Depositional Environments of Coal-Bearing and Associated Formations of Cretaceous Age in the National Petroleum Reserve in Alaska

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By HENRY W. ROEHLER

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CONTENTS

FIGURES

Depositional Environments of Coal-Bearing and Associated Formations of Cretaceous Age in the National Petroleum Reserve in Alaska

By Henry W. Roehler

ABSTRACT

Coal-bearing rocks in the National Petroleum Reserve in Alaska (NPRA) are more then 1,500 m thick and are present in the Cretaceous Corwin, Chandler, and Prince Creek Formations. These formations were deposited mainly as parts of a large bird-foot delta called the Corwin delta and in smaller, laterally adjacent deltas. These deltas were fluvially dominated. They prograded in digitate fashion in a northeast direction from the vicinity of the ancestral Brooks Range into the northern opening of the interior Cretaceous seaway of North America. The shorelines, or delta front, of the Corwin delta are composed of sandstone and shale that make up all or parts of the Kukpowruk, Tuktu, Grandstand, Ninuluk, Seabee, and Schrader Bluff Formations. Prodelta and marine sandstone, siltstone, and shale are present in the upper part of the Torok Formation and in parts of the Seabee and Schrader Bluff Formations.

The Cretaceous formations investigated in NPRA comprise orderly seaward progressions of alluvial-plain, delta-plain, delta-front, prodelta, and marine depositional environments. Each of these depositional environments is distinguished by its geographic location, stratigraphic position, lithologic composition, and sedimentary structures. Most of the coal beds were deposited as organic debris that accumulated in freshwater swamps that occupied interdistributary bays in the delta-plain environment. Interbedded with the coal are gray and brown carbonaceous shale of salt marsh origin; gray, trough-crossbedded sandstone of distributary channel origin, gray, parallel-bedded, splay sandstone of stream overbank origin; and gray shale of brackishwater, bay-fill origin. The depositional environments of the Cretaceous deltas in NPRA are analogous to those in the Holocene Mississippi River delta.

INTRODUCTION

The National Petroleum Reserve in Alaska (NPRA) comprises 95,000 km^2 of the North Slope of Alaska. NPRA is bounded on the south by the northern part of the Brooks Range, on the east by the Colville River, on the north by the Arctic Ocean, and on the west by a line drawn along 162° W. longitude between the Arctic Ocean and the Brooks Range (fig. 1). The physiography of NPRA includes part of the Brooks Range, part of the Arctic Foothills of the Brooks Range, and part of the Arctic Coastal Plain. The structure consists of thrust faults along the north margins of the Brooks Range, linear folds in the Arctic Foothills, and low-angle, mostly seaward dipping beds across the Arctic Coastal Plain. NPRA is located 225 km north of the Arctic Circle, and is primarily a treeless tundra habitat, which is underlain by permafrost. Major drainages flow northward to the Arctic Ocean and include the Colville River and its tributaries, which drain the southern and eastern parts of NPRA, and the Kokolik, Utukok, Kuk, Meade, and Ikpicpuk Rivers and their tributaries, which drain the western and northern parts of NPRA. A detailed analysis of the physical environment is included in "An Environmental Evaluation of Potential Petroleum Development on the National Petroleum Reserve in Alaska," a paper prepared by the U.S. Geological Survey under Section 105(b) of the Naval Petroleum Reserves Production Act of 1976 (December 15, 1979).

The U.S. Geological Survey has investigated NPRA as part of a land use study that was authorized by the Secretary of Interior under provisions of U.S. Public Law 99–258 (1976). A major objective of this land-use study has been to assess mineral resources, including coal. The depositional environments of coal-bearing rocks in NPRA have been investigated in an attempt to predict coal-bed occurrence, geometry, and composition.

The importance of coal exploration in NPRA has been underscored by the large resources that have been reported there in recent years. Martin and Callahan (1978) calculated hypothetical resources of about 1.9 trillion tons of bituminous coal and about 1.4 trillion tons of sub-bituminous coal for NPRA. Most of the coal occurs in widely spaced beds less than 3 m thick. More than 95 percent of the coal occurs at depths of less than 900 m, and 35 percent, or about 1.2 trillion occurs at depths of less than 300 m. For comparison, the entire coal resources of the United States as of January 1, 1974, were estimated by Averitt (1975) to be 3.599 trillion tons.

Coal investigations in NPRA are difficult because of the inaccessibility of outcrops, poor exposures, and

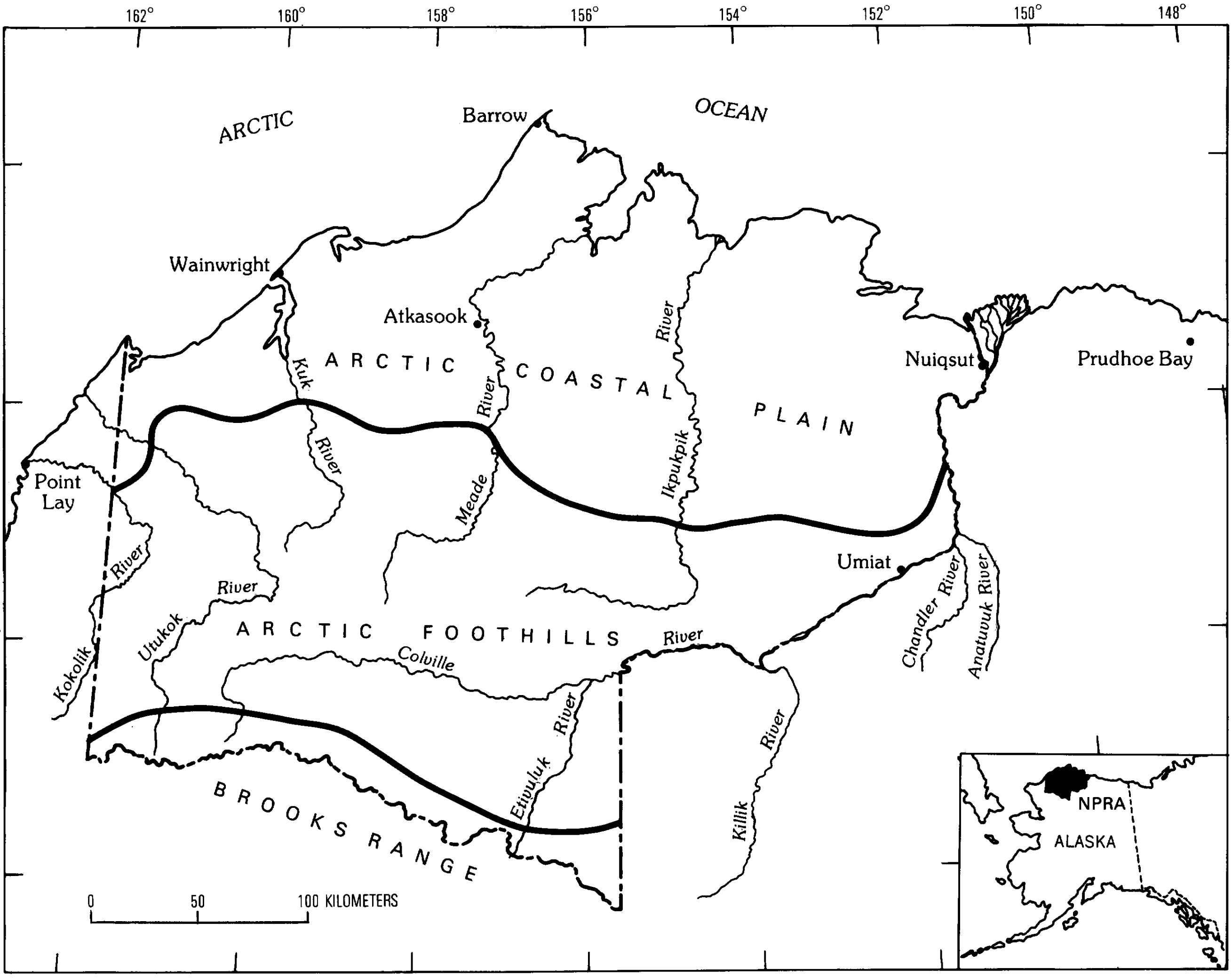

Figure 1. Index map of NPRA.

environmental factors. Outcrops are accessible only by light aircraft, by boats on major drainages, or on foot. There are no permanent roads in NPRA except for those in and around oil fields and villages, and no vehicles are allowed on the tundra during summer months because of environmental restrictions. Less than 5 percent of the Cretaceous coal-bearing rocks in NPRA area exposed. The exposed sections are generally restricted to cutbanks along major drainages and to occasional sandstones that cap rubble-strewn ridges between drainages. Coalbeds rarely crop out on the tundra between drainages, although their presence there may be indicated by coal fragments mixed with other rock fragments on slumped hillsides, or by coal fragments in excavated material at the mouths of rodent burrows. The coal-beds that are the source of these fragments are seldom locatable in place, however, because permafrost and tundra vegetation make trenching impossible. The weather in NPRA is unpredictable. Rain and fog occur frequently, and even during the summer months light snow is possible.

