Correlation Study of Selected Exploration Wells from the North Slope and Beaufort Sea, Alaska
INDEX MAP OF WELLS AND SEISMIC LINES
The Y–0334 Mukluk No. 1 well tested a large, Prudhoe Bay–type structure in Harrison Bay. In early 1984, Sohio and its drilling partners announced that the Mukluk well was a dry hole after spending over $140 million on drilling. Various oil companies paid $1.207 billion for leases on just seven of the tracts over the Mukluk structure.
Correlation Study of Selected Exploration Wells from the North Slope and Beaufort Sea, Alaska

By James Scherr, Susan M. Banet, and Barbara J. Bascle
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ABSTRACT

Previous correlation studies of North Slope geology mainly use outcrop data and onshore well data. This study uses data from 10 wells located in Federal Outer Continental Shelf (OCS) Beaufort Sea waters and 18 coastal wells to extend the geologic correlations to the offshore Beaufort Sea. Six geologic cross sections illustrate the stratigraphic correlations of the 28 wells. Paleontological age data for nine of these wells also appear on the cross sections. Seismic lines are tied to borehole logs from 27 of the 28 wells to illustrate the structural and stratigraphic complexity of the offshore Beaufort Shelf.

We divide the stratigraphy of the North Slope into four different tectonic sequences—basement complex, Ellesmerian, Beaufortian, and Brookian. The basement complex rocks, Devonian in age and older, represent the acoustic and economic basement throughout the area. The Ellesmerian sequence includes the northerly derived clastic sediments and carbonates of Late Devonian to Triassic age deposited on the stable Arctic Platform. The Beaufortian sequence records the transition from a northern to southern sediment source which occurred during rifting of the continental margin from Early Jurassic to middle Cretaceous time. The southerly derived sediments deposited from the Early Cretaceous to the present make up the Brookian sequence.

We recognize six seismic stratigraphic sequences—acoustic basement, Ellesmerian, Beaufortian, Prodelta, Colville/Nanushuk, and Sagavanirktok. The acoustic basement seismic sequence corresponds to the basement complex. The Ellesmerian and Beaufortian seismic sequences relate directly to the tectonic sequences of the same names. The Brookian sequence contains three distinct seismic units—Prodelta, Colville/Nanushuk, and Sagavanirktok.
INTRODUCTION

This study presents an integrated geological and geophysical interpretation of the North Slope of Alaska and adjoining Beaufort Sea. The study area covers a 155 mile-long strip along the coast of the North Slope, Alaska, from longitude 144° 45' W. to 153° 00' W. (Figure 1). Various correlation studies exist for the onshore and nearshore areas of the North Slope (Molenaar, Bird, and Collett, 1986; Bird and Molenaar, 1987; and the Alaska Geological Society, 1971, 1973, 1977, and 1981). We correlate data from selected wells used in these previous publications with unpublished, publicly released State of Alaska and Federal well data. In addition, seismic sequences identified offshore are integrated with the general stratigraphy of the onshore North Slope area.

Publicly available well logs, in addition to selected common-depth-point (CDP) seismic lines, illustrate the interpretation. The borehole logs are from wells drilled in the National Petroleum Reserve in Alaska (NPRA), the State of Alaska's waters and lands, and the Federal Outer Continental Shelf (OCS). The seismic data come from several geophysical contractors who granted us permission to publish these CDP seismic lines. Plate 1 shows the location of wells and seismic data used.
1. DATABASE

Ten of the 28 wells used in the study are in Federal OCS Beaufort Sea waters. These 10 wells represent the locations drilled and completed in the Beaufort Federal OCS prior to January 1987. Three wells are located in NPRA. The remaining 15 wells were drilled in areas regulated by the State of Alaska. Table 1 is a list of the 28 wells.

The principle factors used to select the non-OCS wells include the existence of geophysical borehole logs which start near the surface and preferably end in basement; the use of the well in a published correlation study; and the availability of seismic lines connecting the well with OCS wells.

