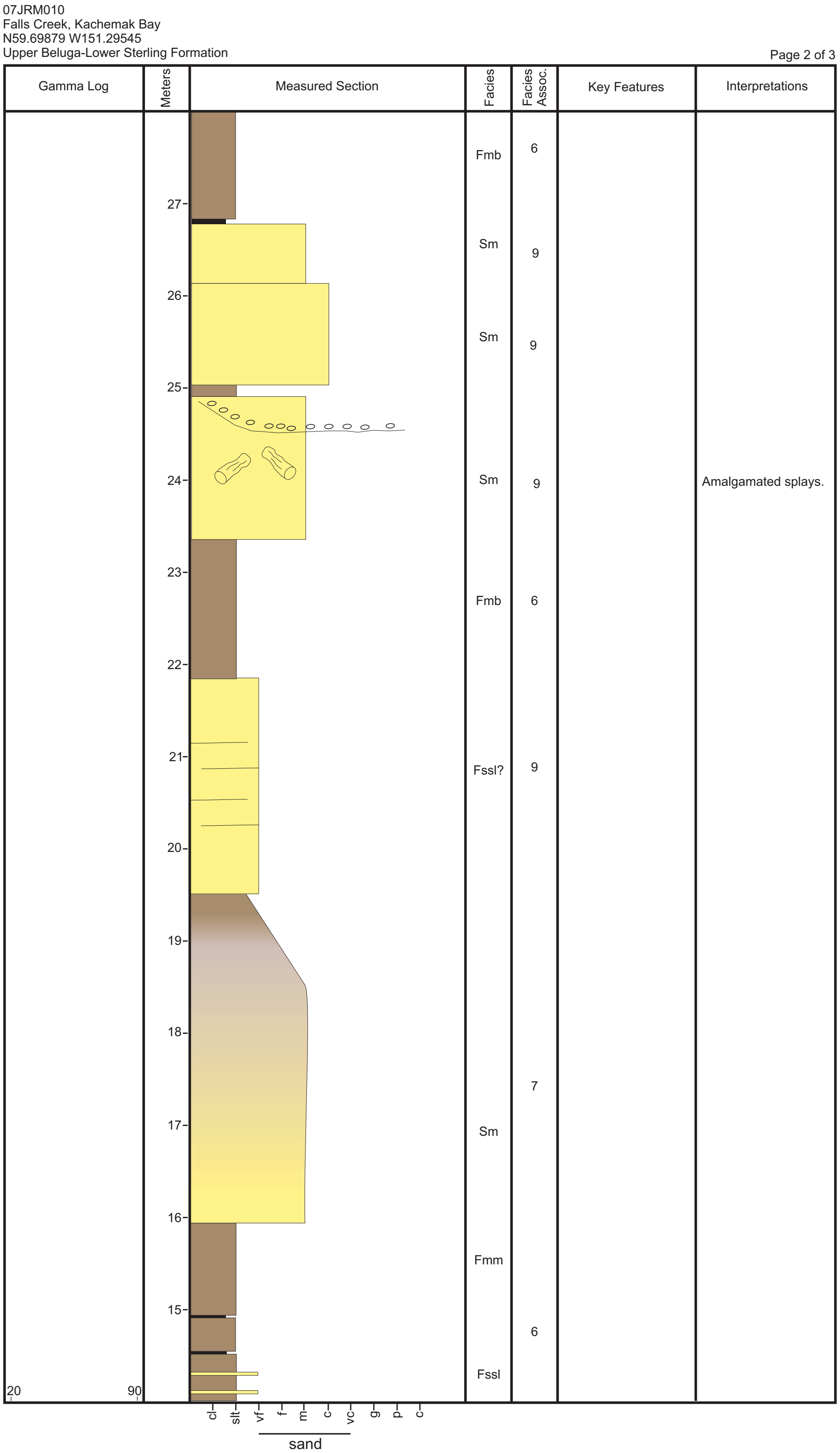

07JRM010
Falls Creek, Kachemak Bay
N59.69879 W151.29545
Upper Beluga-Lower Sterling Formation
Page 2 of 3
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
27
26
25
24
23
22
21
20
19
18
17
16
15
Fmb
Sm
Sm
Sm
Fmb
Fssl?
Sm
Fmm
Fssl
6
9
9
9
6
9
7
6
Amalgamated splays.
20
90
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A15

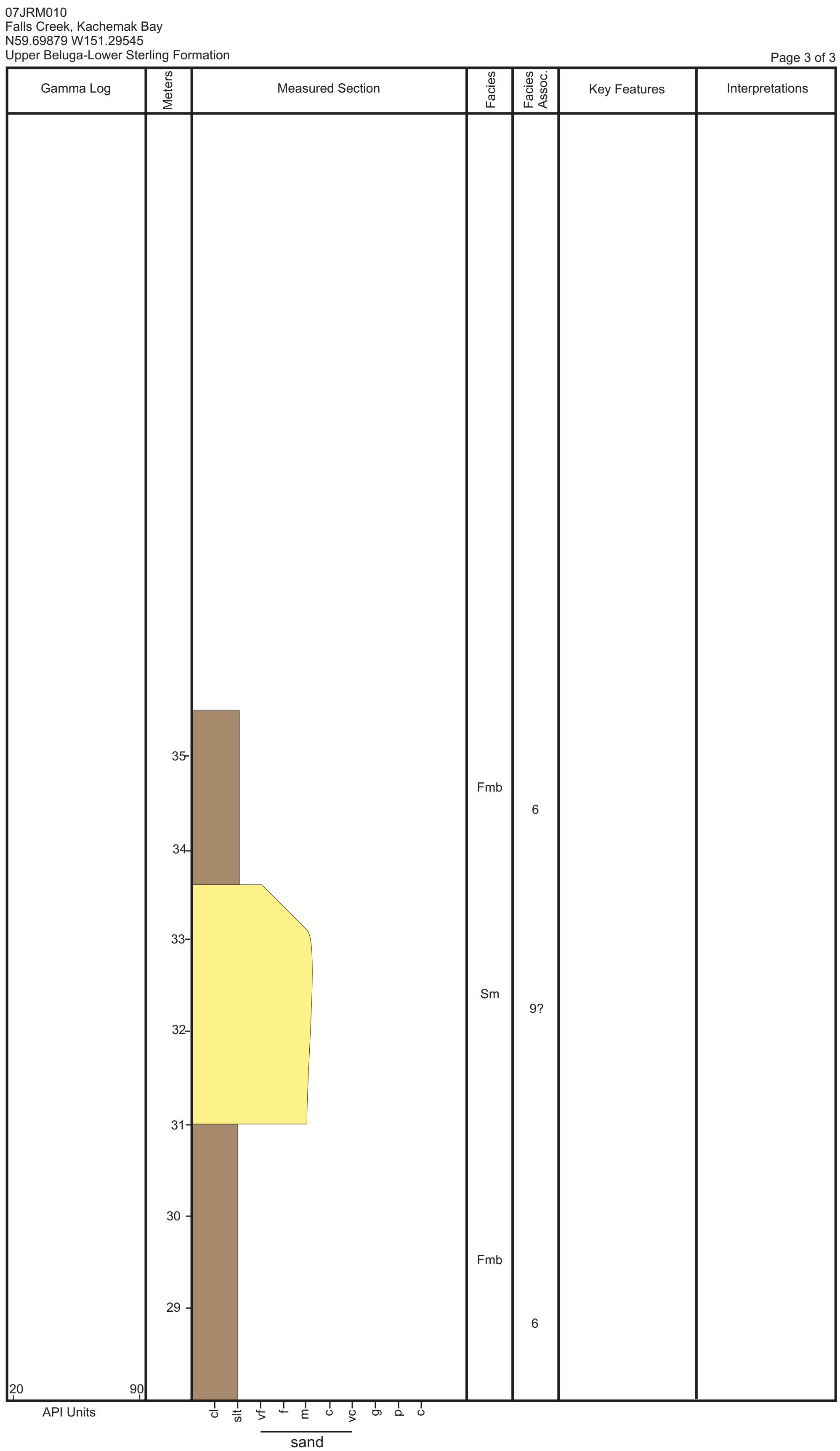

07JRM010
Falls Creek, Kachemak Bay
N59.69879 W151.29545
Upper Beluga-Lower Sterling Formation
Page 3 of 3
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
35
34
33
32
31
30
29
Fmb
6
Sm
9?
Fmb
6
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A16

07JRM011
Falls Creek, Kachemak Bay
N59.77309 W151.12128
Sterling Formation

Page 1 of 3

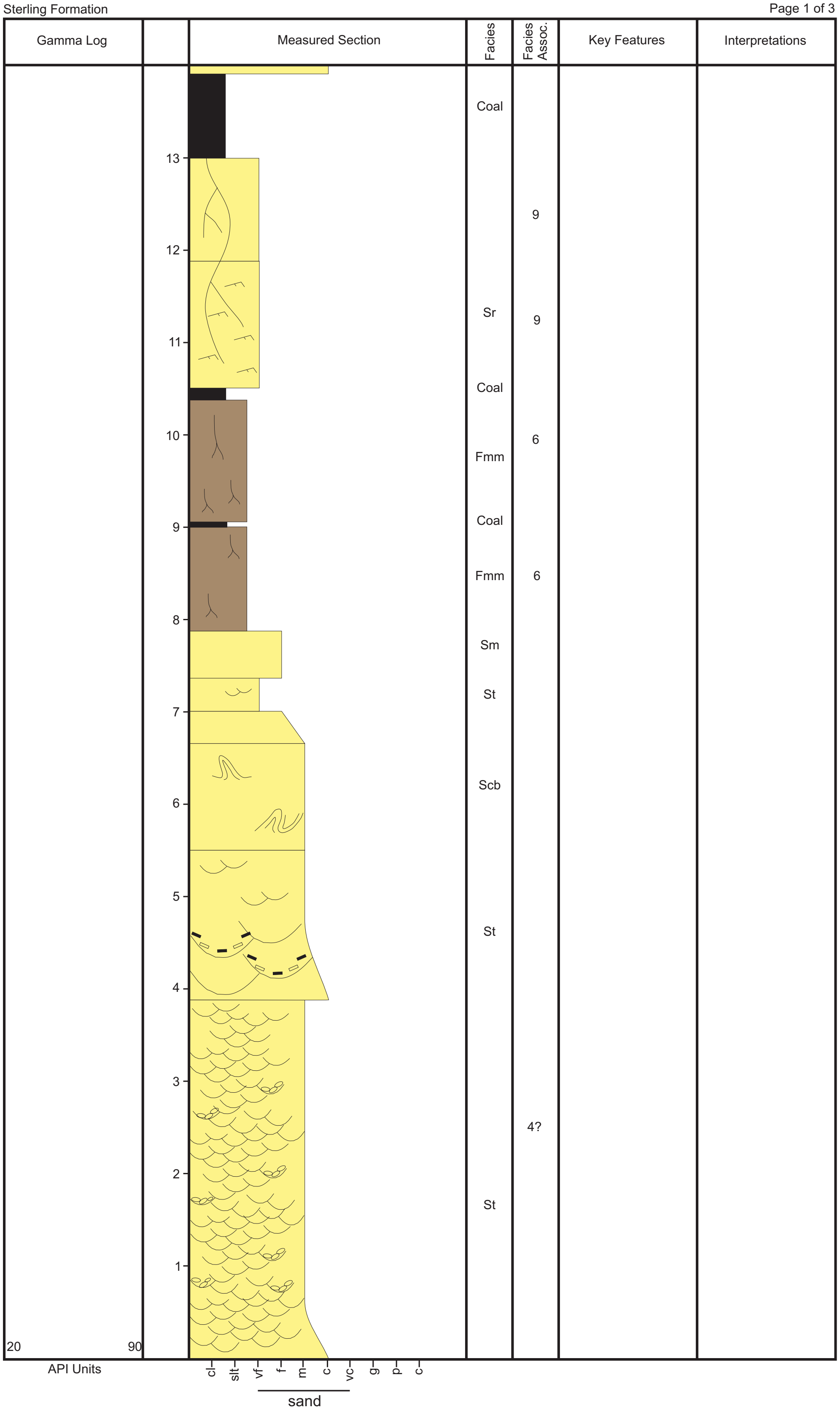


FIGURE A16

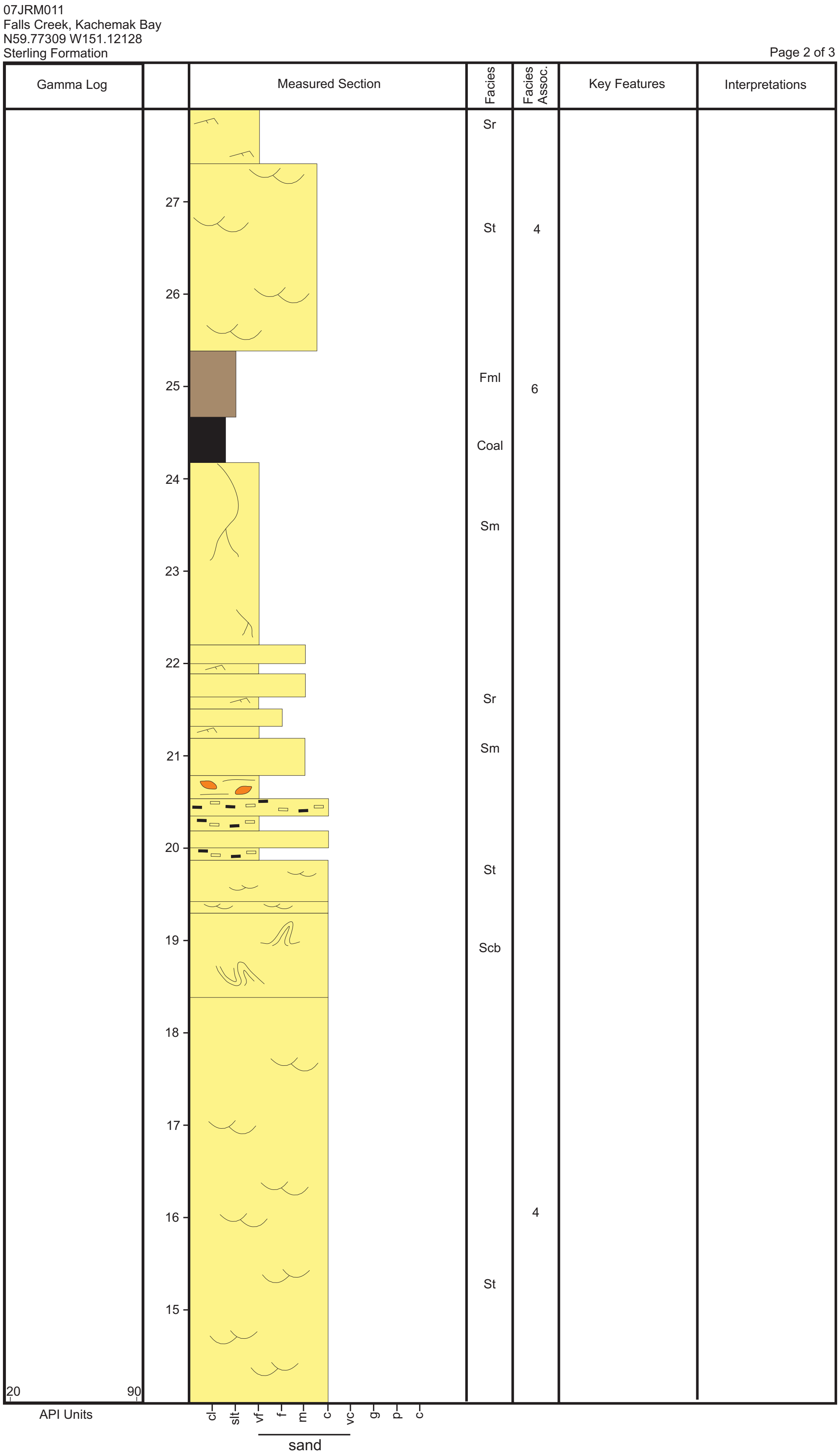

07JRM011
Falls Creek, Kachemak Bay
N59.77309 W151.12128
Sterling Formation
Page 2 of 3
Gamma Log
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
Sr
St
4
Fml
6
Coal
Sm
Sr
Sm
St
Scb
4
St
27
26
25
24
23
22
21
20
19
18
17
16
15
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A16