CRETACEOUS DEPOSITIONAL SETTING

The Cretaceous rocks investigated in NPRA include the Torok, Kukpowruk, Corwin, Tuktu, Grandstand, Chandler, Ninuluk, Prince Creek, Seabee, and Schrader Bluff Formations. These rocks were deposited near the northern opening of the interior Cretaceous seaway (fig. 2), which transected central North America from the vicinity of the Holocene Beaufort Sea north of Alaska and Canada southward to the Gulf of Mexico (Ryer, 1981). Along the western margins of the seaway in northern Alaska was an orogenic belt (the ancestral Brooks Range) from which sediments were carried northeastward by streams to form clastic wedges of nonmarine conglomerate, sandstone, siltstone, shale, and coal, hundreds of meters in total thickness. These clastic wedges project seaward into finer textured marine mudstone and shale (Bird and Andrews, 1979). The subaerial parts of the clastic wedges consist of sediments deposited in alluvial plains adjacent to the orogenic belt, which graded laterally

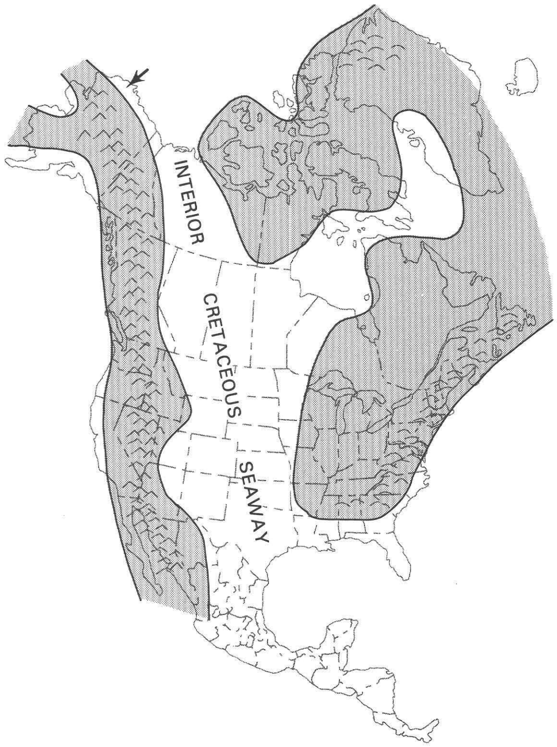

Figure 2. Paleogeographic map of the interior Cretaceous seaway of North America in Turonian time. Arrow points to the location of the study area. (From Ryer, 1981; modified from Williams and Stelck, 1975).

seaward into deltas. The deltas had bird-foot configurations during early stages of development (Ahlbrandt, 1979), but during later stages they coalesced to form a broad west-northwest trending coastal plain. A west-east correlation of stratigraphic units and depositional environments across NPRA is illustrated on figure 3.

The Cretaceous rocks in NPRA are associated with a large delta system called the Corwin delta (Ahlbrandt and others, 1979), with parts of smaller deltas situated lateral to the Corwin delta (Huffman and others, in press), or with marine shelves, slopes, and basins (Molenaar, 1983). The deltas were fluvially dominated, constructional, and prograding, except for two interruptions by marine transgressions across the northeast part of NPRA during the deposition of the Seabee and Schrader Bluff Formations. Beach deposits, which would indicate reworking of the marine shorelines of the deltas by waves, longshore currents, or tides have not been identified by the author in outcrops, but they have been reported in the Grandstand and Kukpowruk Formations in drill holes (Ahlbrandt and others, 1979; Fox, 1979; Huffman and others, in press). Nearshore sandstone bars have been observed locally by the author within marine shale of the Torok Formation in the southwestern part of NPRA, and most of the delta shorelines in the eastern part of NPRA are of distributary mouth bar origin (fig. 4).

The bird-foot deltas prograded in digitate fashion onto shallow, very muddy marine shelves, 75–150 km wide, located along the western margins of the interior seaway (Molenaar, 1981). The pattern of bird-foot delta deposition envisioned by the author for NPRA is illustrated by block diagrams on figure 5. Most of the stream courses across the deltas appear to have been straight to slightly sinuous, based upon channel profiles and sedimentary structures. The channels are usually concave and symmetrical (fig. 6). Sedimentary structures in the channel sandstones are dominantly trough crossbeds, although parallel and planar crossbeds associated with point bars and channel bars are present locally.

Crevasse splay sandstone occurs interbedded with other rocks of deltaic origin (fig. 6). The splay sandstone was deposited along the edges of interdistributary bays in response to stream overflow during periods of flood. The floods probably resulted from either heavy seasonal rains or from occasional torrential rains in nearby mountains. From crevasses, or breaches in riverbanks, the splay sands fanned outward into adjacent bays and flood basins. The sands prograded, and this resulted in upward coarsening and lateral fining away from the crevasses. At its distal edges the splay sandstone generally feathers out into siltstone and shale. Sedimentary structures in the splay sandstone indicate that the flow of water across the splays was partly confined to a network of small distributary channels characterized by trough crossbeds and partly unconfined to sheetlike or laminar flow across the vegetated splay surfaces characterized by thin, subparallel layers of current ripples.

The size and shape of the salt- and brackish-water interdistributary bays in the lower parts of the deltas can be inferred from limited outcrop and well data. The bays were presumably large, roughly triangular, and partly or totally open to the sea. Infilling of the bays progressed seaward, and large swamps and marshes replaced the open waters of the bays as the deltas prograded. The sediments and organic debris that filled the bays resulted in the deposition of randomly layered sandstone, mudstone, carbonaceous shale, shale, and coal beds, which characterize the NPRA deltas.

DEPOSITIONAL ENVIRONMENTS

A descending and laterally seaward progression of Cretaceous depositional environments in NPRA includes alluvial plain, delta plain, delta front, prodelta, and marine. These depositional environments have modern and ancient analogs that have been described by Wright and Coleman (1973), Broussard (1975), Ferm and Horne

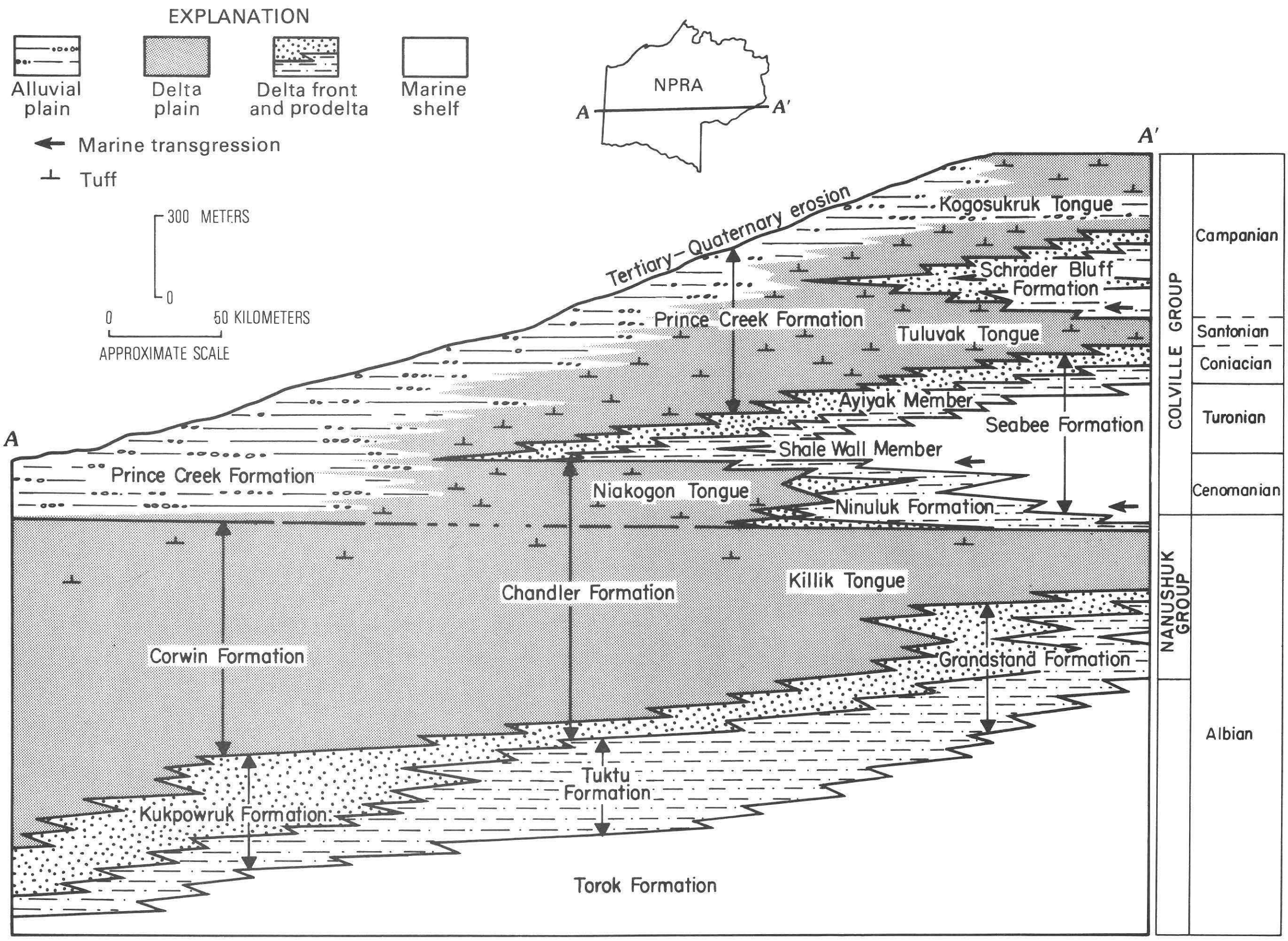

Figure 3. Generalized west-east cross section of NPRA showing formation nomenclature and depositional environments.