The Minerals Management Service (MMS) possesses a large database of proprietary seismic CDP data for the North Slope and the Beaufort Sea. To illustrate the seismic stratigraphy from onshore to offshore, we selected approximately 142 line-miles of this data to tie to 27 of the wells. The seismic data are unmigrated and gathered at different stacking folds.

The selection of the seismic lines was based on four factors: (1) nearness of the seismic line to the well being tied, (2) orientation of the seismic line along the structural dip of the strata, (3) location of more than one well near the line, and (4) permission from the contractor to publish the line.

In addition to well and seismic data, nonproprietary, stratigraphic age data are available for nine of the wells. These data come from palynology and micropaleontology studies done by two companies for MMS. The Bujak Davies Group provided the geologic ages shown on
<table>
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<th>TABLE 1</th>
<th>List of wells used in study</th>
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<th>WELL NAME</th>
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Alaska State A-1 (Plate 5)
Y-0280 Antares No. 1 (Plate 3)
Y-0871 Corona No. 1 (Plate 5)
East Mikkelsen Bay State No. 1 (Plate 8)
Y-0849 Hammerhead No. 1 (Plate 5)
Y-0302 Mars No. 1 (Plates 3 and 6)
Y-0334 Mukluk No. 1 (Plate 3)
Northstar No. 1 (Plate 4)

Palynological data interpreted by Palnex Canada provide the geologic ages for the interval from 8,500 to 9,900 feet in the Y-0370 Sandpiper No. 1 well (Plates 3 and 4).
2. BASIN DEVELOPMENT

The Ellesmerian orogeny of Late Silurian to Early Mississippian time deformed and mildly metamorphosed Precambrian and early Paleozoic sedimentary rocks that compose the present-day basement complex (Grantz, May, and Hart, 1990). Carbonates and northerly sourced clastics were deposited during Early Mississippian through Triassic time across a southward-sloping stable shelf, known today as the Arctic Platform. These shelf sediments lie unconformably on the basement complex rocks (Figure 2, part A).

During Jurassic time, two major tectonic events occurred that affect North Slope geology (Figure 2, part B). Rifting of the northern part of the Arctic Platform began in Early Jurassic time (Grantz and May, 1983). In Late Jurassic time, uplift and deformation in the region of the present central southern Brooks Range began as a result of the initial stages of subduction of the North American plate beneath the intraoceanic Koyukuk arc (Box and Patton, 1987).

The present continental margin of northern Alaska formed as an extensional feature similar to an Atlantic-type, or passive, margin (Grantz and May, 1983). Extensional structures resembling those associated with Atlantic-type margins occur beneath the Alaskan Beaufort Shelf.

Grantz and May (1983) compare the Beaufort Shelf with typical rifted margins as defined by Falvey (1974). Falvey postulates two cycles of uplift, erosion, and subsidence in his model. Formation of a rift-valley system culminates the first cycle of uplift. The Dinkum Graben (Figure 1) formed as a rift valley during this first cycle of uplift and extension.
Uplift and erosion during the rifting cycles occurred in pulses at different locations over time. Sediments eroded from these uplifted areas collected in adjacent low areas, such as downdropped fault blocks or grabens. The sediments filling much of the Dinkum Graben are probably pre-Hauterivian and mainly northerly sourced (Grantz and May, 1983).

Rifting and onset of the Brookian orogeny formed at least three major tectonic features of the North Slope: the Hinge Line, the Barrow Arch, and the Colville Basin (Figure 1 and Figure 2, part C). The Hinge Line marks the point at which the seaward slope of the basement surface increases markedly into the Canada Basin (Grantz and May, 1983). The Hinge Line often appears on seismic data as a zone of down-to-the-north normal faults (Plate 14).

The Barrow Arch is a broad structural high trending along the Arctic coast of Alaska (Figure 1). A combination of various geologic events, rather than a single episode of upwarping or folding, created the arch during Jurassic and Cretaceous time (Grantz, May, and Hart, 1990). The northern flank of the arch formed from postrift subsidence of the northern part of the Arctic Platform in middle Cretaceous time. The southerly dipping Arctic Platform forms the south flank of the arch.