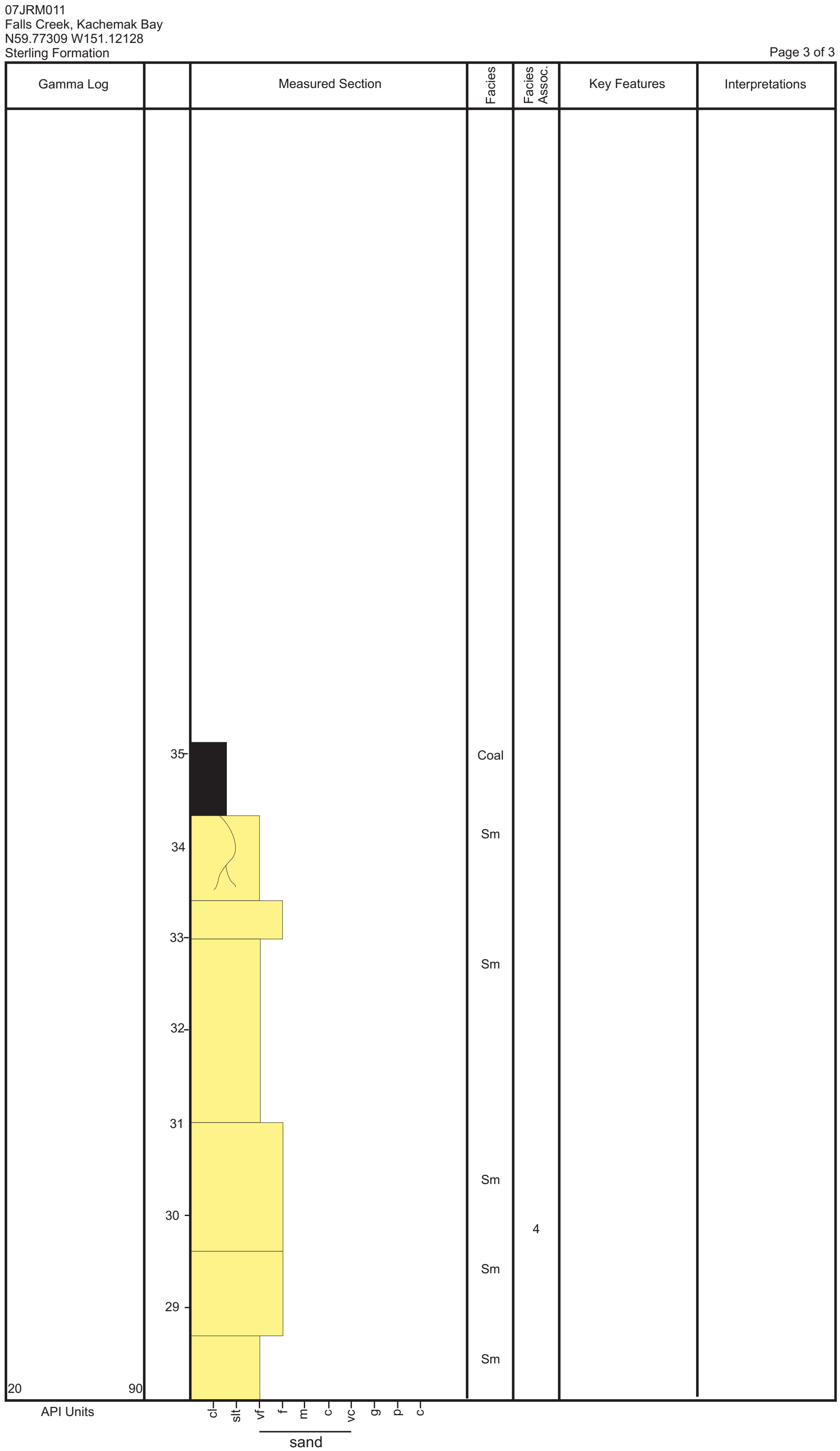

07JRM011
Falls Creek, Kachemak Bay
N59.77309 W151.12128
Sterling Formation
Page 3 of 3
Gamma Log
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
35
34
33
32
31
30
29
Coal
Sm
Sm
Sm
Sm
Sm
4
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A17

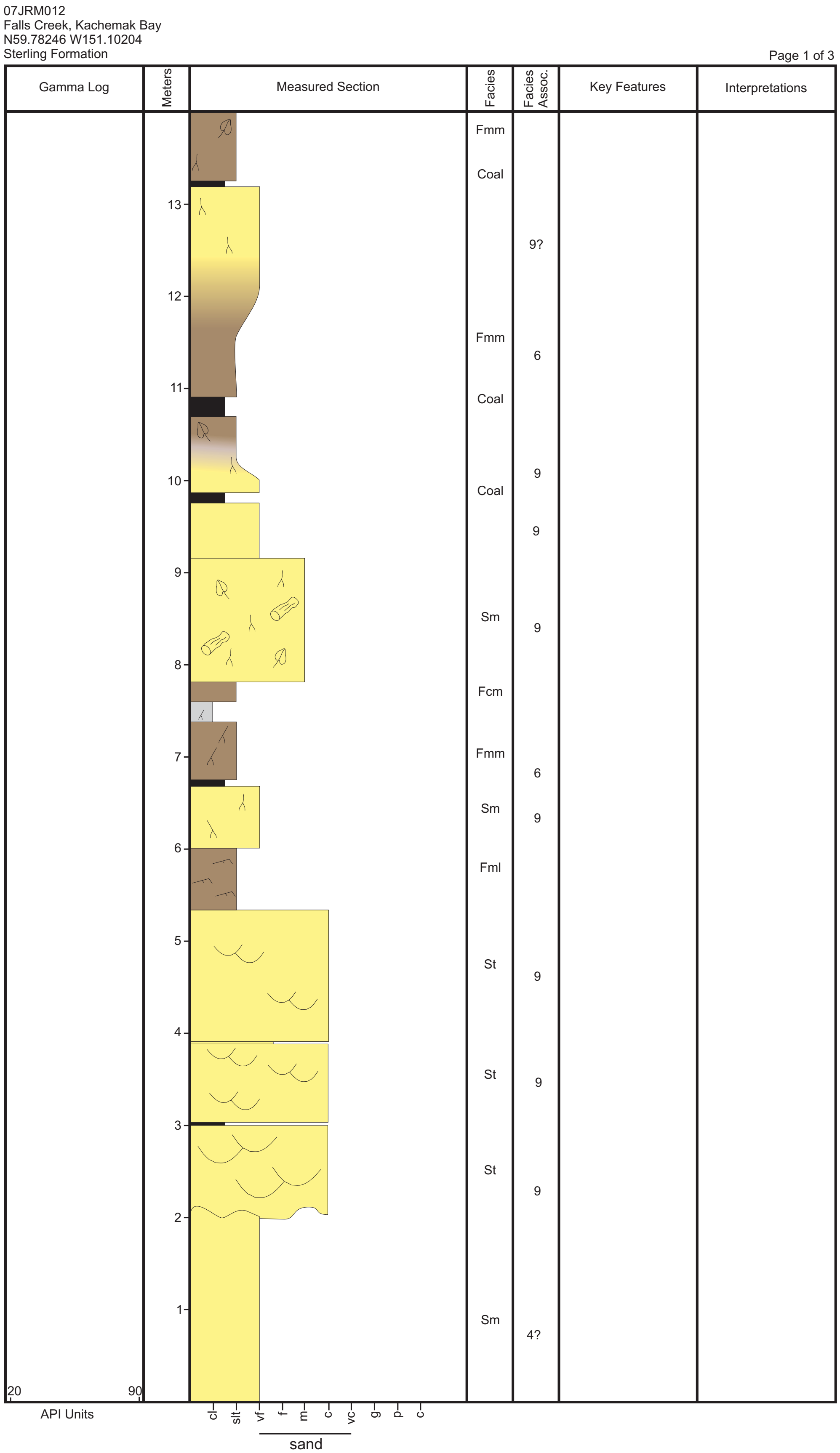

07JRM012
Falls Creek, Kachemak Bay
N59.78246 W151.10204
Sterling Formation
Page 1 of 3
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
Fmm
Coal
9?
Fmm
6
Coal
9
Coal
9
Sm
9
Fcm
Fmm
6
Sm
9
Fml
St
9
St
9
St
9
Sm
4?
13
12
11
10
9
8
7
6
5
4
3
2
1
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A17

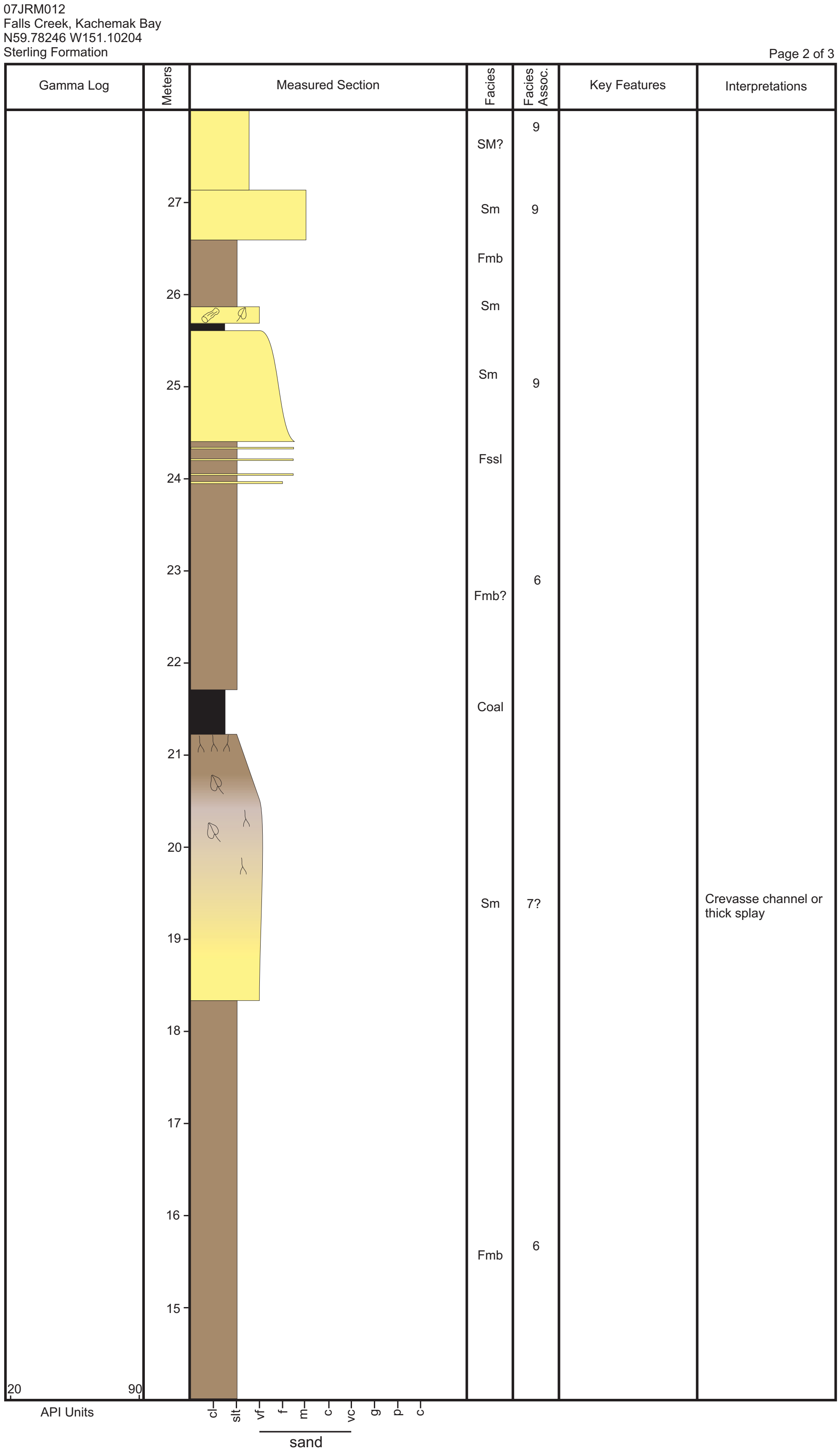

07JRM012
Falls Creek, Kachemak Bay
N59.78246 W151.10204
Sterling Formation
Page 2 of 3
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
27
26
25
24
23
22
21
20
19
18
17
16
15
SM?
9
Sm
9
Fmb
Sm
Sm
9
Fssl
6
Fmb?
Coal
Sm
7?
Crevasse channel or thick splay
Fmb
6
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A17