(1979), and others. A model for the delta plain, delta front, and prodelta environments in NPRA has been constructed in cross section on figure 7.

The alluvial-plain, upper part of the delta-plain, and prodelta depositional environments have fairly uniform lithofacies across NPRA. The lower part of the delta-plain and the delta-front depositional environments, on the other hand, vary from area to area and from formation to formation across NPRA. The three basic types of these environments are illustrated in columnar sections on figure 8. In the western part of NPRA, the delta-front environment (Type A) is situated in the Kukpowruk Formation and is composed mostly of stacked distributary channel sandstone with some interbedded distributary mouth bar sandstone and marine shale (figs. 8 and 9). The lower delta-plain environment is situated in the Corwin Formation in the western part of NPRA and is a thick sequence of mostly bay-fill shale with a few beds of distributary channel sandstone and splay sandstone, and rare thin beds of carbonaceous shale and coal. The Type A environments

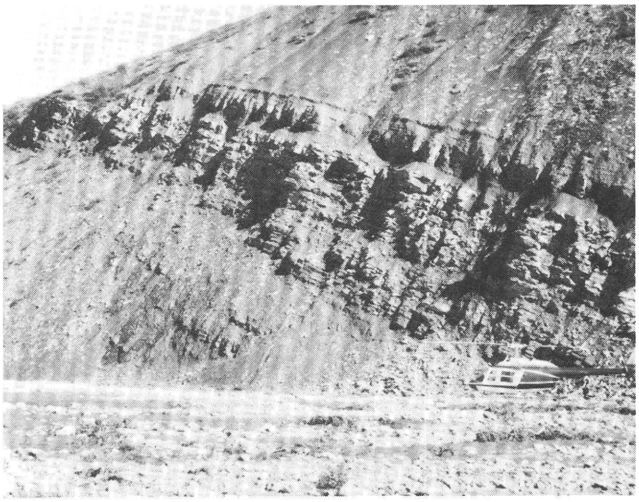

Figure 4. Exposures of the Tuktu Formation on the east side of the Nanushuk River at Arc Mountain 105 km southeast of Umiat. 1, marine shale; 2, coarsening upward distributary mouth bar.

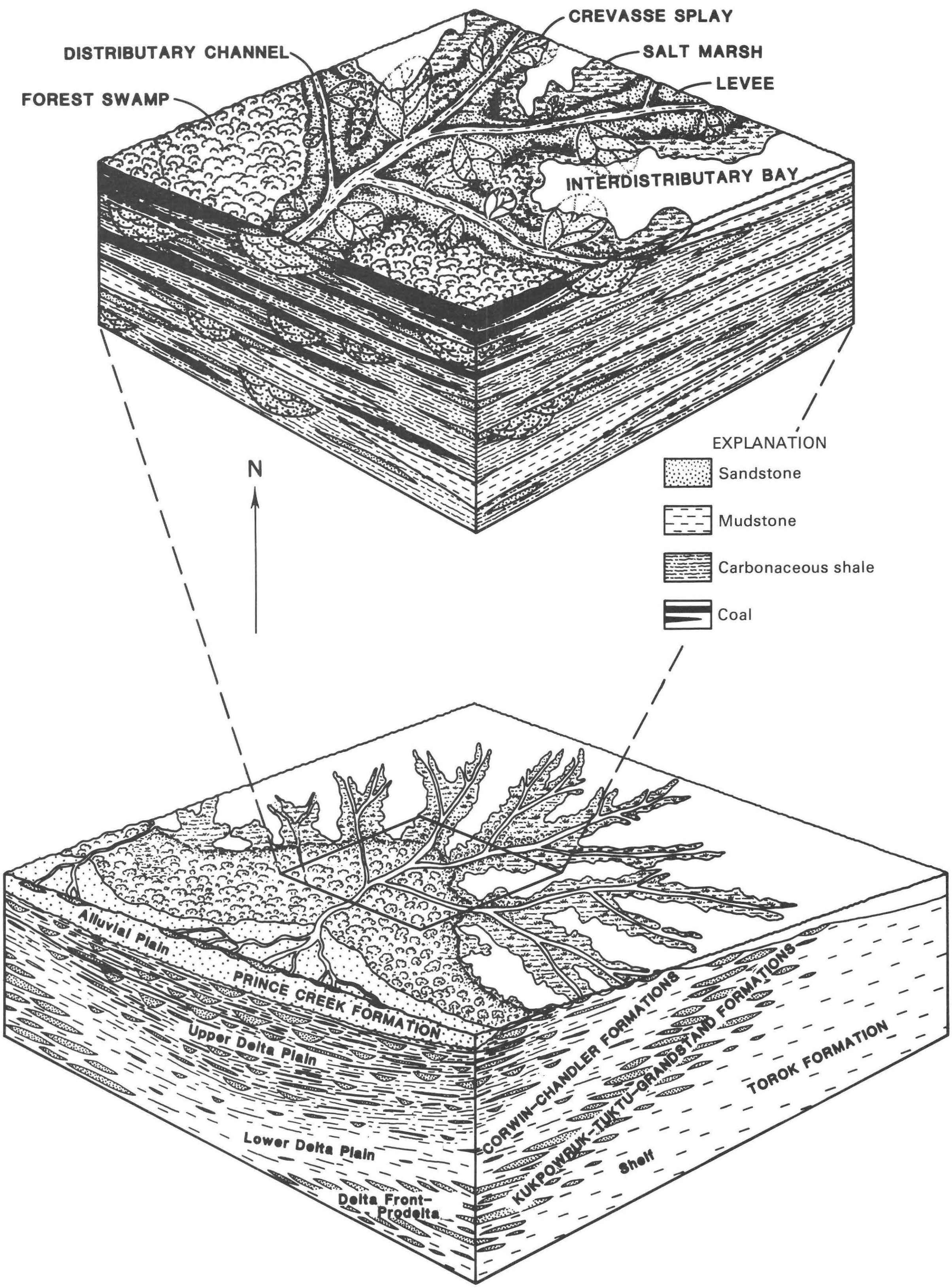

Figure 5. Block diagrams of coal-forming depositional environments interpreted for Cretaceous rocks in NPRA, North Slope of Alaska.

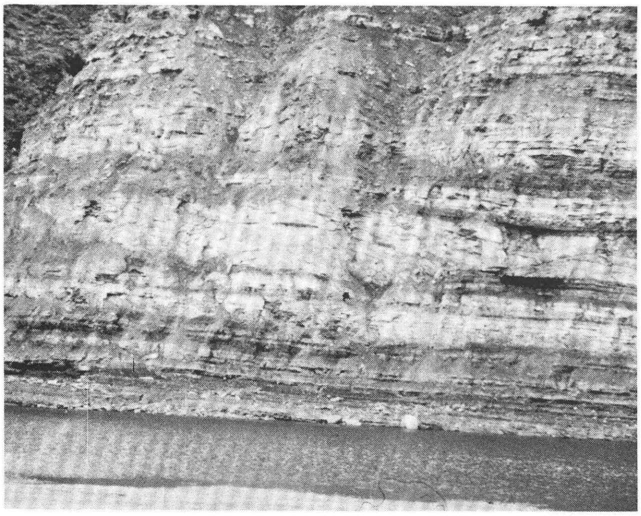

Figure 6. Lens-shaped outcrop near the center of the photograph is a distributary channel sandstone in delta-plain deposits of the Killik Tongue of the Chandler Formation. South bank of the Colville River at Killik Bend 85 km southwest of Umiat. Light-colored, parallel beds surrounding the channel sandstone are crevasse splay sandstones.

in the western part of NPRA probably reflect deposition in distal parts of the Corwin delta in large, closely spaced distributary channels, between which were large, open, brackish-water bays. In the eastern part of NPRA, delta-front environments (Types B and C) are present in the Tuktu, Grandstand, Ninuluk, Seabee, and Schrader Bluff Formations, where the lithofacies consists primarily of distributary mouth bar sandstone and interbedded marine shale. The lower delta plain in the Chandler and Prince Creek Formations, which overlie the delta-front environments in the eastern part of NPRA, are either (1) Type B environments, consisting of interbedded distributary channel sandstone, splay sandstone, thin carbonaceous shale and coal, and some distributary mouth bar sandstone; or (2) Type C environments, consisting of thick beds of laterally persistent distributary mouth bar and splay sandstone and interbedded bay-fill mudstone and fairly thick coal, with rare distributary channel sandstone (fig. 8). The Type B and C environments in the eastern part of NPRA probably reflect deposition in distal parts of the Corwin delta in and between widely spaced distributary channels and in largely filled-in, swampy, interdistributary bays and flood basins.