Tectonic loading by Late Jurassic and Cretaceous sediments and nappes in the ancestral Brooks Range on the southern Arctic Platform tilted the Platform southward, creating the Colville Basin (Figures 1 and 2). Clastic sediments eroded from the Brooks Range filled the Colville Basin and overtopped the Barrow Arch by middle Albion time (Grantz and May, 1983). The Brookian clastic wedge prograded northward and eastward from Late Cretaceous through Tertiary time, filling the basins formed by postrift subsidence on the north side of the Barrow Arch (Figure 2, part C).
3. STRATIGRAPHY

The basement complex is an informal and simplistic term used for all subsurface rocks older than the Endicott Group (Bird, 1988). The basement complex ranges in age from Precambrian to Devonian. Some authors (e.g., Lerand, 1973; Hubbard, Edrich, and Rattey, 1987) refer to the basement complex as the Franklinian. The basement complex rocks represent the acoustic and economic basement throughout the North Slope.

Bird and Molenaar (1987) describe the basement complex as including at least 40 different rock units. The rock units vary from slightly metamorphosed sedimentary rocks to metamorphic rocks, to local volcanic and intrusive igneous rocks. On Plates 3 through 8, the basement complex is divided into two general lithologic groups. The lithology of the first group, metamorphosed sedimentary rocks, includes:

- argillite
- schist
- phyllite
- volcanogenic sediments
- quartzites
- graptolitic shales
- cherts

The second group—interbedded, metamorphosed carbonate and clastic sedimentary rocks—includes the following lithologies (Banet, 1990):

- limestone
- dolostone
- argillite
- shale
The East Teshekpuk No. 1 well encountered granite below the Mississippian rocks (Plate 6). The granite yields radiometric ages of 332 Ma from K-feldspar and 243 Ma from biotite (Bird et al., 1978). The 332 Ma is considered a minimal age from the slightly altered feldspar. Banet (1990) suggests that the age is closer to the age of the granites in the Brooks Range in the Arctic National Wildlife Refuge (maximum age of 430 Ma).

Hubbard, Edrich, and Rattey (1987) separate the sediments above the basement complex of northern Alaska into three tectonic sequences—Ellesmerian, Beaufortian, and Brookian. Each sequence represents a complete cycle of basin development. This study uses a modified version of these sequences for correlation purposes (Plate 2).

The base of the Endicott Group and the disconformity at the top of the Sag River Formation define the bottom and top of the Ellesmerian sequence, respectively. The sequence includes the carbonates and clastics deposited on the southward-sloping, stable Arctic Platform prior to the onset of rifting in the Early Jurassic.

Endicott strata (Lower to middle Mississippian) represent a regressive-transgressive cycle. Deposition began with swamp, braided-stream, floodplain and fluvial environment sediments, grading upward into intertidal and shallow marine sediments (Woidneck et al., 1987). The transgressive cycle culminates with deposition of the shallow marine carbonates in the Lisburne Group (Mississippian to Early Permian) along with minor amounts of shale and sand.

Uplift and partial erosion of the Lisburne Group followed in Early Permian time. Deposits of the Sadlerochit Group include shallow marine, fluvial, floodplain, alluvial fan, and point-bar sediments. This transgressive-regressive cycle occurred from middle Permian to Late Triassic time (Hubbard, Edrich, and Rattey, 1987).

The Shublik and Sag River Formations (Triassic) record a final Ellesmerian transgressive-regressive cycle. The rocks of the Shublik are shallow marine carbonates and shales, commonly rich in organic matter. The Sag River Formation is a glauconitic, commonly bioturbated sandstone deposited in a nearshore environment (Hubbard, Edrich, and Rattey, 1987).
between the Beaufortian and Brookian sequences. The LCU is usually
discernible on both well logs and seismic data throughout the study
area. When locally sourced sandstones, such as the Point Thomson
Sandstone, Put River Sandstones, and their equivalents, lie on top of
the LCU, we place the top of the Beaufortian sequence at the top of
these sandstones (Plate 2).