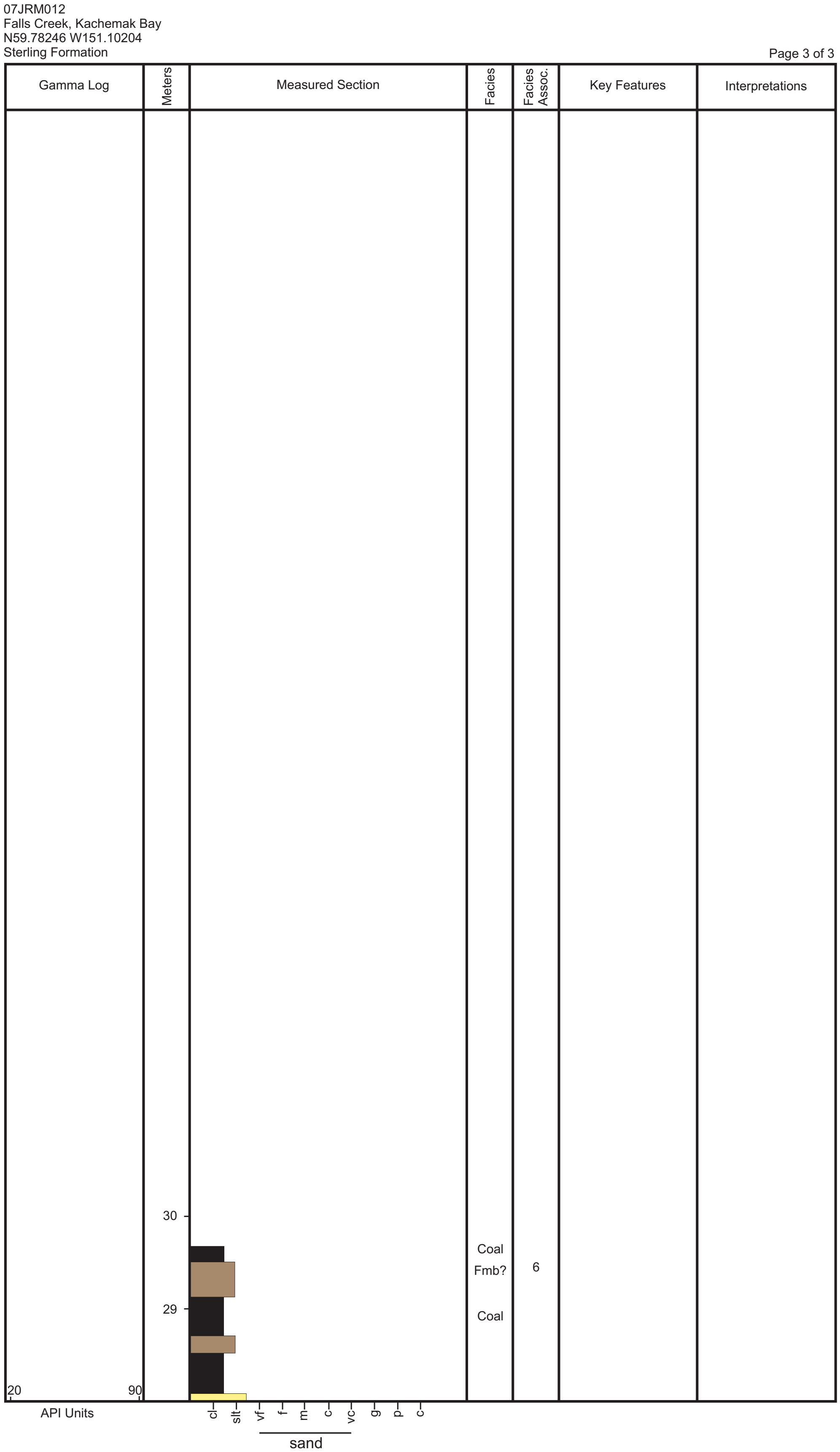

07JRM012
Falls Creek, Kachemak Bay
N59.78246 W151.10204
Sterling Formation
Page 3 of 3
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
30
29
Coal
Fmb?
Coal
6
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A18

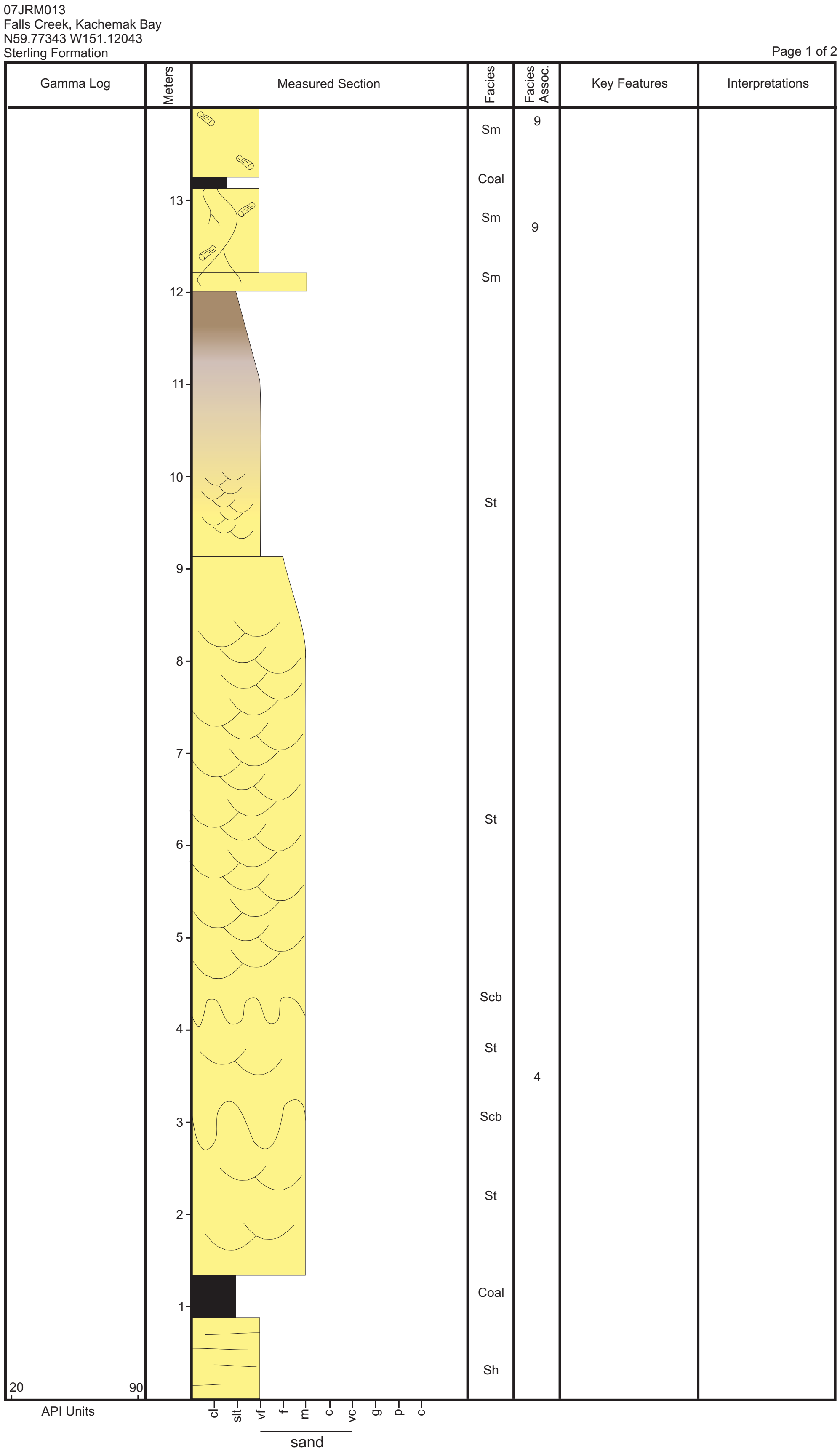

07JRM013
Falls Creek, Kachemak Bay
N59.77343 W151.12043
Sterling Formation
Page 1 of 2
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
Sm
Coal
Sm
Sm
St
St
Scb
St
Scb
St
Coal
Sh
9
9
4
13
12
11
10
9
8
7
6
5
4
3
2
1
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A18

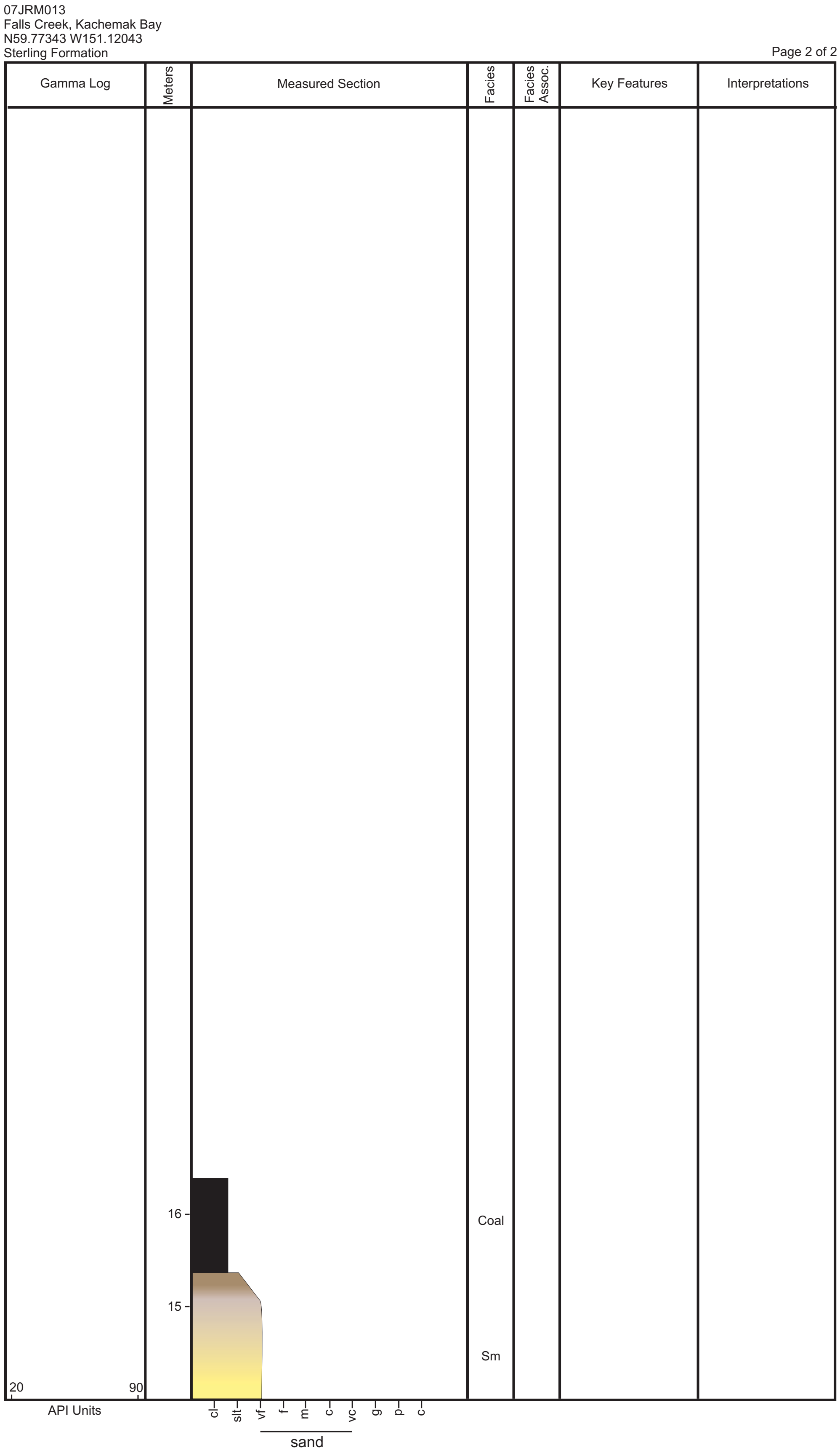

07JRM013
Falls Creek, Kachemak Bay
N59.77343 W151.12043
Sterling Formation
Page 2 of 2
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
16
15
Coal
Sm
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A19

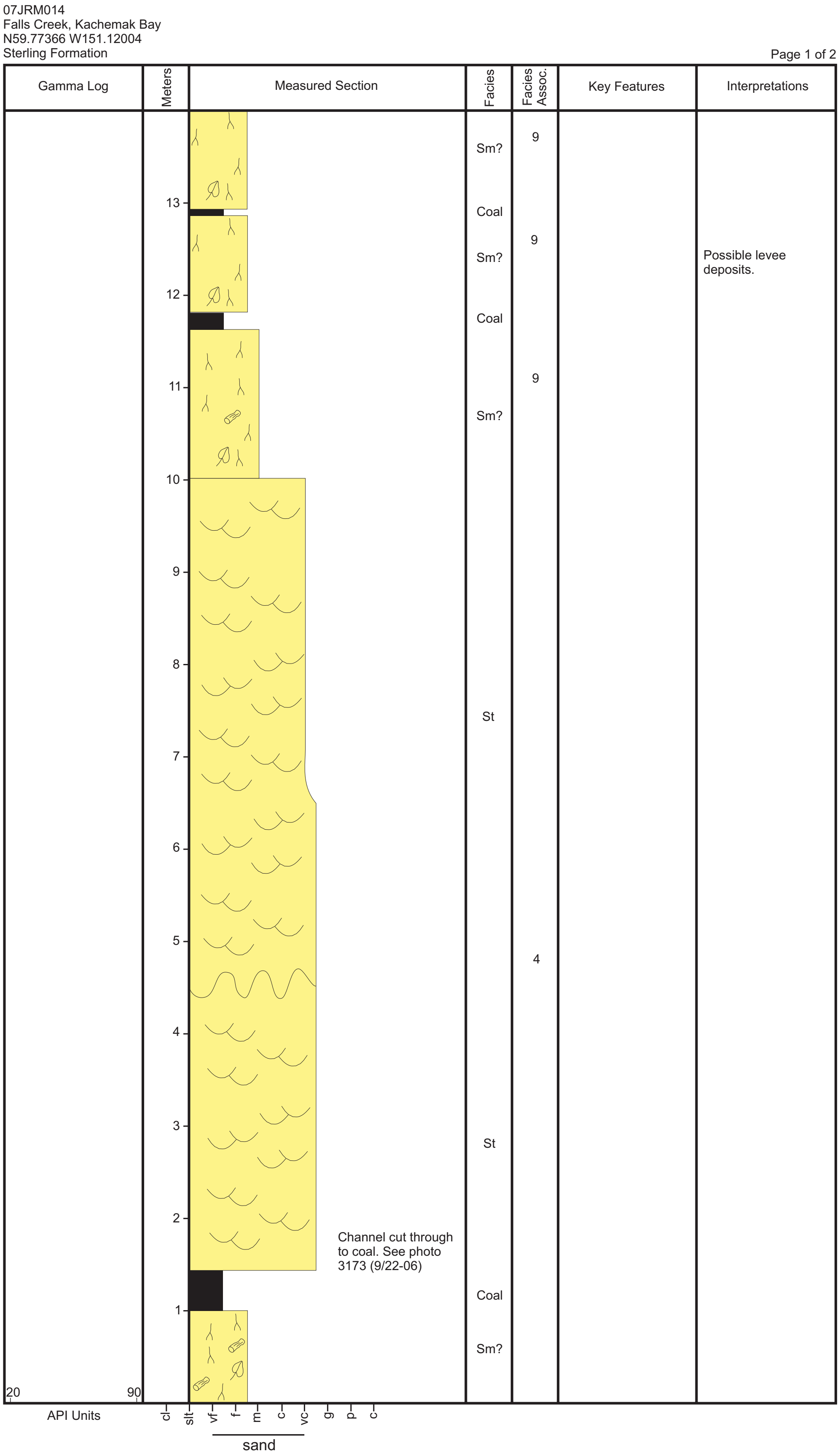

07JRM014
Falls Creek, Kachemak Bay
N59.77366 W151.12004
Sterling Formation
Page 1 of 2
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
13
12
11
10
9
8
7
6
5
4
3
2
1
Sm?
Coal
Sm?
Coal
Sm?
St
St
Coal
Sm?
9
9
9
4
Possible levee deposits.
Channel cut through to coal. See photo 3173 (9/22-06)
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A19