Alluvial Plain

The Prince Creek Formation is of alluvial plain origin where it is exposed along the lower Utukok and Kokolik Rivers in the western part of NPRA. The formation there is composed of more than 80 percent fine-grained to very coarse grained, trough-crossbedded sandstone that contains lenses of pebble- to cobble-size quartzite conglomerate (Chapman and Sable, 1960). These sandstones are gray, salt-and-pepper-type, carbonaceous, and locally ferruginous; they occur in lenticular, fining-upward beds up to 15 m thick that have scoured bases. Pebble- to cobble-size coal fragments are common. Interbedded with the sandstones are thin beds of coal, gray shale, and gray to green bentonite. The coalbeds are generally less than 1.3 m thick, commonly bony, and laterally discontinuous. A similar bed of alluvial-plain sandstone containing conglomerate lenses is present about 50 m above the base of the Kogosukruk Tongue of the Prince Creek Formation on the west bank of the Colville River 30 km northeast of Umiat. The alluvial-plain environment reflects deposition by large and small, broadly meandering, and anastomosing streams, which were interspersed with small interchannel mud-filled flood basins. In places, vegetation accumulated along the margins of the flood basins to form peats containing impurities derived from the influx of detritus during floods.

Delta Plain

Delta-plain environments in NPRA are present in the Corwin, Chandler, and part of the Prince Creek Formations. The delta-plain environments in these formations are divided into upper and lower delta-plain subenvironments, primarily by differences in sedimentary lithofacies (Roehler and Stricker, 1979), and to a lesser extent on the basis of floral zonations (Scott and Smiley, 1979). The recognition and separation of the delta-plain subenvironments are important because thick, economically important beds of coal occur most frequently in the upper delta plain.

The upper delta-plain subenvironment is separated from the lower delta-plain subenvironment in modern deltas by water salinity changes (fresh to brackish) and accompanying vegetation changes that take place across the deltas (Coleman, 1976). They are separated in ancient deltas by distinctly differing patterns of sedimentation (Fisher and McGowen, 1969). The upper and lower delta-plain subenvironments over most of NPRA are similar to those described and illustrated in a delta model prepared by Ferm (1976). The upper delta plain is characterized by numerous, thick beds of sandstone with interbeds of carbonaceous shale and coal, and sparse, thin beds of mudstone and noncarbonaceous shale. One of the best exposures of an upper delta plain in NPRA is found at Killik Bend on the Colville River, 85 km southwest of Umiat (fig. 10). The lower delta-plain lithofacies are variable, as discussed above, but usually consist of very thick beds of mudstone and noncarbonaceous shale; sparse, thin beds of sandstone and carbonaceous shale;

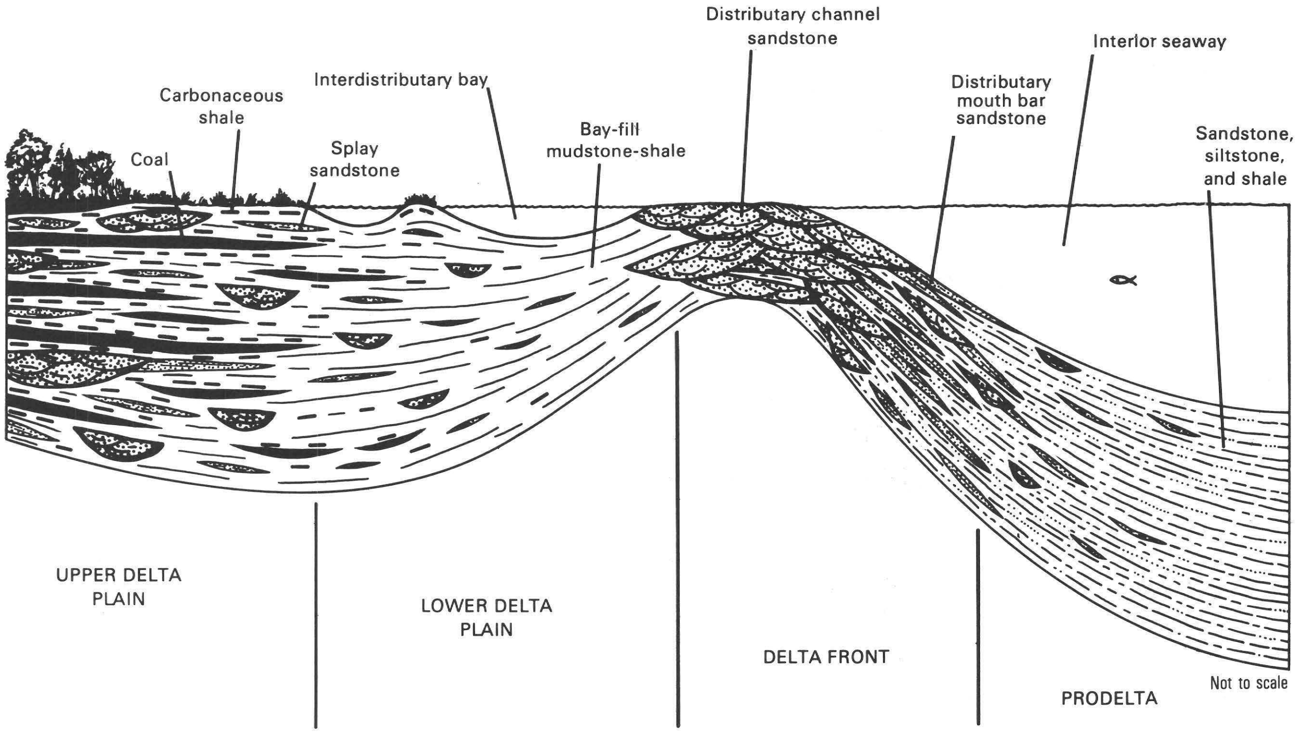

Figure 7. Cross-sectional model for fluvially dominated Cretaceous deltas in NPRA, North Slope of Alaska. Delta-plain and prodelta thicknesses are exaggerated.

and rare, thin beds of coal. A typical lateral lithofacies change from the upper to lower delta plains in NPRA is illustrated on the cross-sectional model, figure 7. As suggested on figure 7, the change is gradational, and the boundary defining the change is hence arbitrarily located.

Investigations of plant megafossils and microfossils by Scott and Smiley (1979) have resulted in the division of Cretaceous rocks in NPRA into eight floral zones and 21 floral subzones. Each zone and subzone has characteristic genera and species. The zonations are based primarily upon the distribution of the megafossils, but the accuracy of the zone boundaries is supported by spore and pollen data. The lower five floral zones subdivide the Torok, Kukpowruk, and Corwin Formations and their lateral equivalents, and the upper three zones subdivide the Prince Creek Formation and its lateral equivalents. The variations in floral zones and subzones are interpreted as resulting mostly from regional paleoclimatic changes, but changes in depositional environments may also be important contributing factors.

The distributary channel and crevasse splay sandstones of the upper and lower deltaplain subenvironments weather mostly to tan, hard, resistant escarpments between valleys formed in softer, drab-gray shale and coal. The distributary sandstone is broadly lenticular, and occurs in fining upward, trough crossbeds (fig. 11) that have scoured bases. Pebble lenses, carbonized wood fragments, and ironstone concretions are fairly common, particularly in the lower parts of the channel sandstone. The dimensions of this sandstone are variable, but it may be as much as 20 m thick and hundreds of meters wide. The splay sandstone coarsens upward and is silty and lenticular. It commonly occurs as very thin, parallel, current-rippled beds (fig. 12). Gray nodular limestone concretions and thin limestone lenses are found in the distal parts of some splays near the places where they wedge out into bay-fill shale.

Carbonaceous shale beds in the delta-plain sections are gray and contain black, carbonized stem and leaf fragments and in some places laminae of coal. Thick laminae and beds of coal are generally composed of alternating bright and dull bands of vitrain, durain, and fusain up to a few millimeters thick. Nearly perpendicular coal cleats trend about N. 10° W. and N. 85° E. (Roehler and Stricker, 1979).

Interdistributary bay deposits consist mainly of gray shale, but many contain laminae and thin lenses of gray siltstone and slightly carbonaceous shale. The bay shale is similar in color and texture to marine shale, but it is distinguishable by its stratigraphic positions above delta-front sandstone.