The Beaufortian sequence records the transition from a northern to
southern sediment source which occurred from Early Jurassic to middle
Cretaceous time. The northerly derived Kingak Shale and Miluveach
Formation consist largely of silts and shales deposited across a marine
shelf (Hubbard, Edrich, and Rattey, 1987). Local regressive cycles are
represented by the Barrow and Simpson Sands.

Deposition of the upper Beaufortian sequence was strongly controlled
by rifting. Erosion of Ellesmerian and some of the basement complex
rocks occurred along the rift margin uplift. Coarse-grained sediments,
such as the marine Kuparuk Sandstone and the fluvial Put River and
Point Thomson Sandstones (Hubbard, Edrich, and Rattey, 1987),
accumulated in nearby topographic lows.

The Brookian sequence includes the series of southerly derived, deltaic
sediments deposited from Early Cretaceous to the present time. The
depocenter for each delta shifted from west to east through time.
Paleontological data on Plates 3, 4, and 5 illustrate the decreasing age
of the Brookian to the east. The formalized Brookian terminology,
developed mainly from outcrop data (Lerand, 1973), does not apply
well to the offshore Brookian strata. The onshore Brookian strata are
mostly nonmarine to shallow-marine facies in the southern and western
North Slope. Along the coast and offshore, distal delta facies make up
a greater part of the Brookian strata in the subsurface. Thus, existing
stratigraphic nomenclature needs to be redefined for the offshore strata.
Our solutions to problems we encountered with Brookian terminology
are explained below.

Usage of the term Pebble Shale is the first problem we encountered.
Previous reports refer to part or all of this informally named unit as
follows:
- the Hue Shale (Bird and Molenaar, 1987; Molenaar, Bird, and
  Kirk, 1987; Molenaar, Bird, and Collett, 1986)
- the Highly Radioactive Zone (HRZ) (Hubbard, Edrich, and Rattey,

Definitions for these various unit names seem to depend on the area studied and the authors' view of the lithology and the source of sedimentation.

We chose to use the HRZ because it allows consistent correlations to be made in the wells examined. The definition for the HRZ as used in this study is the first prominent increase in gamma-ray log values above the LCU. We do not use the Pebble Shale or Hue Shale (as defined in the references listed above) for correlation purposes in this report because neither of them appear different from younger Brookian or older Beaufortian shales on the borehole logs or on the seismic lines.

The HRZ consists of relatively thin sections of organic-rich, radioactive shales that range in age from Hauterivian to early Coniacian (Plates 3 and 4). These shales represent a series of condensed-section, distal facies that accumulated during different cycles of deposition (Carman and Hardwick, 1983; Hubbard, Edrich, and Rattey, 1987; Mickey and Haga, 1987; Molenaar, Bird, and Kirk, 1987; Grantz, May, and Hart, 1990). Portions of the HRZ that are older than Aptian age probably represent deposition in a starved basin (low sedimentation rates) prior to the influx of Brookian deltaic sediments from the Colville Basin. The transgressive age of the HRZ from west to east corresponds to the progradation of the Brookian deltaic lobes. Therefore, the HRZ of Aptian to Coniacian age consists of distal basin facies associated with the prograding prodelta shale facies.

The next terminology problem is defining the different prodelta shales. The Torok Formation is lithologically recognizable only west of the Colville River delta where it lies between the HRZ and the sands of the Nanushuk. When the Nanushuk sands lap out near the Colville River delta, the Torok Formation can no longer be lithologically distinguished from the shale of the Colville Group or the Canning Formation. However, paleontological age data on Plate 3 clearly show the age difference between the older Torok Formation shales in the Y-0302 No. 1 well and the middle Cretaceous prodelta shales in the Y-0334
For the other prodelta shales we propose a stratigraphic cutoff, following guidelines proposed by Krumbein and Sloss (1963, p. 350), at the Nanushuk Group pinch-out. At the cutoff, the shale of the Colville Group changes to the Canning Formation (Plates 2, 3, and 7).

