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

U.S. GEOLOGICAL SURVEY BULLETIN 1575

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

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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 subbituminous 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

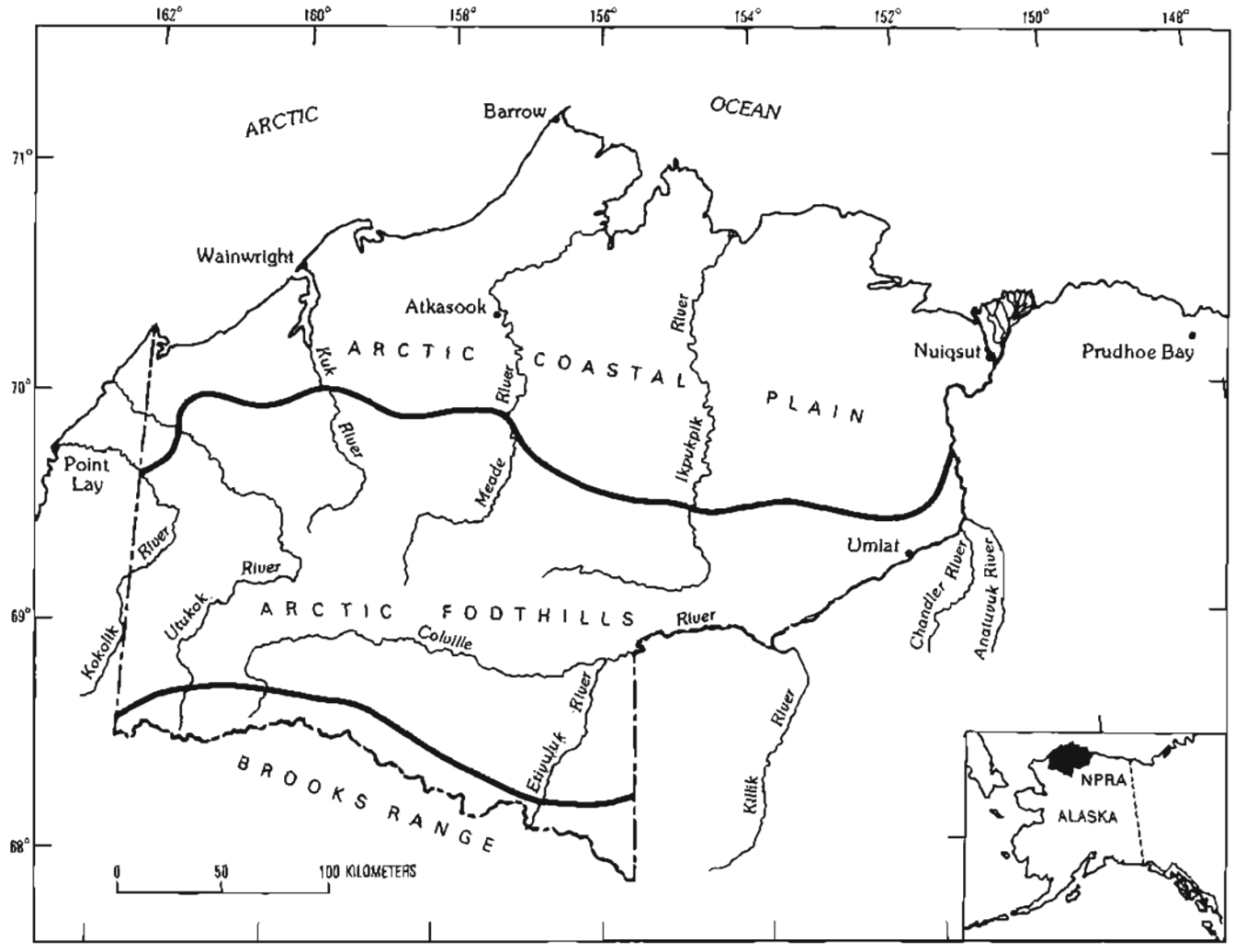

Figure 1. Index map of NPRA.