Delta Front

The Kukpowruk, Tuktu, Grandstand, and Ninuluk Formations and the Ayiyak Member of the Seabee

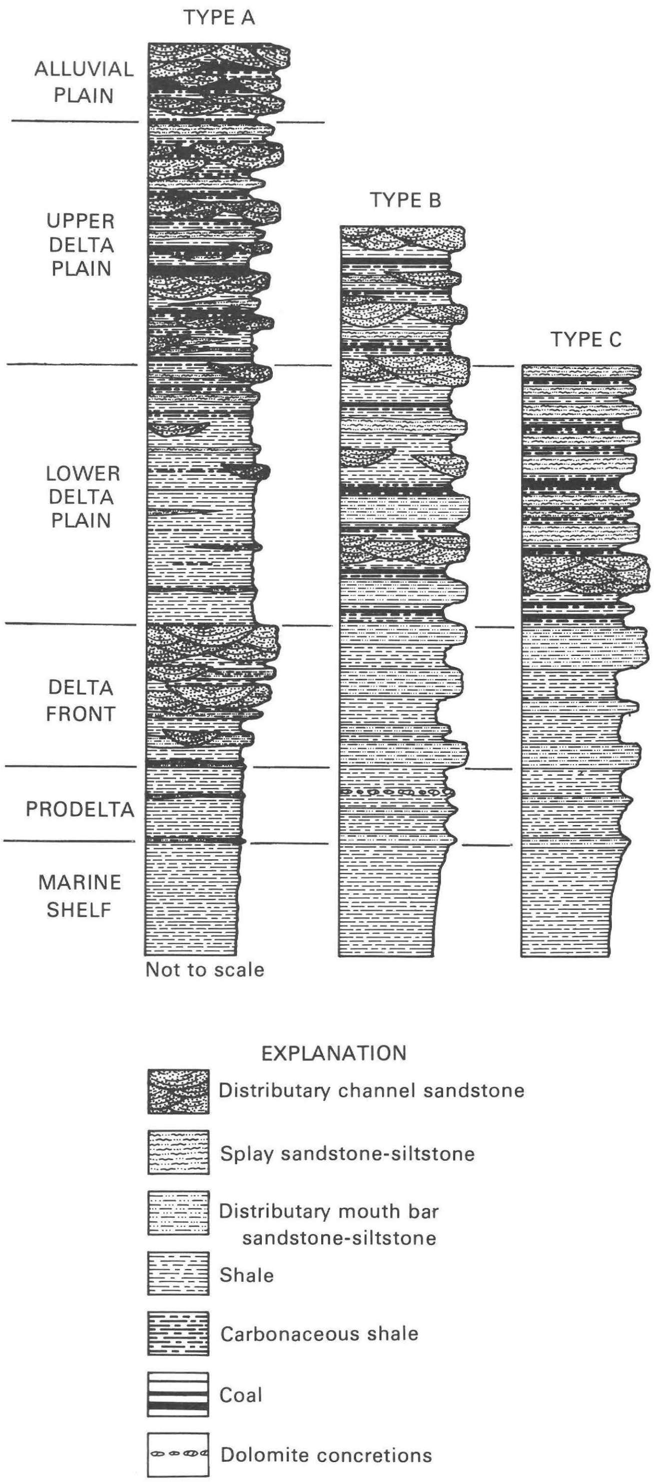

Figure 8. Columnar sections illustrating the three basic types of delta-front and lower delta-plain depositional environments in NPRA, North Slope of Alaska.

Figure 9. Aerial view of the Kukpowruk Formation looking east in the Utukok River region in the southwestern part of NPRA. The light-colored bands are mostly superposed, lenticular, distributary channel sandstones.

Formation were deposited by distributary streams at the seaward edges (delta front) of the Corwin delta. These deposits consist of irregularly interbedded sandstone, siltstone, and shale. The sandstones in the delta front are of two types, based upon their mode of deposition and geometry. They are either trough-crossbedded distributary channel deposits that fine upward and have sharp, scoured bases, or they are parallel-bedded distributary mouth bar deposits (figs. 13 and 14) that coarsen upward and have transitional bases. The sandstones are all graywackes. They are composed of subangular, poorly sorted, and well-cemented grains composed 30–70 percent of tan, white, and gray quartzite and quartz; 25–65 percent of dark-gray and black chert; and about 5 percent of feldspar, muscovite, biotite, siliceous or white clay cement, and miscellaneous varicolored rock fragments. The overall color of the sandstones varies from medium to dark gray. The sandstones that compose the distributary mouth bars are characteristically dark gray, very fine to fine grained and contain large amounts of interstitial clay and mud. The distributary channel sandstones are characteristically medium gray, fine to coarse grained, quartzose, and cleaner than the distributary mouth bar sandstones. Differences in composition, sedimentary structures, stratigraphic position, and weathering make it easy to distinguish distributary mouth bar and distributary channel sandstones on outcrops.

The delta-front sandstones and siltstones in NPRA appear to have been deposited by the simple extension of distributary channels into shallow, quiet, nearshore marine waters. Where the streams entered the sea, their flow velocities and sediment transporting capabilities decreased and deposition occurred. In the receiving basin near the mouth of a distributary stream, sediment infilling was most rapid across subjacent shallow submarine depressions. A stream would discharge its sediments into one of these depressions to form a distributary mouth bar. After the depression was filled, the stream would

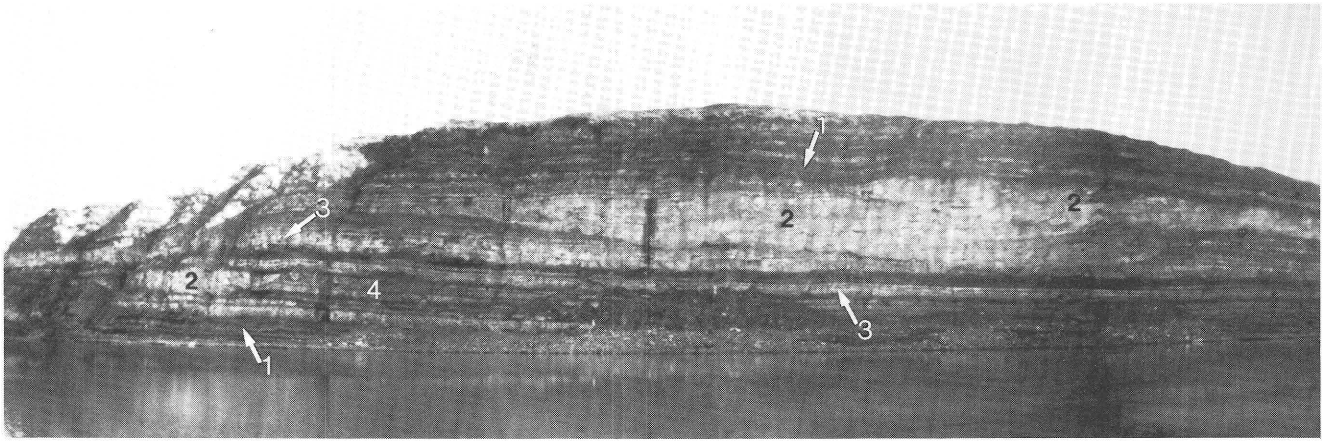

Figure 10. Exposures of an upper delta-plain subenvironment in the Killik Tongue of the Chandler Formation at Killik Bend on the Colville River, 85 km southwest of Umiat. Height of the bluff is approximately 50 m. 1, shale and carbonaceous shale; 2, distributary channel sandstone; 3, splay sandstone; and 4, coal.

alter its course to fill another nearby depression. Because of this pattern of sediment infilling and channel switching, distributary channel sandstones often occur interbedded with or in juxtaposition to distributary mouth bar sandstones along delta-front outcrops. The distributary channel and distributary mouth bar sandstones of the delta front apparently were not affected by tidal currents, although at times they may have been affected by north-northwest trending longshore currents (Molenaar, 1981; Huffman and others, in press).

Prodelta and Marine

Prodelta and marine deposits are present in the upper part of the Torok Formation where it intertongues with the Kukpowruk, Tuktu and Grandstand Formations, in parts of the Seabee Formation, and in parts of the Schrader Bluff Formation (fig. 3). These deposits erode to form low hills with smooth slopes that are occasionally interrupted by small ledges. The exposures are generally obscured by tundra vegetation, by the affects of permafrost, and by slumping. The prodelta and marine deposits are mostly shale with some interbedded dark gray, very fine to fine-grained sandstone and siltstone in thin, coarsening-upward sequences that were deposited under shallow marine conditions on the shelves seaward of the deltas.

PALEOGEOGRAPHY

Early Stages of Deposition (Middle Albian)

The first of the Cretaceous deltas to appear in NPRA was the Corwin delta (fig. 3). It prograded northeastward from the southwest corner of NPRA onto the shallow shelf of the interior Cretaceous seaway (fig. 15). The lower part of the Corwin delta near the southwest corner of NPRA consists of 200–550 m of prodelta and delta-front sandstone, siltstone, and shale of the Kukpowruk Formation and hundreds of meters of sandstone, shale, carbonaceous shale, and coal of the overlying delta plain comprising the Corwin Formation.

The provenance for the early Corwin delta sediments was probably the ancestral Brooks Range southwest of NPRA. Chapman and Sable (1960) found a perceptible change in the amount and the direction of the intertonguing and replacement of the Kukpowruk and Corwin Formations by the underlying marine Torok Formation across the southwest part of NPRA. They observed that the intertonguing of these units took place in a N. 32° E. direction along a rising replacement gradient of about 11 m/km. A southwest source direction for the early delta sediments is further indicated by numerous northeast-trending paleocurrent directions measured in nonmarine stream channels in the Corwin Formation (Bird and Andrews, 1979) and by northeast-trending foreset dips in marine slope deposits in the Torok Formation, which are correlatable by seismic and drill-hole data (Molenaar, 1981).