No clear lithologic break separates the Colville Group and the Sagavanirktok Formation in many of the wells. Molenaar (1983) suggests the two sequences may be part of the same deltaic sequence and, therefore, not divisible into distinct formations. For these reasons, we extend the stratigraphic cutoff to the surface near the Colville River delta. West of the cutoff is the undifferentiated Sagavanirktok Formation and Colville Group; east of the cutoff is the Sagavanirktok Formation (Plates 2, 3, and 7).

The Gubik Formation, a deposit of unconsolidated sediments only a few hundred feet thick (Bird, 1982), is the surface formation along most of the coast. However, it cannot be distinguished on either the borehole logs or the seismic lines. Therefore, we combine the Gubik Formation with the Sagavanirktok Formation. We define the top of the Sagavanirktok Formation as either the ground level or the seafloor on borehole logs or seismic lines.
4. WELL LOG CORRELATION CROSS SECTIONS

The wells shown on the cross sections (Plates 3 through 8) tie with wells used in previous correlation studies. Wells correlated by Molenaar, Bird, and Collett (1986) include:

- Alaska State A-1
- Alaska State D-1
- Colville Delta State No. 1
- East Mikkelsen Bay State No. 1
- East Teshekpuk No. 1
- Nechelik No. 1

The wells correlated by Tailleur and Weimer (1987) include:

- Alaska State A-1
- Alaska State D-1
- East Mikkelsen Bay State No. 1

Each geologic formation or group shown on the cross sections has distinctive characteristics allowing correlation across the North Slope. The correlations were determined by examining borehole geophysical logs, core reports, mud logs, paleontological reports, and CDP seismic lines. Plate 2 shows the stratigraphic relationships of the correlations.

Basement Complex

The basement complex is composed of pre-Mississippian rocks (Plate 2) of varying depositional environments and lithologies. The top of basement is an unconformity of varying age. The ages of three of these erosional events are pre-Mississippian, Permian, and Lower Cretaceous. The basement complex is characterized by:

- lithologies varying from...
• one of the above lithologies on the mud logs but no consistent response on the geophysical logs
• locally steep dips

Ellesmerian Sequence

The Ellesmerian sequence consists of Upper Mississippian to Triassic age sediments deposited from a northerly source. The lithology varies from carbonates of the Lisburne Group and Shublik Formation to the sandstones and shales of the Endicott Group, Sadlerochit Group, and Sag River Formation (Plate 2). The thickness of the Ellesmerian deposits was affected by several erosional events and depositional hiatuses. Ellesmerian rock is missing in the wells located either on the crest of the Barrow Arch or northeast of the arch (Plates 3, 4, 5, 6, and 8).

Endicott Group

The Endicott Group is the basal unit of the Ellesmerian sequence along the Barrow Arch. It is composed of nonmarine sediments and coals overlain by a marine shale (Bird and Molenaar, 1987). The Endicott Group is characterized by:
• interbedded conglomerates, sandstones, thin coals, and shales
• a wide range of response on borehole logs (Plate 4) due to the varied lithology
• a thickness ranging from 130 to 1,600 feet where present (Plate 8)

Lisburne Group

The Lisburne Group represents a period of marine transgression when a diverse assortment of transgressive and platform carbonate facies were deposited (Armstrong and Bird, 1976). The Lisburne Group is characterized by:
• a regionally continuous, massive limestone with some dolomite and minor amounts of sand and shale
• low gamma-ray values and high resistivity values on the borehole logs (Plate 6)
Sadlerochit Group

The Sadlerochit Group grades upward from marine sands to marine shales to an alluvial fan-delta deposit. The fluvial sands of the fan-delta complex (Ivishak Formation) constitute the primary hydrocarbon reservoir on the North Slope. The Sadlerochit Group is characterized by:

- an unconformity at the base of the Sadlerochit (Atkinson, Trumbly, and Kremer, 1988)
- fine-grained sands grading upward into a shale which is overlain by a coarsening-upward complex of silts, sands, and conglomerates
- a sharp break on the borehole logs at the top of the group where it passes into the overlying Shublik Formation or the LCU
- a serrated pattern on the gamma-ray log in the lower shaly section and a blocky pattern on the gamma-ray log in the upper alluvial fan-delta clastic section
- a thickness ranging from 116 to 1,080 feet where present (Plate 7)