07JRM014
Falls Creek, Kachemak Bay
N59.77366 W151.12004
Sterling Formation

Page 2 of 2

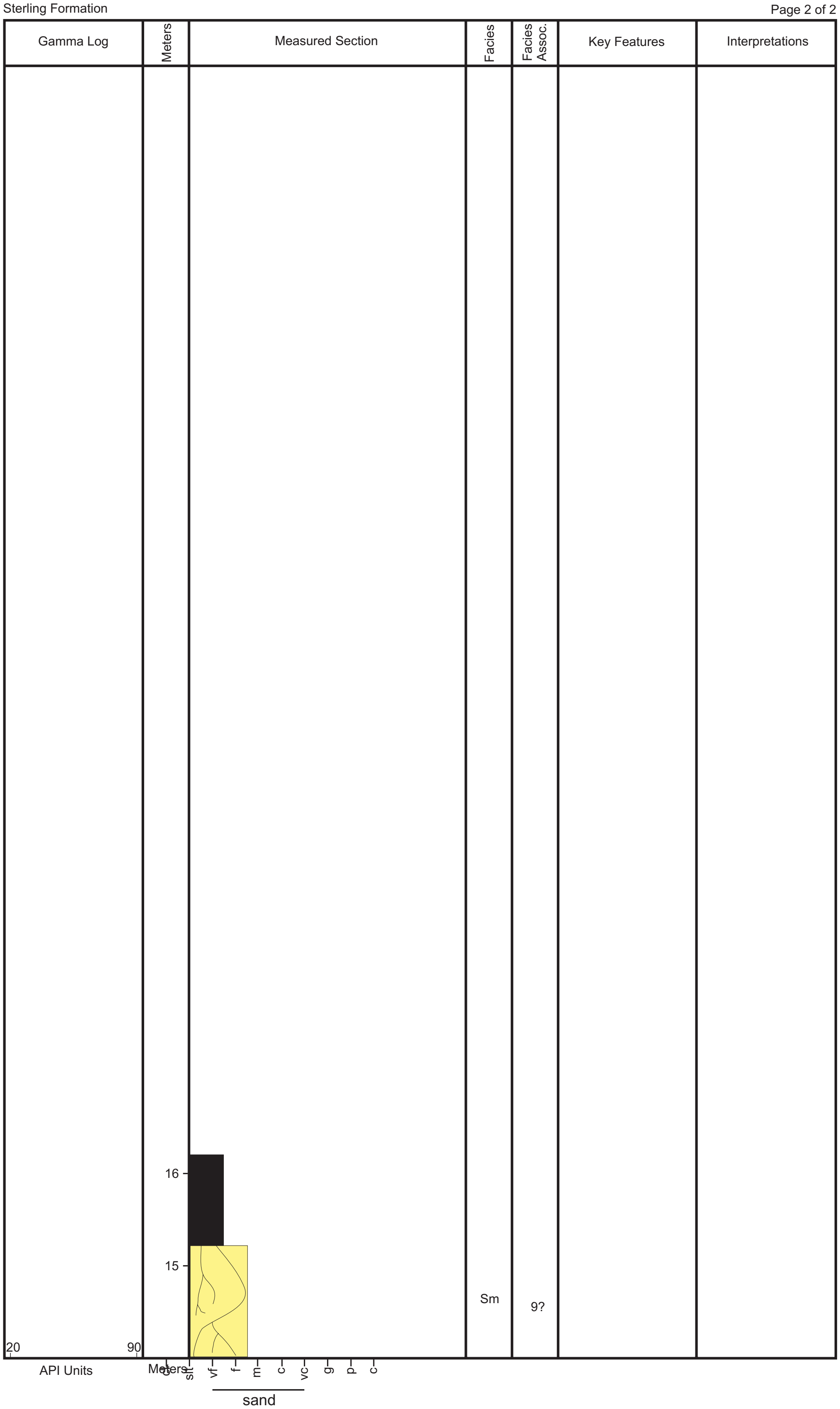


FIGURE A20

06PD212
Fox River, Kenai National Wildlife Refuge
N59.91270 W150.82426
Sterling Formation

Page 1 of 3

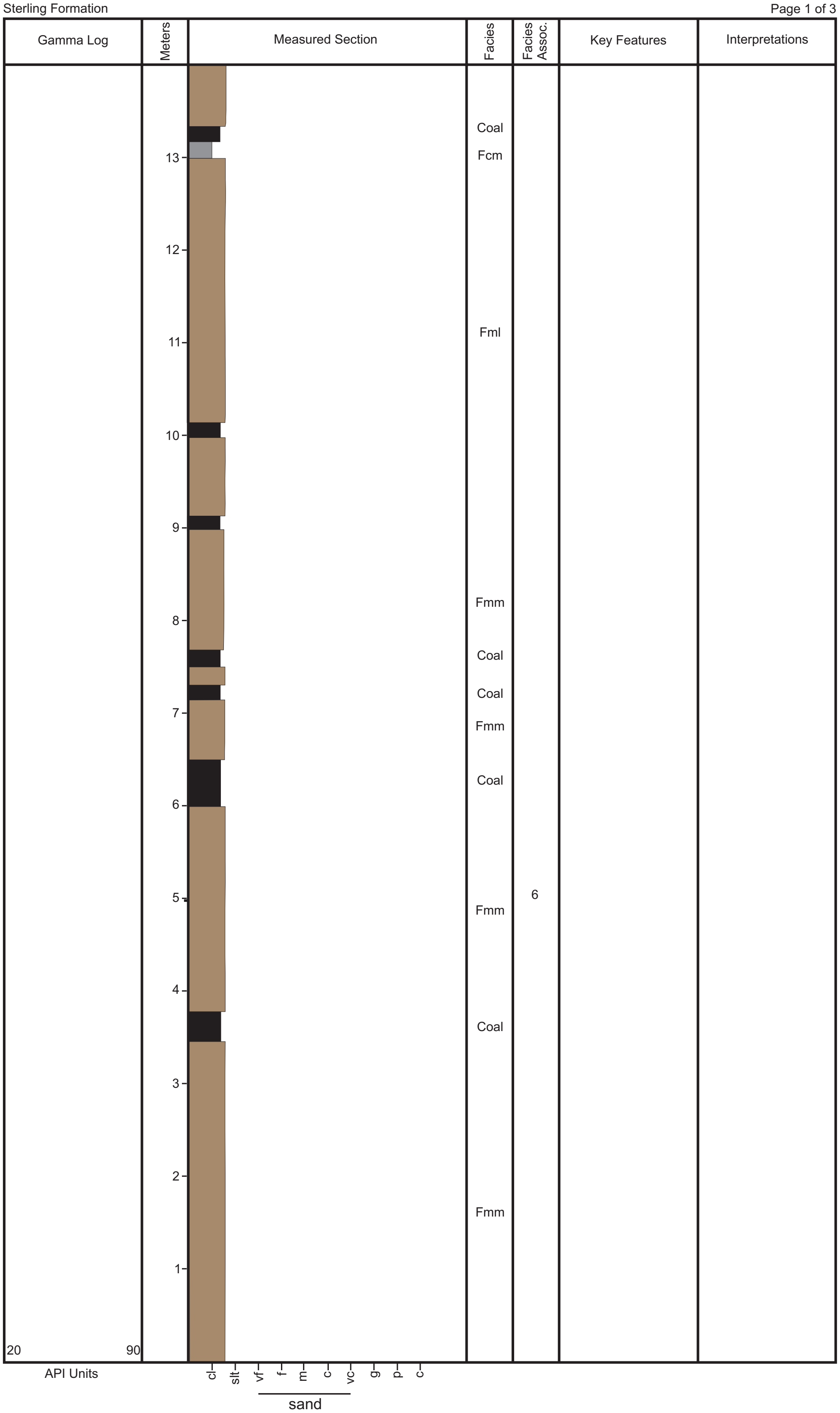


FIGURE A20

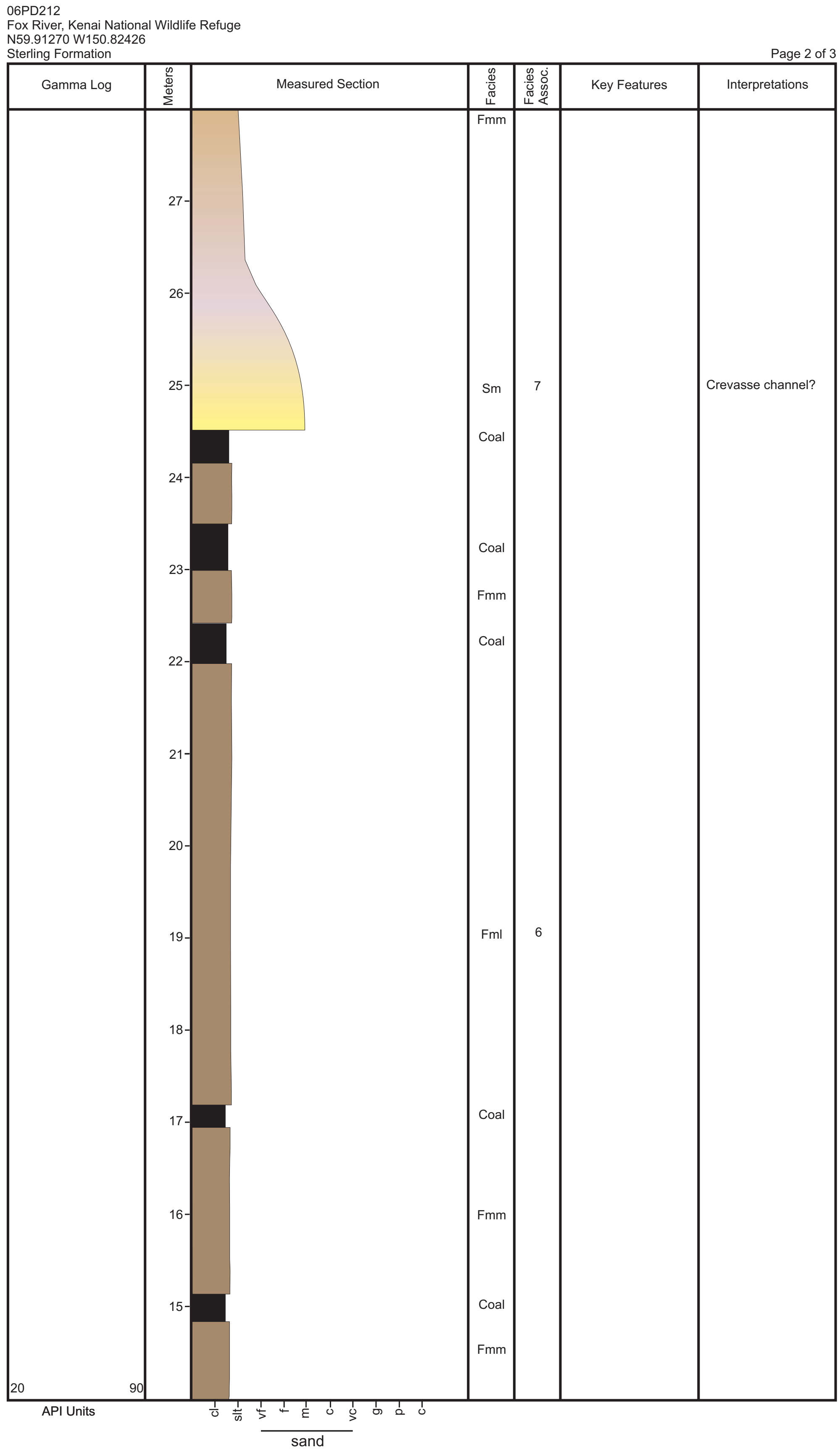

06PD212
Fox River, Kenai National Wildlife Refuge
N59.91270 W150.82426
Sterling Formation
Page 2 of 3
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
Fmm
27
26
25
Sm
7
Crevasse channel?
Coal
24
Coal
23
Fmm
Coal
22
21
20
19
Fml
6
18
Coal
17
16
Fmm
Coal
15
Fmm
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A20