Middle Stages of Deposition (Late Albian)

The Corwin delta prograded northeastward from middle Albian to the end of Albian time across a horizontal distance of more than 400 km and through a vertical stratigraphic interval of more than 1,800 m (Molenaar, 1981). The progradation lasted several million years, and during this period of time the delta coalesced along its eastern margins with smaller deltas that were building

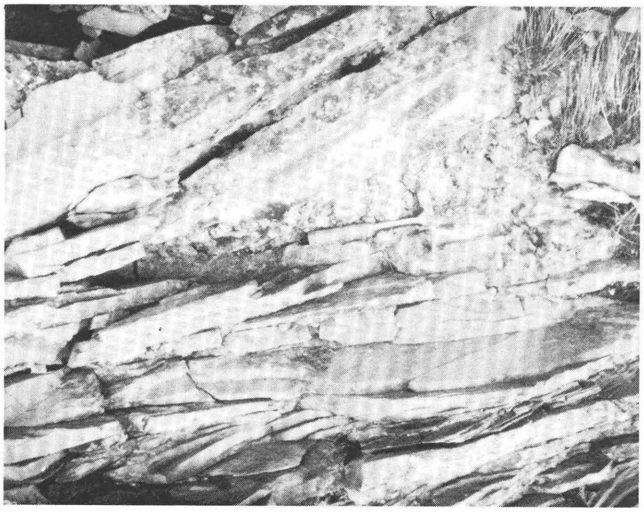

Figure 11. Crossbedded sandstone in a distributary channel exposed near the base of the Killik Tongue of the Chandler Formation on the east bank of the Killik River, 25 km southeast of the confluence with the Colville River.

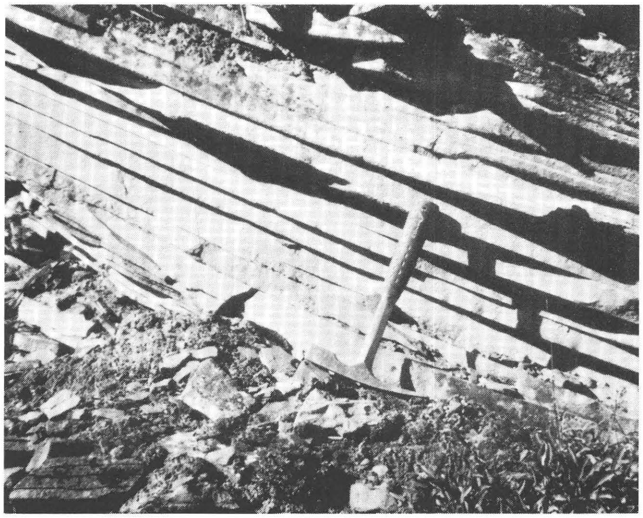

Figure 13. Thin, parallel-bedded distributary mouth bar sandstone in the Grandstand Formation on the west bank of the Nanushuk River, 65 km southeast of Umiat.

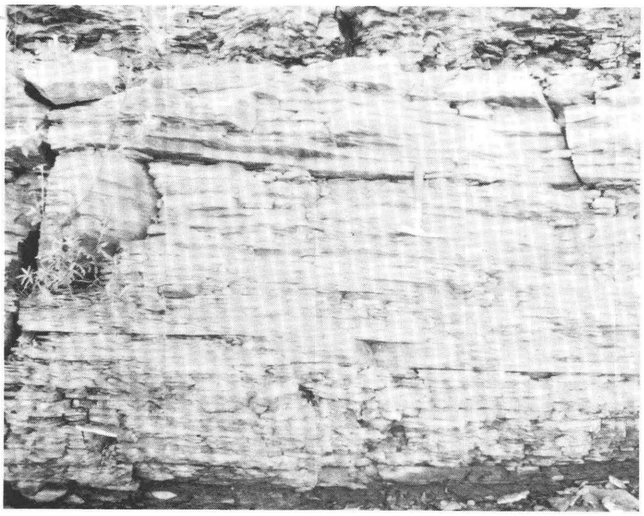

Figure 12. Coarsening upward splay sandstone in a delta-plain environment in the Killik Tongue of the Chandler Formation exposed at Killik Bend on the Colville River, 85 km southwest of Umiat.

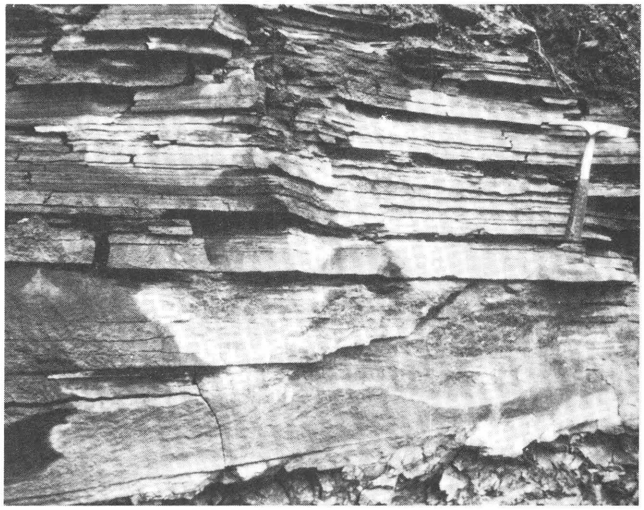

Figure 14. Thin, parallel-bedded distributary mouth bar sandstone exposed in a delta-front depositional environment in the Tuktu Formation on the north bank of the Colville River, 13 km east of the confluence with the Etivuluk River, 165 km southwest of Umiat.

northeastward from the shores of the interior Cretaceous seaway. A separate southern provenance in the ancestral Brooks Range is indicated for the sediments in one of these deltas (called the Umiat delta by some authors) that was located mostly east of NPRA. The stratigraphic position and geographic boundaries of this delta are poorly defined, but it probably includes parts of the Killik Tongue of the Chandler Formation and part of the Grandstand Formation. The sandstones in this delta are coarser grained and more conglomeratic, but contain less rock fragments and more quartz, igneous, and metamorphic grains and pebbles than do the sandstones deposited in the Corwin delta in the western part of NPRA (Bartsch-Winkler, 1979). The presence of delta sandstones derived from multiple sediment sources is not unique; in the late Quaternary Niger Delta, three independent sediment sources with characteristic mineral suites have been identified (Allen, 1965).

The shoreline of the interior Cretaceous seaway trended northwest during late Albian time. The Corwin delta and the deltas to the east occupied most of the central part of NPRA, and a broad alluvial plain was

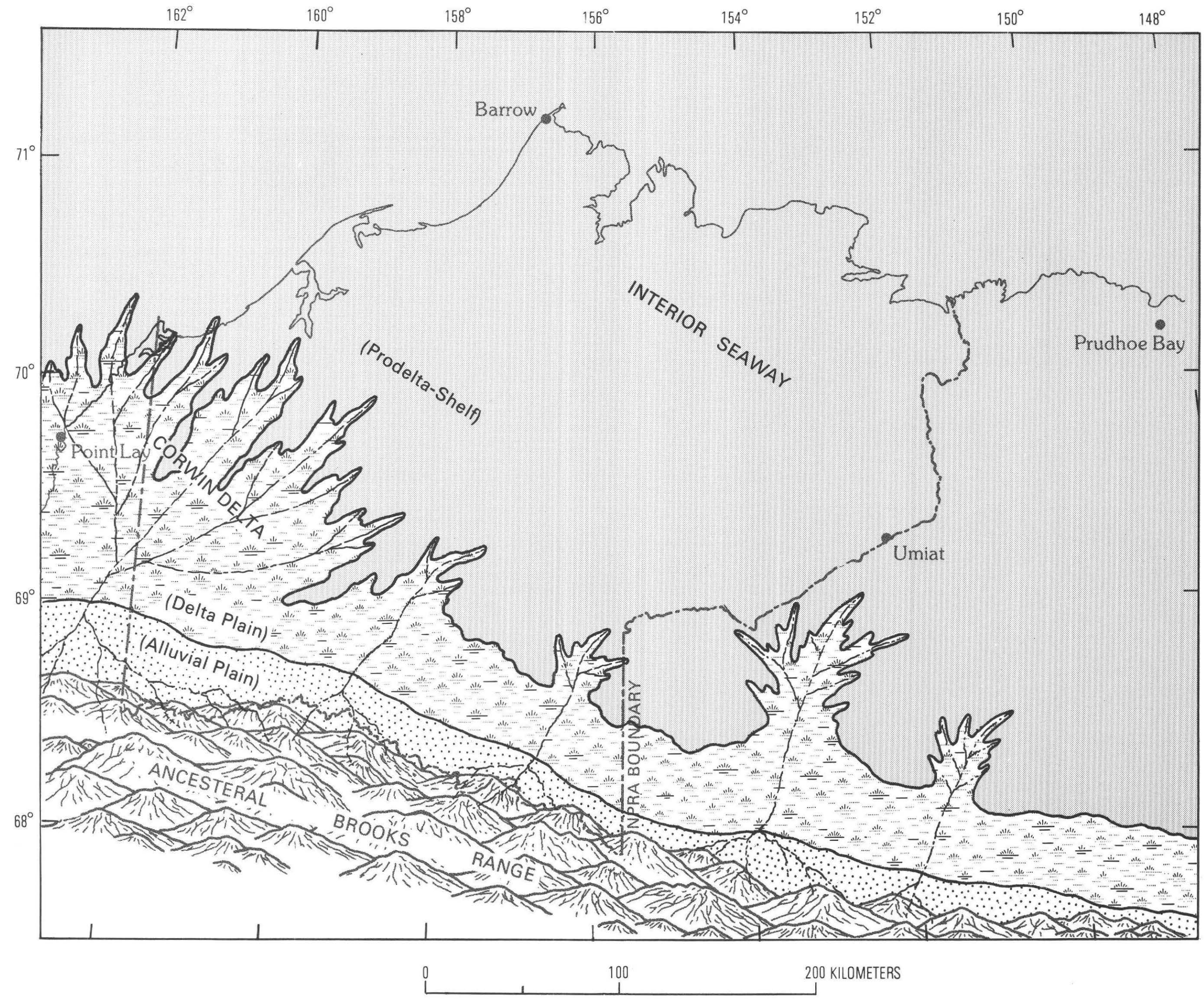

Figure 15. Paleogeography of NPRA and adjacent areas in middle Albian time.

present landward of the deltas along the northern margin of the Brooks Range. Figure 16 interprets the paleogeography at the close of deposition of the Killik Tongue of the Chandler Formation.