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

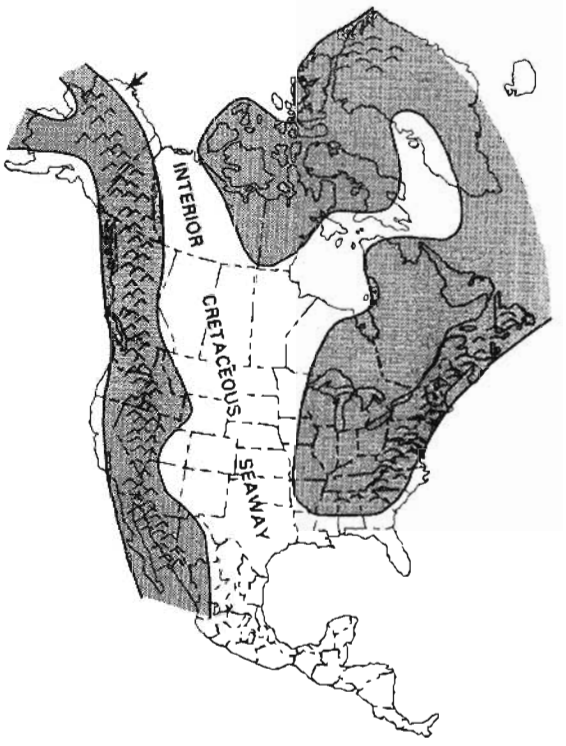

Figure 2. Paleogeographic map of the interior Cretaceous seaway of North America in Turonian time. Arrow points to the location of the study area. (From Ryer, 1981; modified from Williams and Stelck, 1975).

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

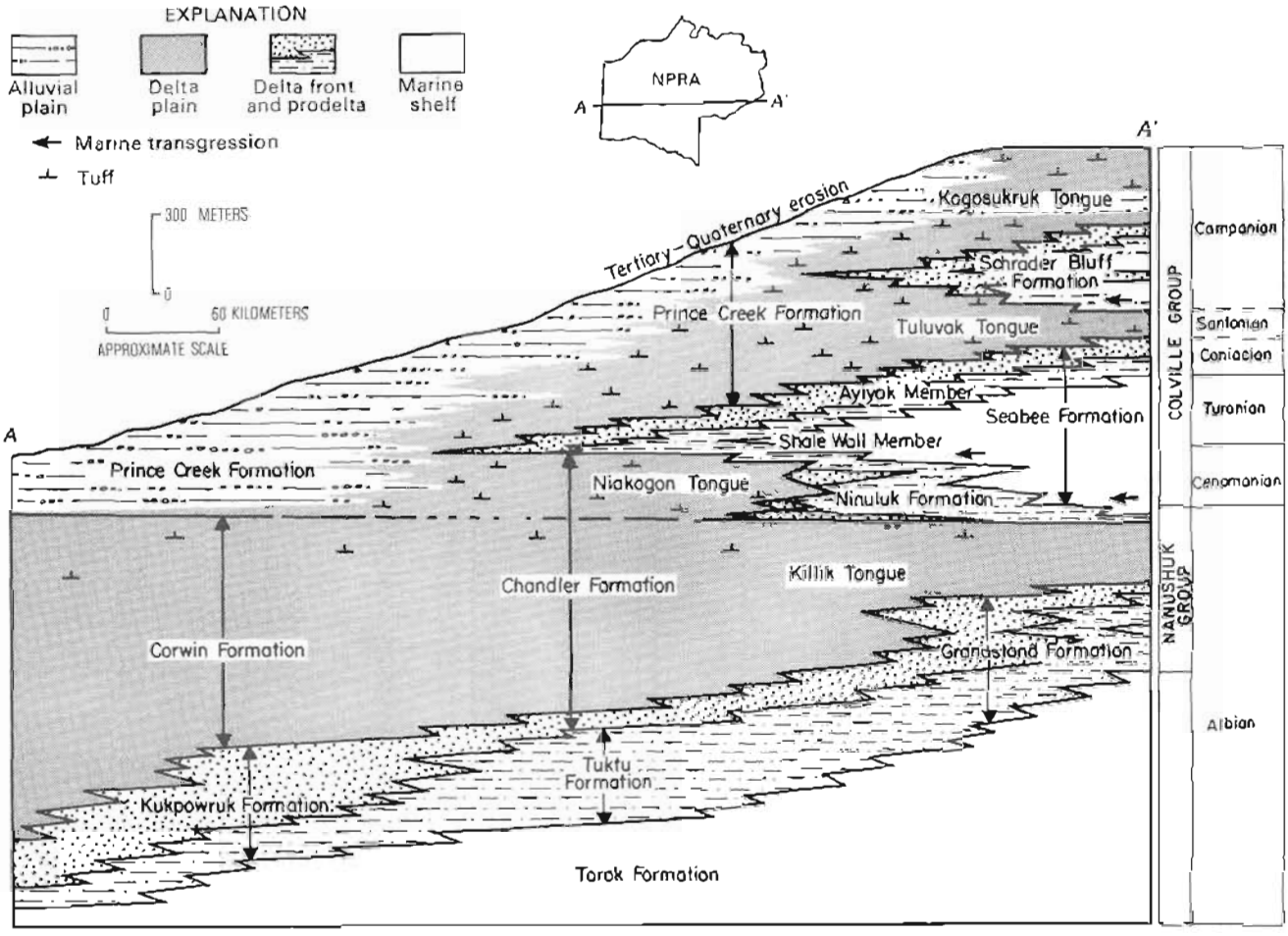

Figure 3. Generalized west-east cross section of NPRA showing formation nomenclature and depositional environments.