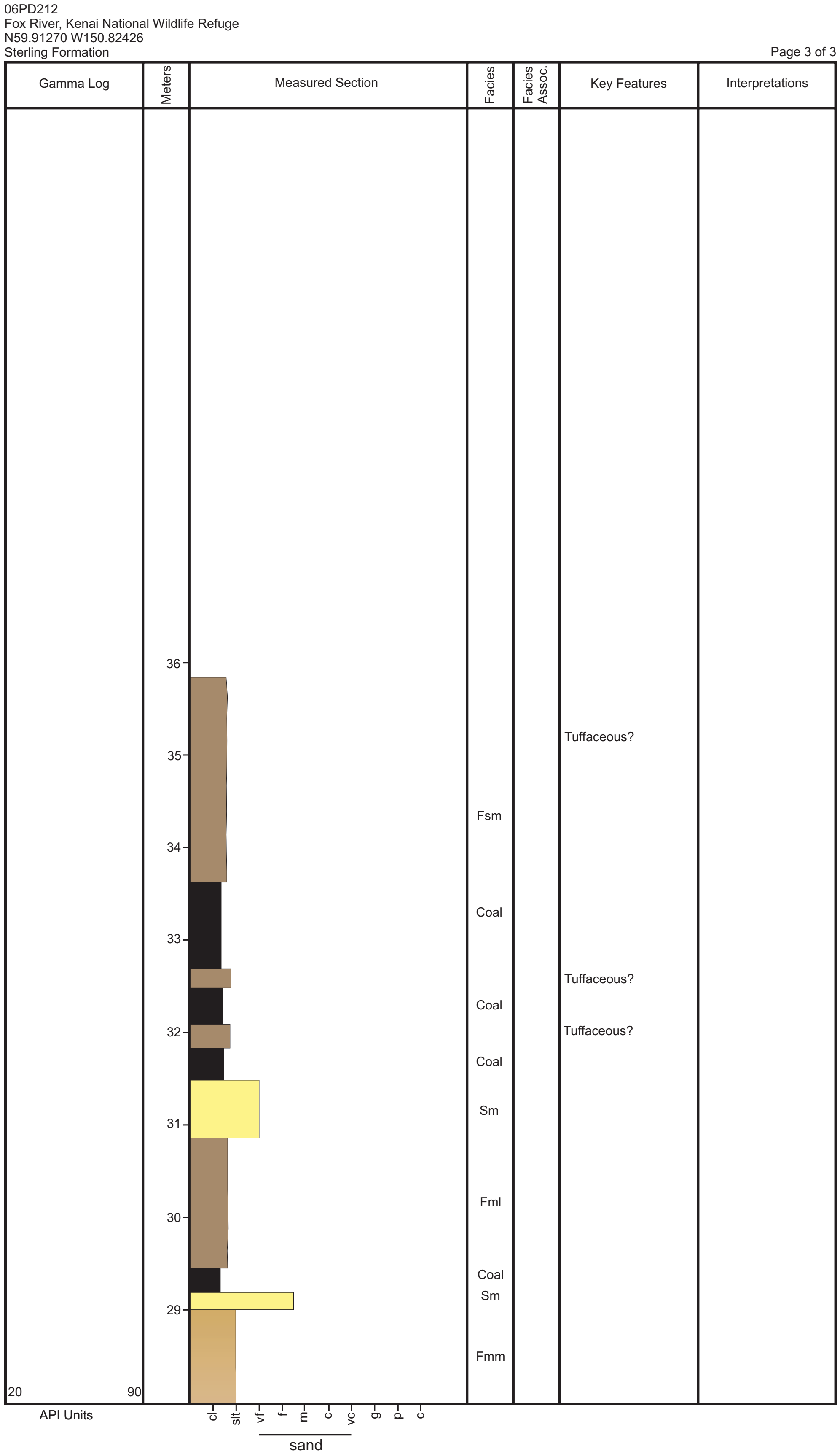

06PD212
Fox River, Kenai National Wildlife Refuge
N59.91270 W150.82426
Sterling Formation
Page 3 of 3
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
36
35
34
33
32
31
30
29
Tuffaceous?
Fsm
Coal
Tuffaceous?
Coal
Tuffaceous?
Coal
Sm
Fml
Coal
Sm
Fmm
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A21

06MAW203
Upper Fox River, Kenai National Wildlife Refuge
N59.98066 W150.79642
Sterling Formation

Page 1 of 6

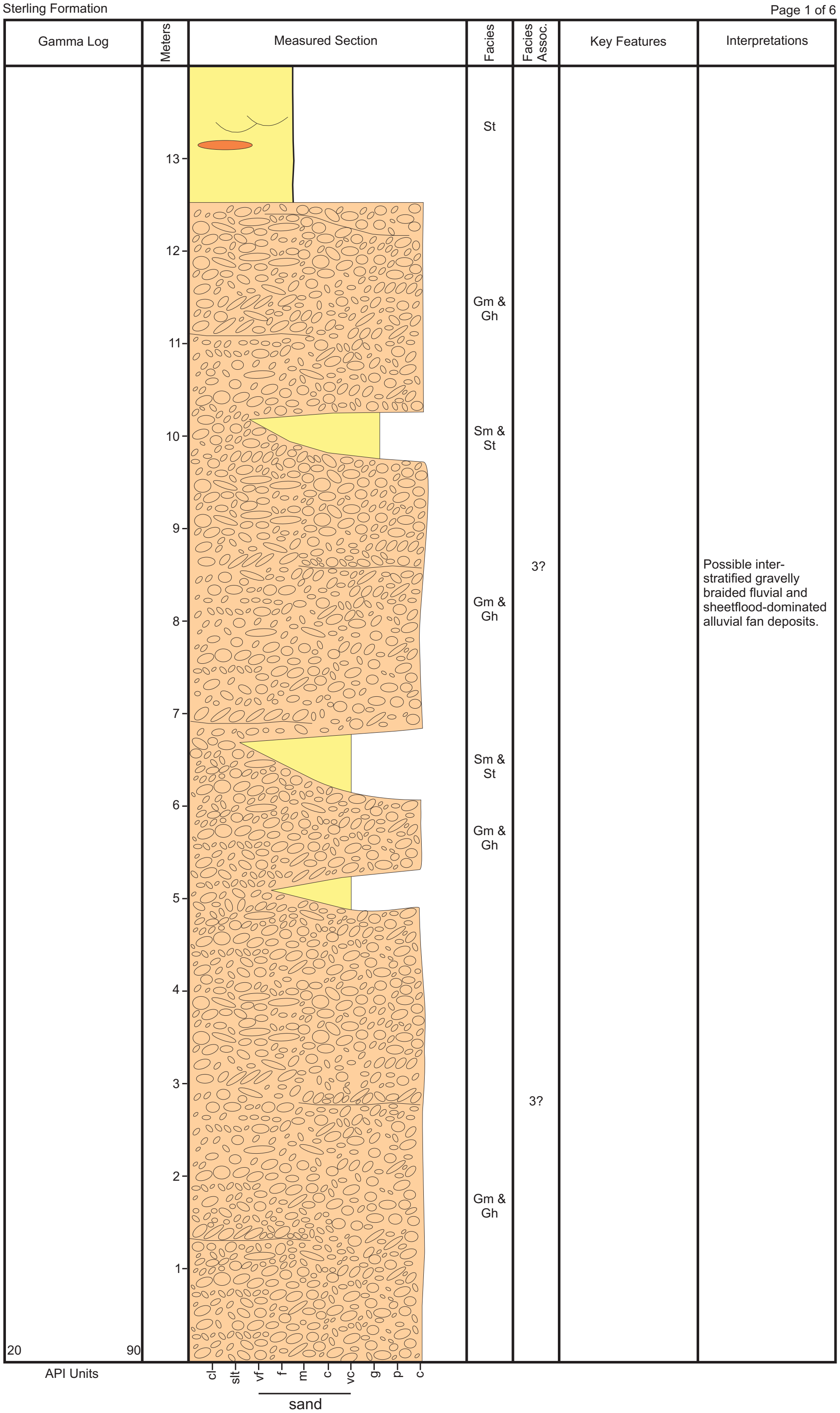


FIGURE A21

06MAW203
Upper Fox River, Kenai National Wildlife Refuge
N59.98066 W150.79642
Sterling Formation

Page 2 of 6

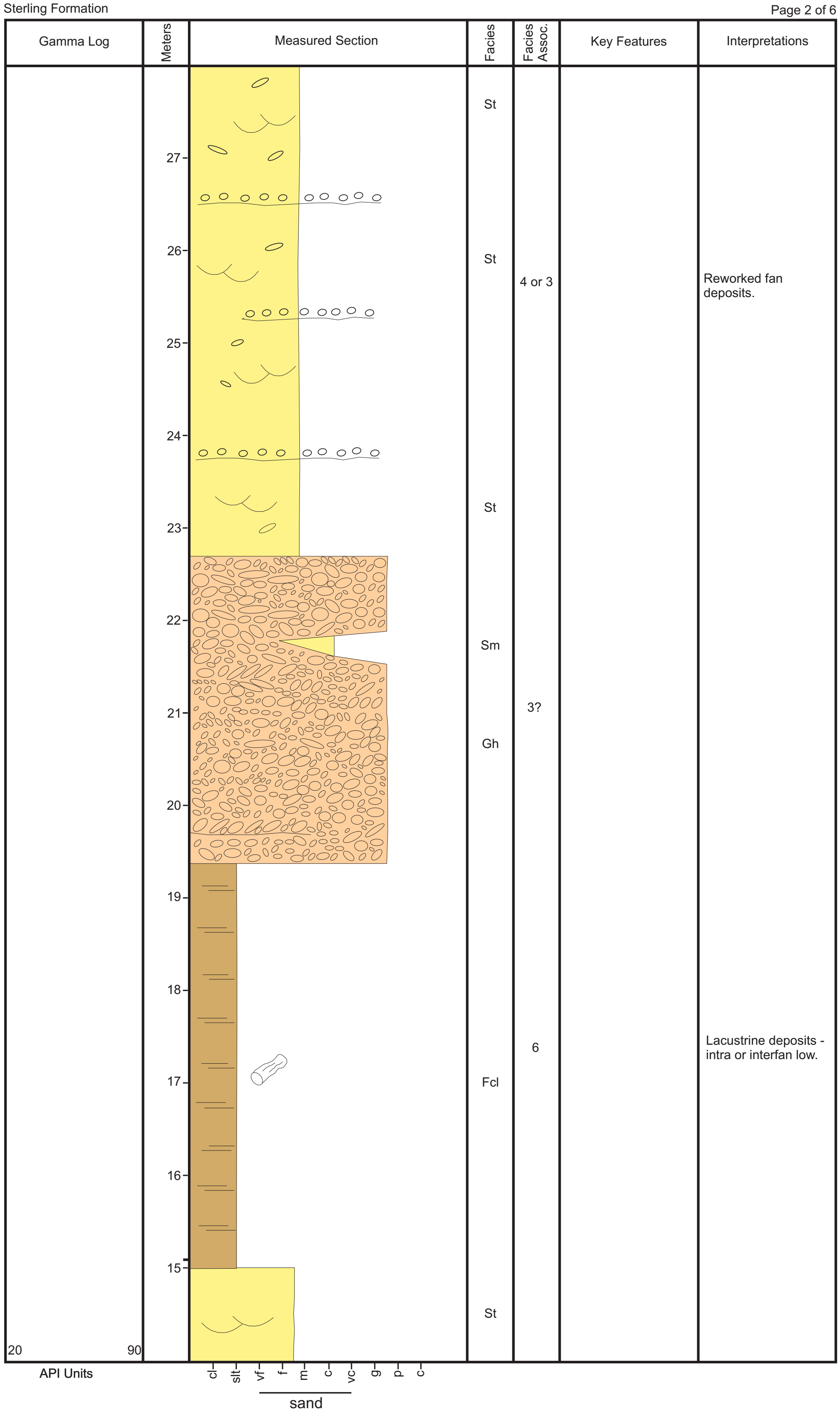


FIGURE A21

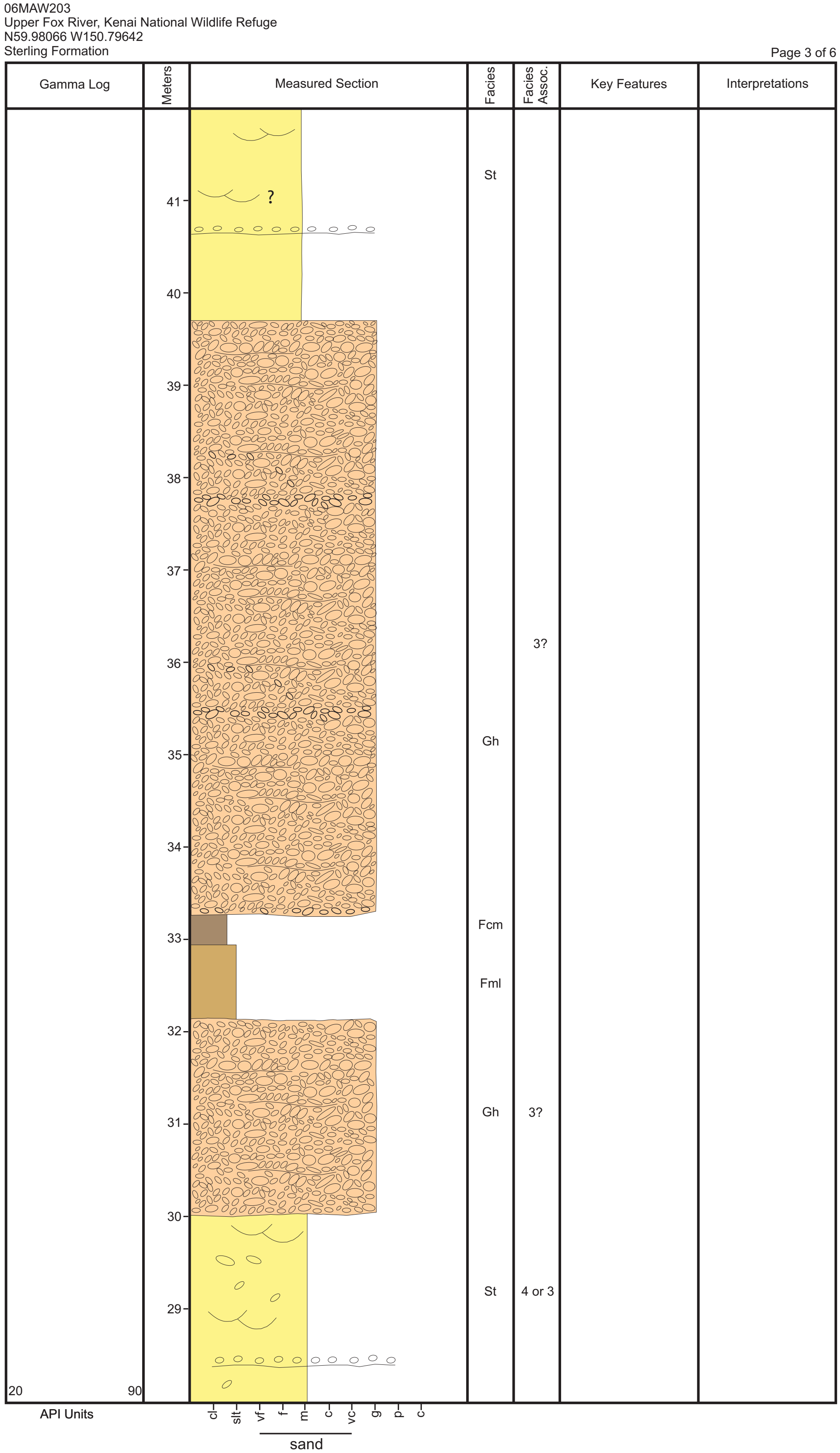

06MAW203
Upper Fox River, Kenai National Wildlife Refuge
N59.98066 W150.79642
Sterling Formation
Page 3 of 6
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
41
40
39
38
37
36
35
34
33
32
31
30
29
?
St
3?
Gh
Fcm
Fml
Gh
3?
St
4 or 3
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A21

06MAW203
Upper Fox River, Kenai National Wildlife Refuge
N59.98066 W150.79642
Sterling Formation