Late Stages of Deposition (Campanian)

The next and last period of Cretaceous deposition in NPRA that includes coal-bearing strata is represented by about 500 m of mudstone, siltstone, shale, bentonite, and coal that crop out along the Kogosukruk and lower Colville Rivers at the eastern edge of NPRA. These rocks comprise the Kogosukruk Tongue of the Prince Creek Formation (Gryc and others, 1951). The Kogosukruk Tongue intertongues with and is laterally replaced eastward by the upper part of the Schrader Bluff Formation which has been dated as Campanian (Whittington, 1956).

The Campanian shoreline of the interior Cretaceous seaway trended northwest across the northeast part of NPRA, as shown on figure 17. Tertiary and Quaternary erosion has removed all of the Kogosukruk Tongue from the central and southern parts of NPRA, and the restoration of the paleogeography of those areas shown on figure 17 is consequently based upon speculation.

COAL-FORMING ENVIRONMENT IN NPRA

Prerequisites for peat and coal formation normally include the following physical, chemical, and biological conditions: (1) a climate that produces abundant vegetation; (2) water-saturated soils or water-covered surfaces that allow for peat preservation without adverse weathering, oxidation, or biogenic degradation; (3) subsidence to accommodate peat accumulation and maturation; and (4)

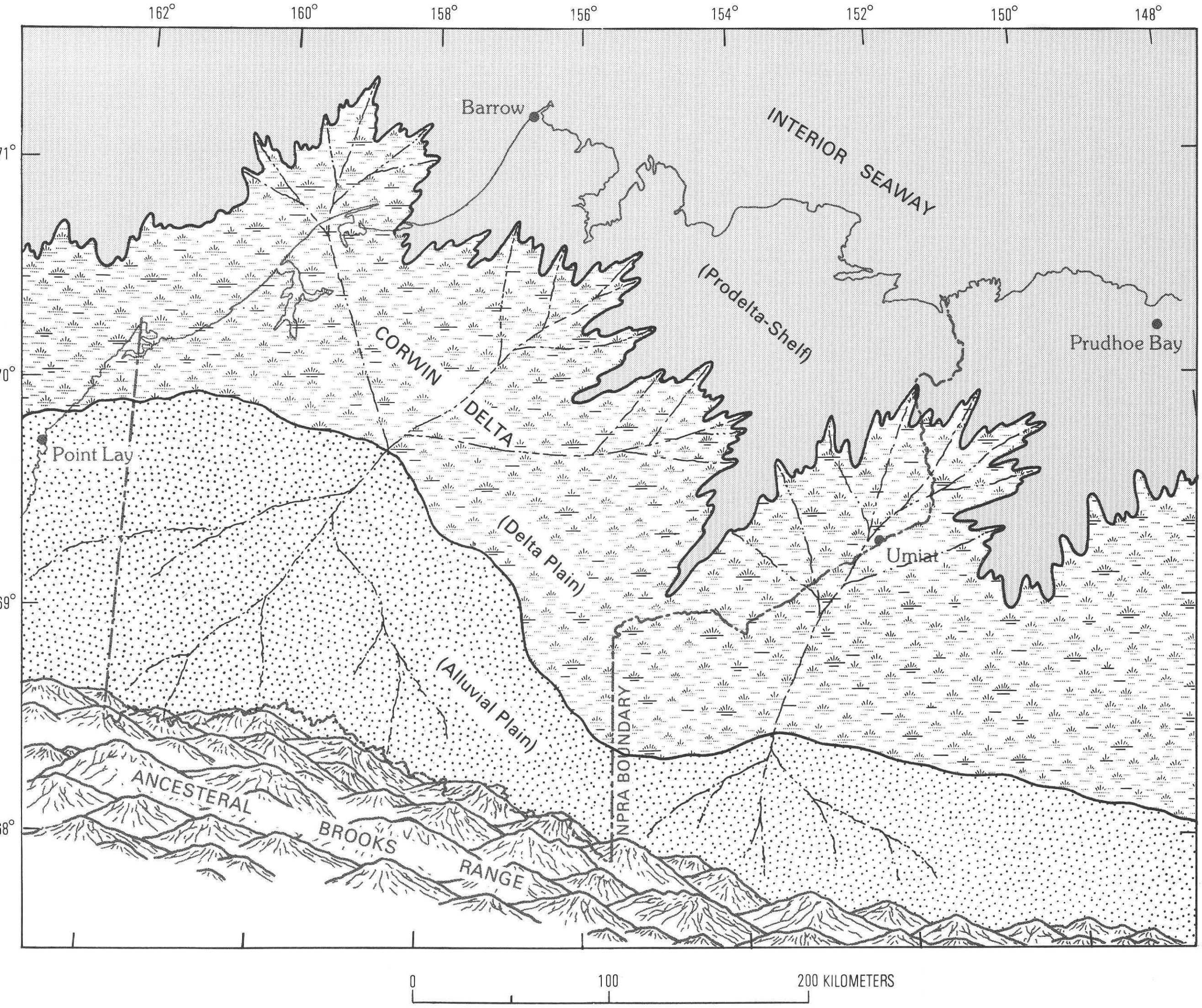

Figure 16. Paleogeography of NPRA and adjacent areas in late Albian time.

deep burial to coalify the peat. These conditions were present during the Cretaceous in NPRA.

The Cretaceous climate in NPRA ranged from subtropical in early Albian time to warm-temperate during latest Albian through Turonian time (Scott and Smiley, 1979). Precise temperature and precipitation ranges are unknown, but they favored the luxuriant growth of vegetation including conifers, dicots, cycads, ginkgos, and ferns, from which thick peat accumulations were possible.

The coal deposits in NPRA apparently resulted from accumulations of plant remains (peat) in forest swamps within the interdistributary areas of delta plains in a pattern of development similar to that described by Frazier and Osanik (1969) for the Mississippi River. As distributary streams prograded across the shallow marine shelves at the seaward edges of the deltas, the interdistributary areas evolved into large, brackish-water bays that converged landward but were open to the sea. The margins and landward parts of these open-water bays rapidly filled with sand, mud, and silt as a result of overbank flooding of the distributaries. Resulting splay and levee deposits provided a stable platform for freshwater vegetation. As the infilling of the bays continued, the bays eventually were abandoned, and their landward parts were occupied by freshwater swamps. Plant debris accumulated in these swamps near or below water level, and extensive beds of peat developed.

The Cretaceous deltas in NPRA subsided during long periods of sedimentation. This is apparent from the superpositioning of numerous coal-beds within stratigraphic intervals of delta-plain origin that are as much as 1,500 m thick. Because the peat beds from which the coal formed were deposited at or near sea level, the delta-plain areas obviously had to subside to accommodate this thick interval of rocks. Deep burial and deformation are suggested for the beds in the southern part of NPRA across the folded foothills of the Brooks Range, where the rank of the coal is bituminous (Martin and Callahan, 1978). Northward across NPRA, the rocks are largely undisturbed, the depths of burial decrease, and the rank of the coal decreases to subbituminous.

The amount of compaction or compression of peat during the coalification process varies with the composition and rank of the coal (Stach and others, 1982). Coal of forest swamp origin and bituminous and subbituminous ranks normally has peat-to-coal compaction ratios from 5:1 to 10:1. A few coal beds in NPRA reach thicknesses of as much as 4 m, and the peats responsible for these beds thus ranged in thickness from 20 to 40 m.

PEAT-FORMING ANALOGS IN THE MISSISSIPPI DELTA

Peat deposits of the Mississippi Delta have been investigated extensively by the Louisiana Geological Survey since 1981. During these investigations, Kosters (1983) identified several peat-forming depositional settings. The two most important are lenticular peat beds that form in subsiding interdistributary basins and blanket peat beds that form across the top of slowly subsiding abandoned delta lobes. Of lesser importance are peat beds deposited as abandoned channel fill or as organic detrital material. One of the peat deposits studied, identified as the Barataria Prospect, is presently forming in a subsiding interdistributary basin similar to those postulated for the Cretaceous NPRA deltas. The Barataria Prospect (Kosters, 1983) occupies an area of more than 85 km^2 in Jefferson and Lafourche Parishes southeast of Lake Salvador. The peat beds in the prospect are as much as 4 m thick, but in most places they are horizontally and vertically discontinuous because of the influx of clastic detritus. The detritus consists of silt and clay that forms wedges and lenses within the peat. The detritus is derived from the periodic overbank flooding of Bayou Barataria, a distributary located along the eastern edge of the prospect. The Barataria peat bed is composed of organic material derived mostly from brackish-water marsh plants including *Spartina* and other grasses. The Barataria peat bed will produce a thin coalbed with numerous splits and partings and a high ash content.