(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.

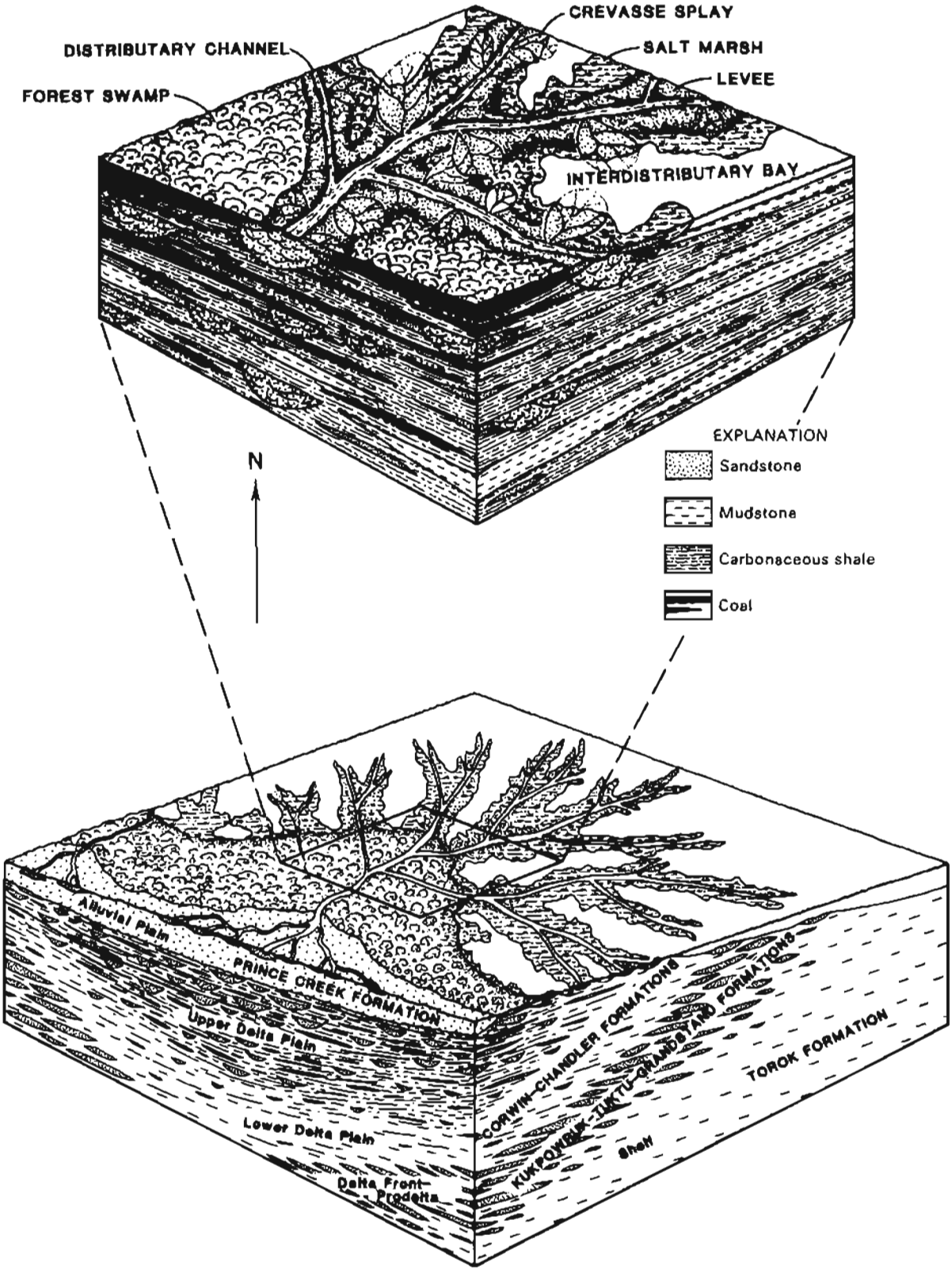

Figure 5. Block diagrams of coal-forming depositional environments interpreted for Cretaceous rocks in NPRA, North Slope of Alaska.