Page 4 of 6

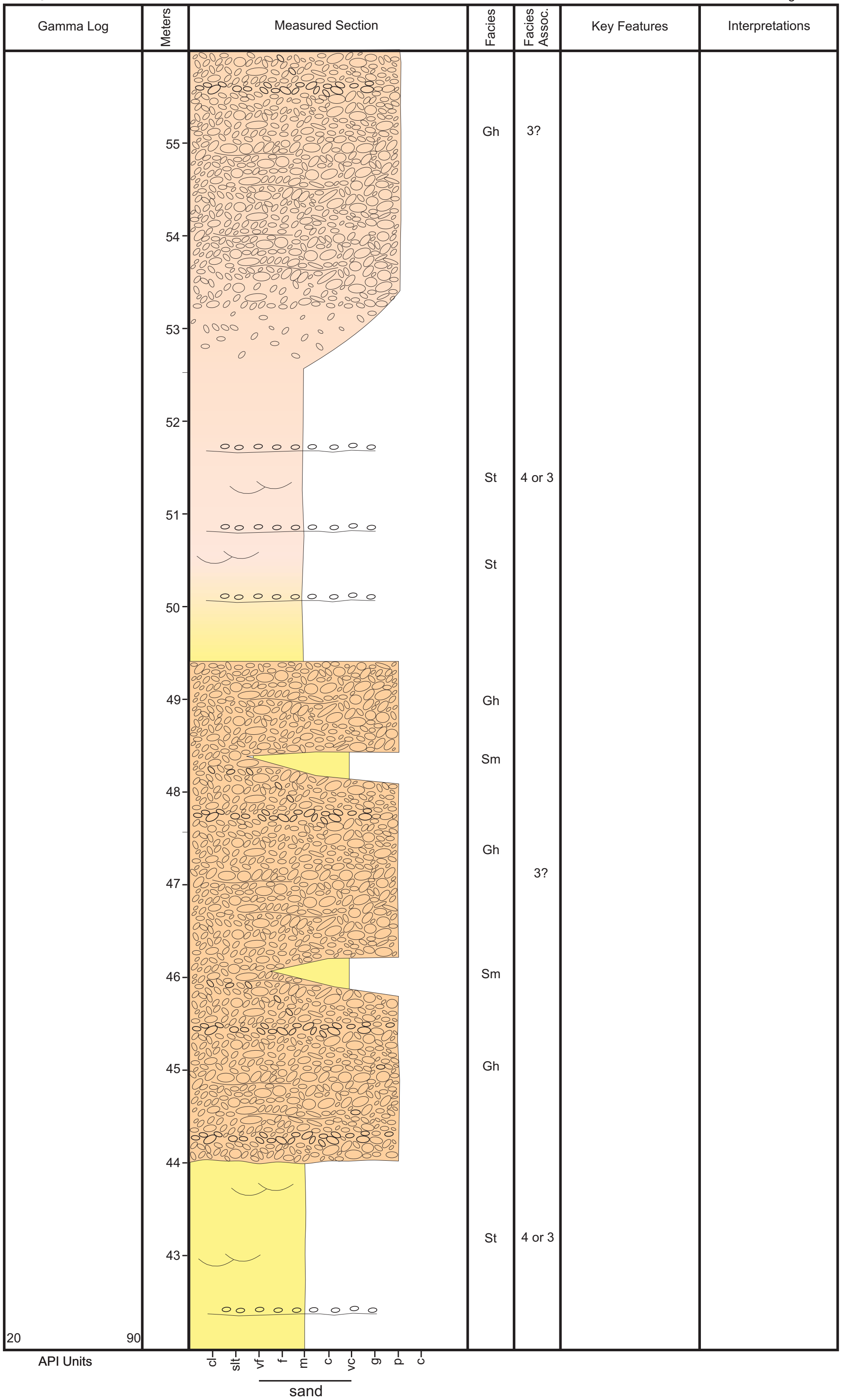


FIGURE A21

06MAW203
Upper Fox River, Kenai National Wildlife Refuge
N59.98066 W150.79642
Sterling Formation

Page 5 of 6

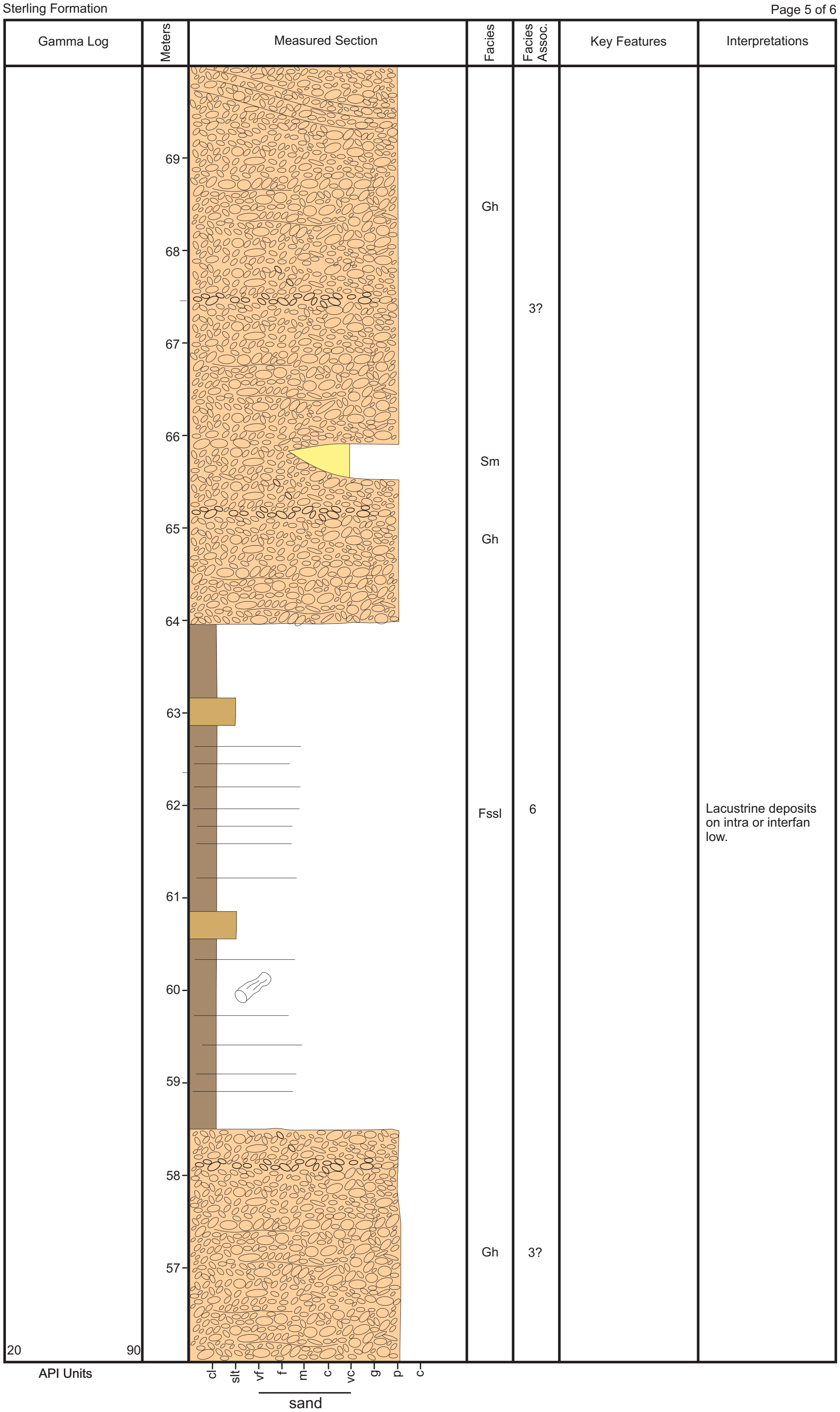


FIGURE A21

06MAW203
Upper Fox River, Kenai National Wildlife Refuge
N59.98066 W150.79642
Sterling Formation

Page 6 of 6

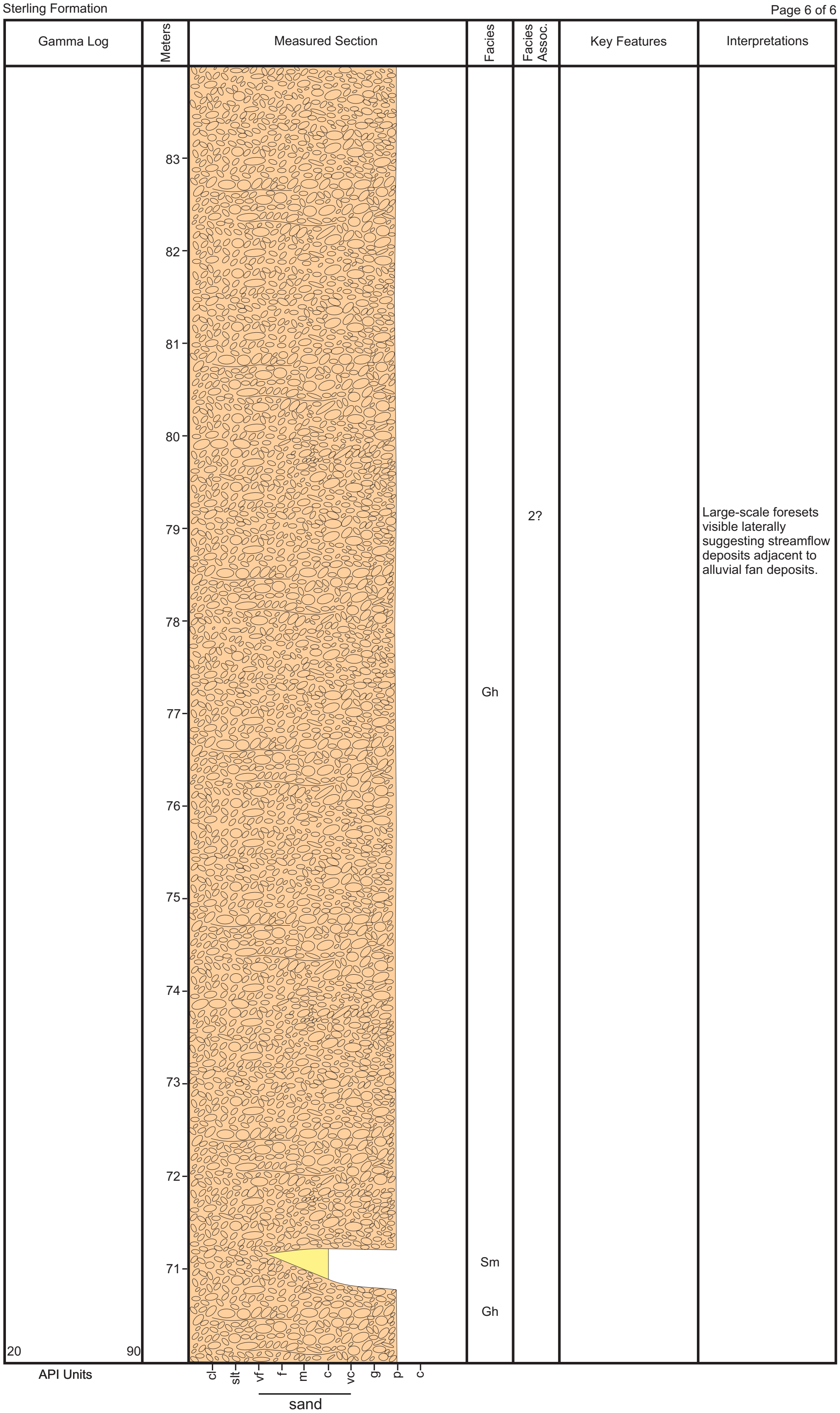


FIGURE A22

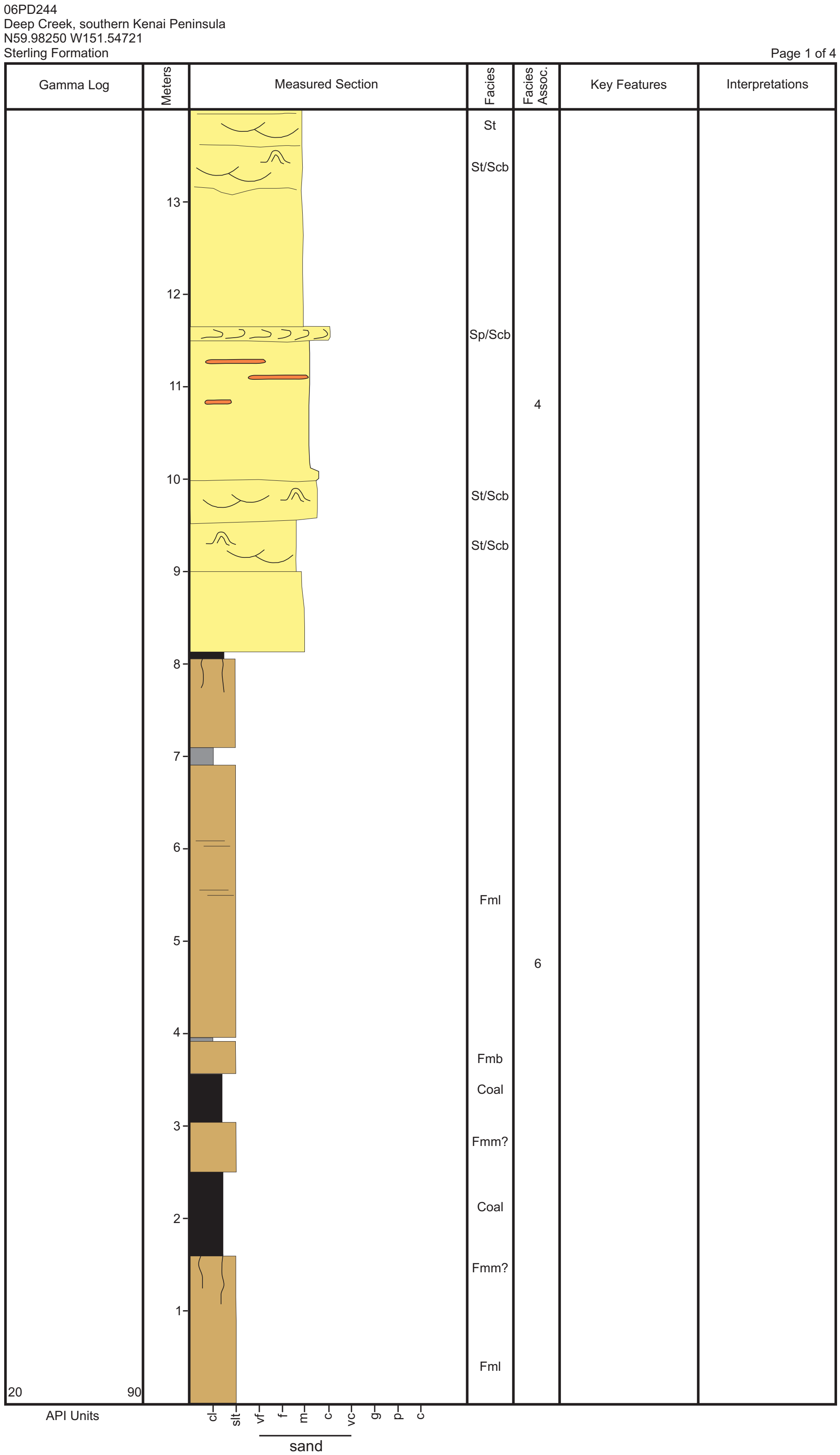

06PD244
Deep Creek, southern Kenai Peninsula
N59.98250 W151.54721
Sterling Formation
Page 1 of 4
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
St
St/Scb
Sp/Scb
4
St/Scb
St/Scb
Fml
6
Fmb
Coal
Fmm?
Coal
Fmm?
Fml
13
12
11
10
9
8
7
6
5
4
3
2
1
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A22