Frazier and Osanik (1969) reported peat accumulations as much as 6 m thick between natural levees along the Teche and Lafourche Bayous in the Mississippi Delta. These peat beds are derived from forest swamp vegetation, mostly cypress and gum, that accumulated in broad, subsiding inland flood basins during progradational-aggradational river phases. Analyses of these peat beds indicated that they contain less than 1 percent sulfur and about 15 percent ash. They may have closer affinities to the NPRA peats than do those of the Barataria Prospect because of their forest swamp origin and lower sediment influx.

Several swamps are present in the upper parts of the delta plain on the east side of the Mississippi River northeast of New Orleans. These swamps contain peat beds, but they are deteriorating due to the incursion of salt water from the Gulf of Mexico associated with delta lobe subsidence. Saxena (1979) stated that the swamp trees common to these areas, including cypress, red maple, black willow, tupelo gum, and cottonwood thrive in freshwater, but they cannot tolerate water of even moderate salinity. As the freshwater swamps die off, they are replaced by salt-tolerant marsh vegetation and mangrove. Similar salinity and vegetation changes are postulated for NPRA following the marine transgressions that took place during deposition of the Seabee and Schrader Bluff Formations (fig. 3).

SUMMARY AND CONCLUSIONS

The National Petroleum Reserve in Alaska contains as much as 3.3 trillion tons of bituminous and subbituminous coal of Cretaceous age in beds mostly less than 3 m thick and at depths of less than 900 m. The coal beds are situated in low- to moderately dipping, partly folded and faulted strata in a stratigraphic interval more than 1,500 m thick.

The Cretaceous rocks investigated in NPRA were deposited as a thick wedge of clastic sediments that projected northeastward from the ancestral Brooks Range into the northern opening of the North American interior Cretaceous seaway. They comprise an orderly seaward progression of alluvial-plain, delta-plain, delta-front, prodelta, and marine depositional environments. Each of the depositional environments is distinguished by its geographic location, stratigraphic position, lithologic composition, and sedimentary structures.

Alluvial-plain depositional environments were situated between the ancestral Brooks Range and deltas that were building seaward along the coastline of the interior Cretaceous seaway. The alluvial-plain environment was characterized by large and small broadly meandering and anastomosing streams that were occasionally interspersed with small interchannel swamps and mud-filled flood basins. Rocks deposited in the environment are restricted to upper parts of the Prince Creek Formation where they consist of trough-crossbedded, conglomeratic sandstone, and some thin interbedded shale and coal.

The coal-bearing rocks in NPRA were deposited in delta-plain depositional environments in the Corwin, Chandler, and Prince Creek Formations. They are parts of a large delta complex called the Corwin delta and parts of smaller, laterally adjacent deltas. The Corwin and adjacent deltas were fluvially dominated, constructional,

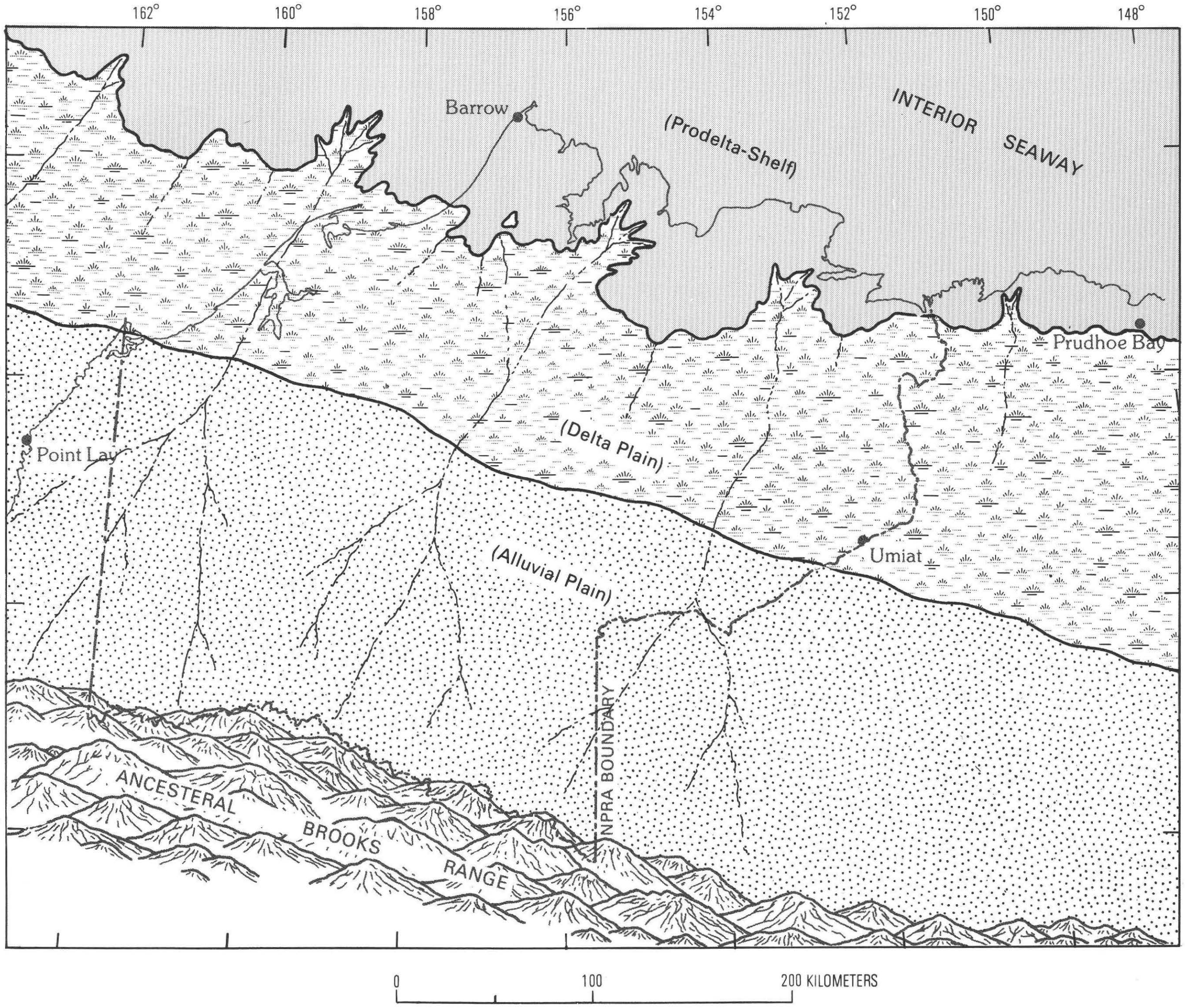

Figure 17. Paleogeography of NPRA and adjacent areas in Campanian time.

and prograding, except for two interruptions by marine transgressions during deposition of the Seabee and Schrader Bluff Formations. The delta-plain depositional environment consisted of bifurcating distributary streams between which were broad areas of freshwater swamps and open, brackish-water interdistributary bays. Rocks deposited in the delta-plain environment are mostly randomly interbedded sandstone, shale, and coal. The sandstones are either lenticular, trough-crossbedded distributary channel deposits, or parallel-bedded, current-rippled, crevasse splay deposits. The shales are partly carbonaceous and of reed swamp origin and partly noncarbonaceous and of bay-fill origin. The coalbeds formed from peats that accumulated on the floor of forest swamps that occupied abandoned parts of interdistributary bays.

Delta-front environments are present in the Kukpowruk, Tuktu, Grandstand, Ninuluk, Seabee, and Schrader Bluff Formations. The environment was characterized by distributary streams that prograded into the shallow waters of marine shelves at the seaward edges of the Cretaceous deltas in NPRA. Between the distributary streams were large, brackish-water, and salt-water bays that were open to the sea. Rocks deposited in the environment are mostly interbedded sandstone and shale. The sandstones are partly trough-crossbedded distributary channel deposits that fine upward and partly parallel-bedded, distributary mouth bar deposits that coarsen upward. The sands in these deposits were not reworked by tides and longshore currents. The shales are seldom carbonaceous.

The prodelta and marine depositional environments were located along the shallow marine shelves seaward of the NPRA deltas. Rocks deposited in the prodelta environment are mainly shale with some interbedded coarsening-upward and seaward-fining beds of sandstone and siltstone. The marine environment consists mostly of shale that was deposited in deep waters at distances off the shores of the interior Cretaceous seaway. The prodelta and marine environments in NPRA comprise the upper part of the Torok Formation and parts of the Seabee and Schrader Bluff Formations.

The coal-bearing and associated rocks in NPRA weather gray, tan, or brown on outcrops. The sandstones are all graywackes and are composed mostly of quartzite, quartz, and chert grains with minor feldspar, muscovite, biotite, and rock fragment grains. The cementing materials are silica and white clay. The sandstones are usually very fine to medium grained, poorly sorted, subangular, well cemented, and often contain large amounts of interstitial clay and mud.

The paleoclimate in NPRA during the Cretaceous Period was warm-temperate to subtropical and supported abundant vegetation from which thick peat accumulations were possible. The delta environments in NPRA are analogous to the Holocene Mississippi River delta. The peats in both places accumulated in freshwater swamps in forested habitats at or near sea level. The resulting coal usually has high heating value and low sulfur and ash content.

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