06PD244
Deep Creek, southern Kenai Peninsula
N59.98250 W151.54721
Sterling Formation

Page 2 of 4

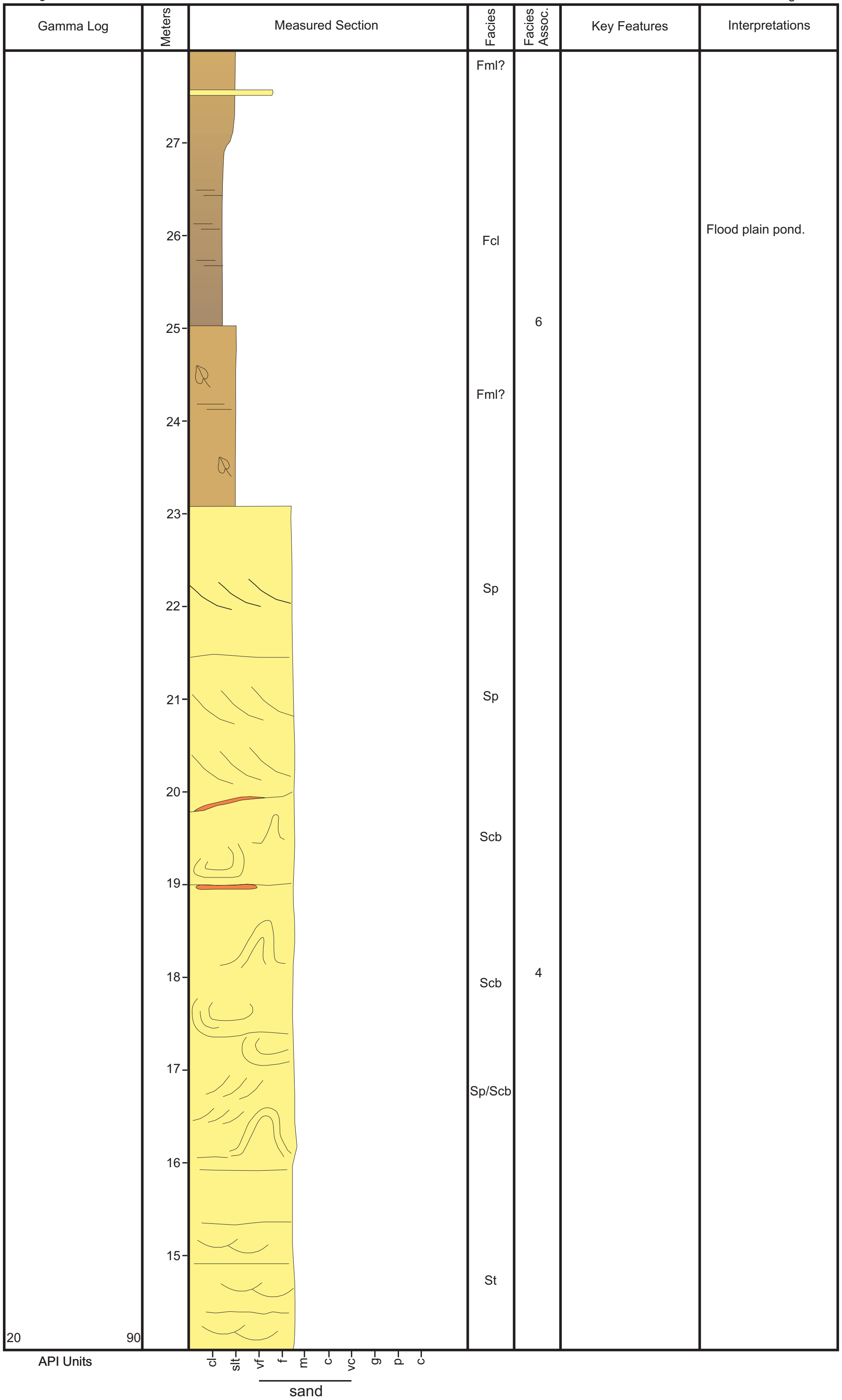


FIGURE A22

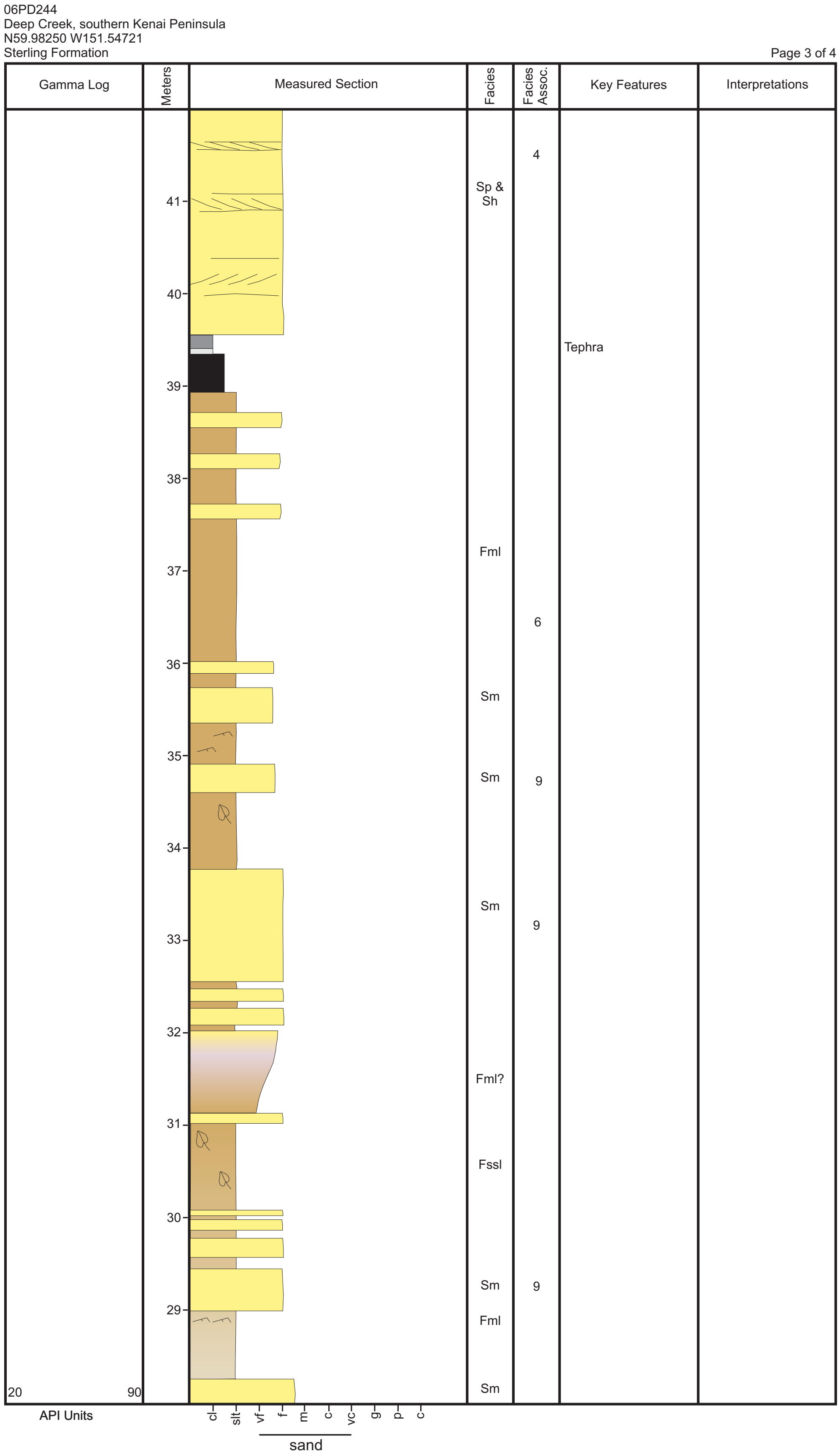

06PD244
Deep Creek, southern Kenai Peninsula
N59.98250 W151.54721
Sterling Formation
Page 3 of 4
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
41
40
39
38
37
36
35
34
33
32
31
30
29
4
Sp & Sh
Tephra
Fml
6
Sm
Sm
9
Sm
9
Fml?
Fssl
Sm
9
Fml
Sm
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A22

06PD244
Deep Creek, southern Kenai Peninsula
N59.98250 W151.54721
Sterling Formation

Page 4 of 4

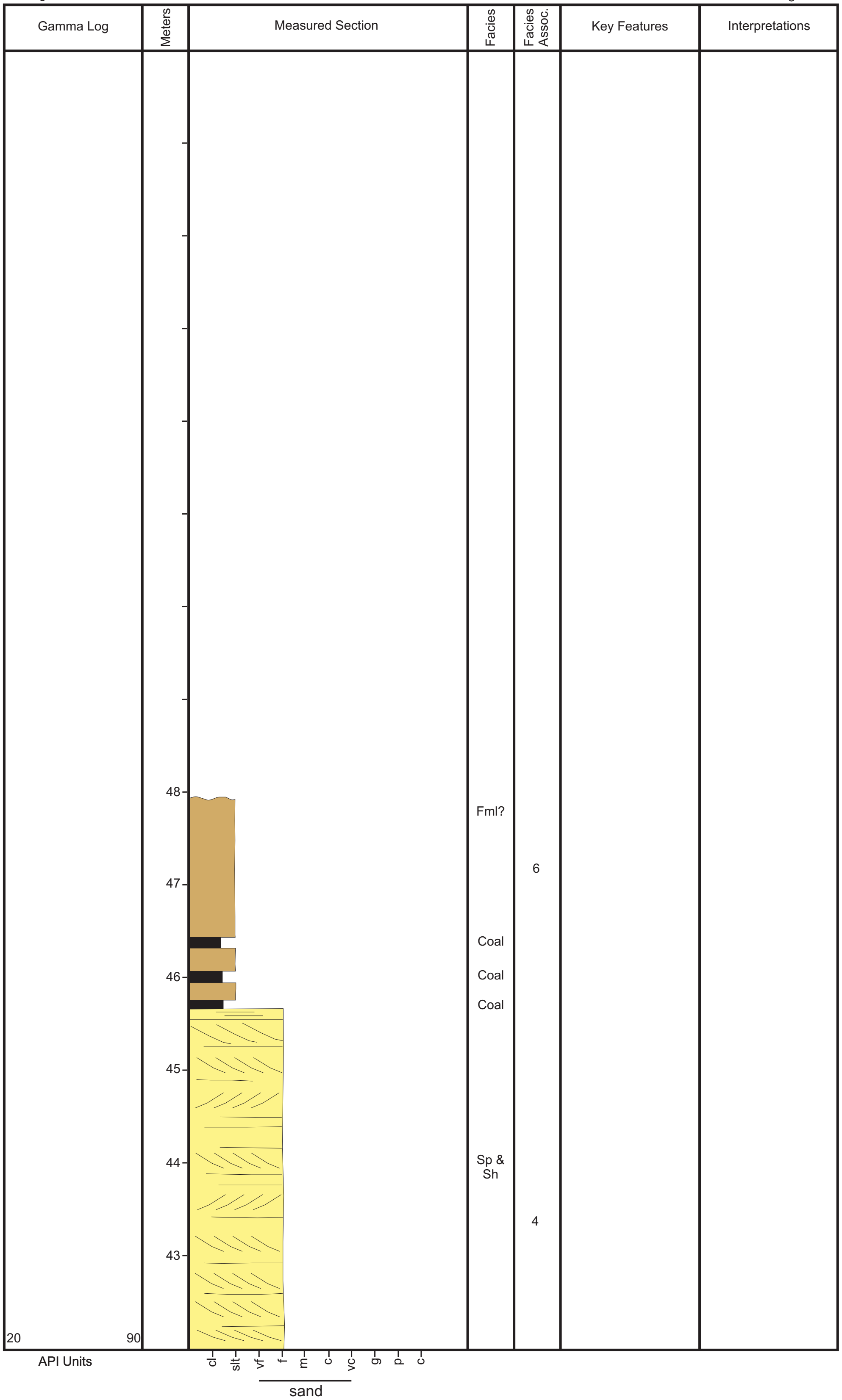
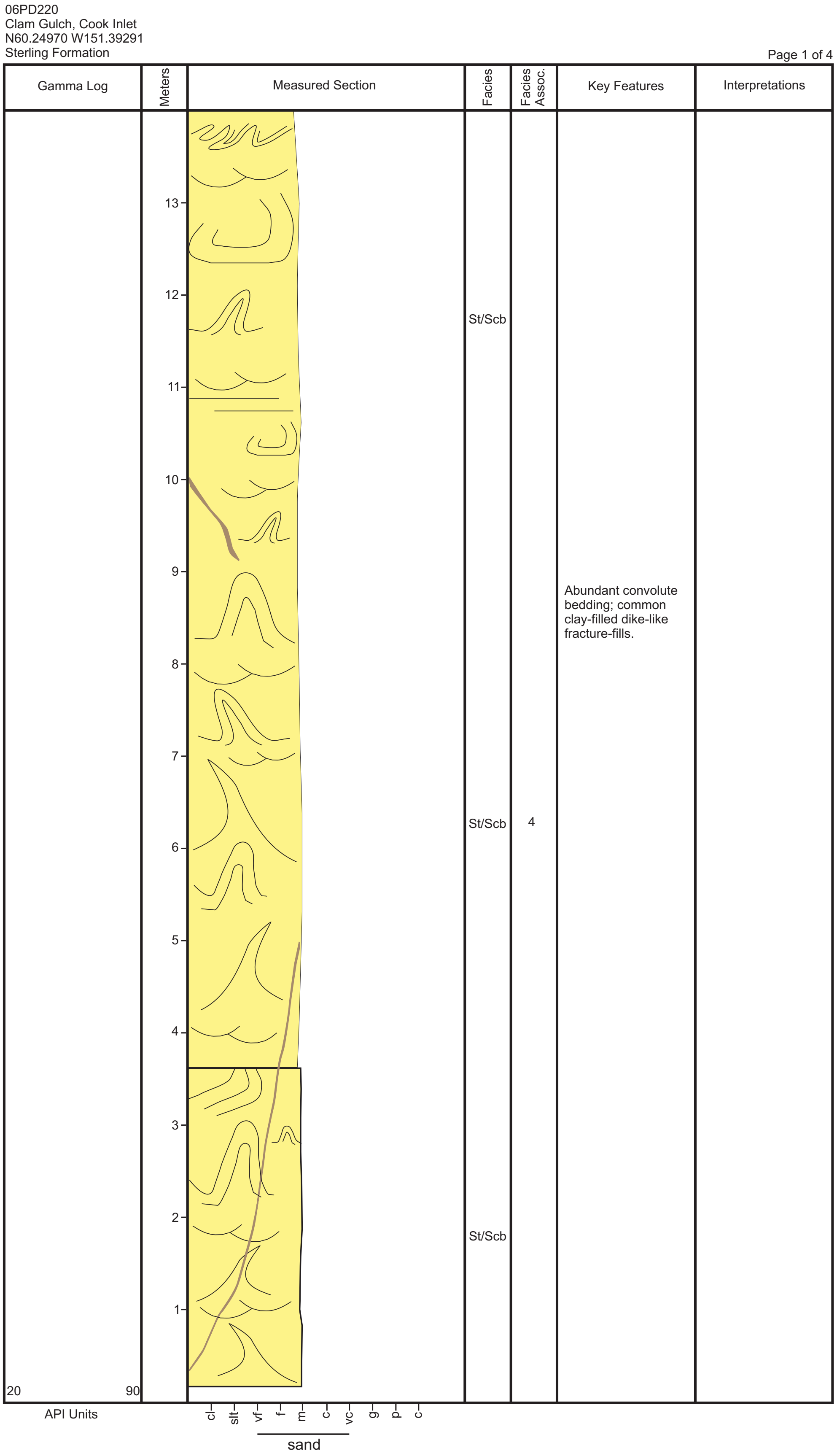


FIGURE A23



06PD220
Clam Gulch, Cook Inlet
N60.24970 W151.39291
Sterling Formation
Page 1 of 4
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
13
12
11
10
9
8
7
6
5
4
3
2
1
St/Scb
St/Scb
4
St/Scb
Abundant convolute bedding; common clay-filled dike-like fracture-fills.
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A23

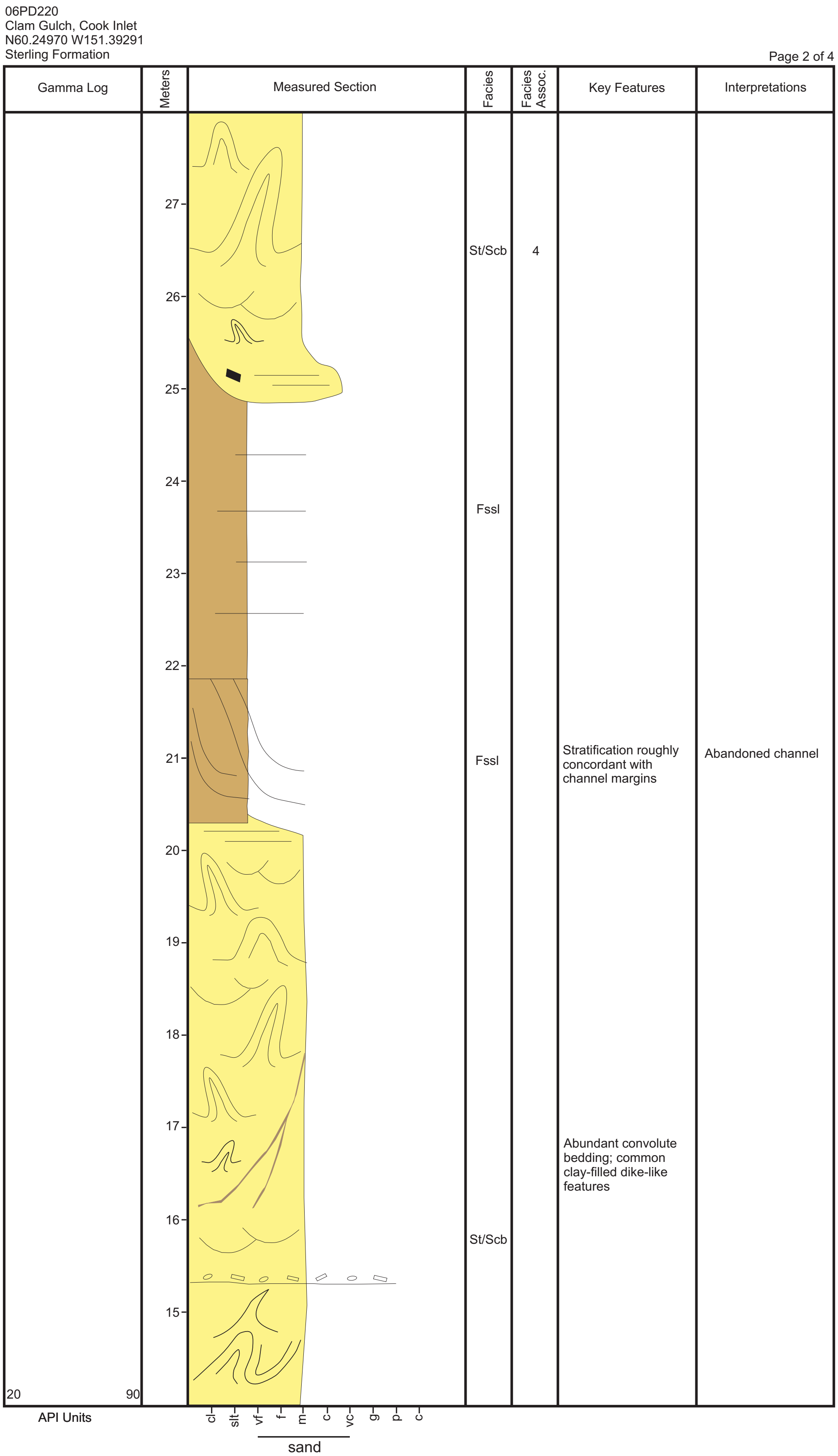

06PD220
Clam Gulch, Cook Inlet
N60.24970 W151.39291
Sterling Formation
Page 2 of 4
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
27
26
25
24
23
22
21
20
19
18
17
16
15
St/Scb
4
Fssl
Fssl
Stratification roughly concordant with channel margins
Abandoned channel
Abundant convolute bedding; common clay-filled dike-like features
St/Scb
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A23

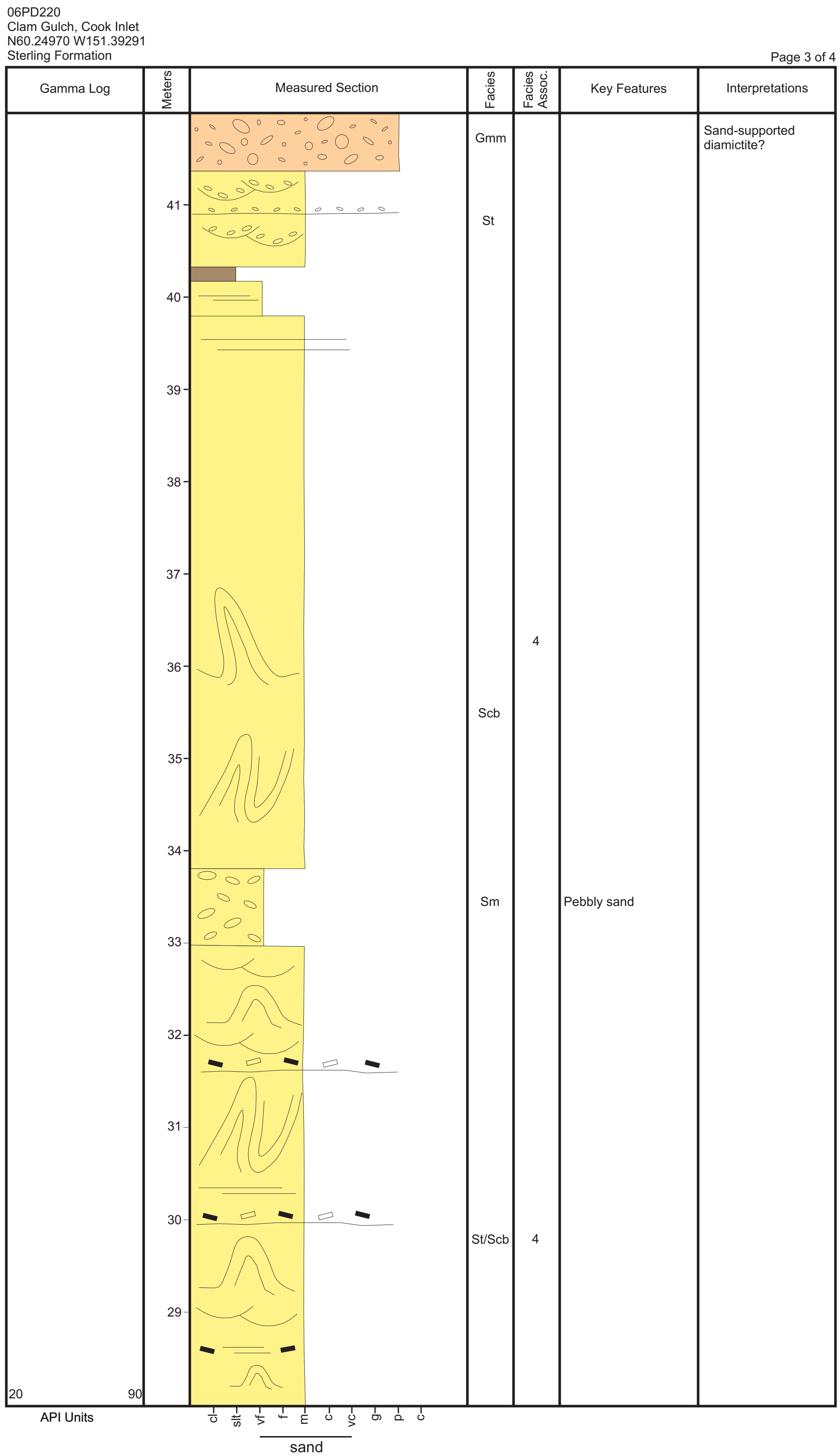
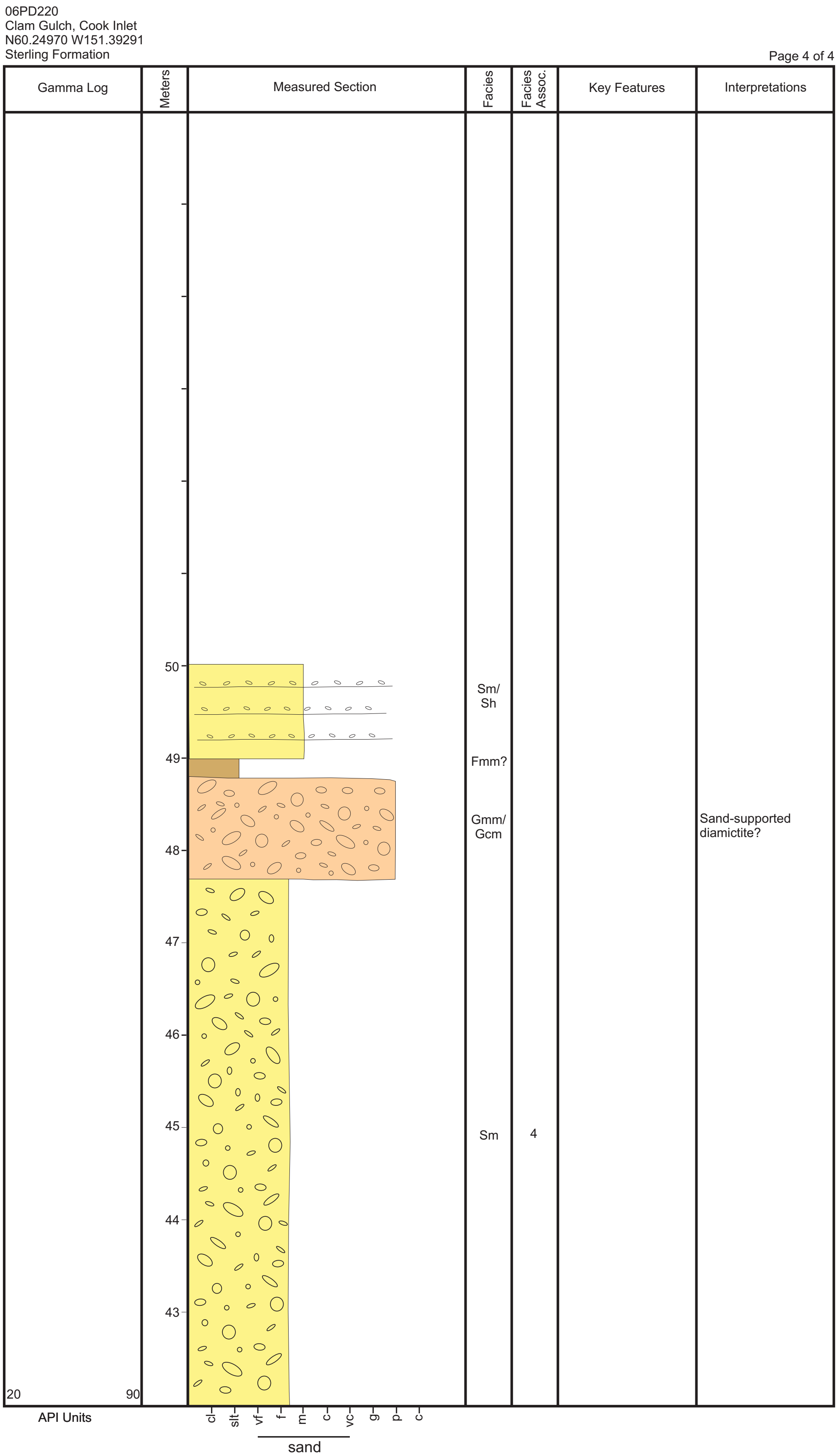

06PD220
Clam Gulch, Cook Inlet
N60.24970 W151.39291
Sterling Formation
Page 3 of 4
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
Gmm
Sand-supported diamictite?
St
Scb
4
Sm
Pebbly sand
St/Scb
4
41
40
39
38
37
36
35
34
33
32
31
30
29
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand

FIGURE A23


06PD220
Clam Gulch, Cook Inlet
N60.24970 W151.39291
Sterling Formation
Page 4 of 4
Gamma Log
Meters
Measured Section
Facies
Facies Assoc.
Key Features
Interpretations
50
49
48
47
46
45
44
43
Sm/
Sh
Fmm?
Gmm/
Gcm
Sand-supported
diamictite?
Sm
4
20
90
API Units
cl
slt
vf
f
m
c
vc
g
p
c
sand