Shublik Formation

The transgressive marine sediments of the Shublik Formation were deposited in a shelf or shelf-slope environment (Parrish, 1987). These deposits include fossiliferous limestone, mudstone, and calcareous siltstone. The Shublik Formation is characterized by:

- moderately high gamma-ray values and a prominent kick on the resistivity logs, indicative of carbonate-rich sediments (Plate 4)
- a sharp break on the well logs at the base of the formation where it passes into the underlying Sadlerochit Group
- a thickness ranging from 58 to 457 feet (Plate 3)

Sag River Formation

The Sag River Formation, the youngest rock in the Ellesmerian sequence, is a fine-grained, shaly, bioturbated, glauconitic sandstone that was deposited in a low-energy marine environment (Barnes, 1987). On the borehole logs, the Sag River Formation shows the following characteristics (Plate 6):

- a gamma-ray signature typical of shaly sandstones
Beaufortian Sequence

The Beaufortian sequence consists of thick marine shales, such as the Kingak and Miluveach Formations, and relatively thin sands, such as the Simpson and Barrow Sand members of the Kingak, the Kuparuk Formation, and the Point Thomson and Put River Sandstones (Plate 2). The Point Thomson Sandstone, a member of the Beaufortian sequence, is described separately on the cross sections. The Beaufortian sequence appears on the borehole logs as:
- relatively featureless on both the gamma-ray and resistivity logs owing to the predominance of shale
- ranging in thickness from 15 to 2,050 feet where present (Plate 4)

Point Thomson Sandstone

The Point Thomson Sandstone is a marine sand eroded from nearby uplands during the LCU erosional event. It is rich in carbonate lithic fragments locally derived from rocks of the basement complex. This sandstone may be correlative to the Put River Sandstone (Gautier, 1987). The Point Thomson Sandstone is characterized by:
- low gamma-ray values and high resistivity measurements on the well logs
- a thickness ranging from 0 to 47 feet in this study, but much thicker onshore (Plate 5)

Brookian Sequence

The lower part of the Brookian sequence consists of the condensed shales of the HRZ and the thick, prodelta shales of the Torok Formation, the shale of the Colville Group, and the Canning Formation. These shales grade southward and upward into age-equivalent, deltaic sandstones—the Nanushuk Group, the Colville Group, and Sagavanirktok Formation, respectively (Plate 2). These sediments span the time from the Lower Cretaceous to the Pliocene.

Highly Radioactive Zone (HRZ)
Jeanette Island No. 1, the HRZ is missing because of either nondeposition or erosion (Plate 5). The shale has a distinctive high gamma-ray-log reading, except in the Sandpiper and Northstar No. 1 wells (Plate 4), where palynology tops help confirm the gamma-ray-log pick. The HRZ has the following characteristics:

- high gamma-ray-log reading due to uranium and thorium concentrated in the organics (Carman and Hardwick, 1983)
- a thickness ranging from 30 to 990 feet where present (Plate 4)

**Torok Formation**

The Torok Formation is a thick, prodelta shale which grades into the overlying Nanushuk Group. The Torok laps out near the Colville River delta (Plate 3). The Torok Formation is characterized by:

- a relatively featureless response on the gamma-ray and resistivity logs
- a thickness ranging from 0 to 3,600 feet (Plate 6)

**Nanushuk Group**

The Nanushuk Group is a shallow marine to nonmarine deltaic sequence of sandstone and siltstone which grades into the underlying Torok Formation (Molenaar, 1983). The Nanushuk pinches out in the Colville River delta area (Plate 3). The Nanushuk Group is characterized by:

- interbedded sands and thin shales which form a serrated pattern on the gamma-ray log
- a thickness ranging from 0 to 1,300 feet (Plate 6)

**Colville Group**

The Colville Group represents a major regressive sequence above the Nanushuk Group. The Colville Group consists of prodelta shales grading upward into marine sandstones. The top of the Colville Group is not readily distinguishable lithologically from the base of the Sagavanirktok Formation. Therefore, west of the Colville River delta, we refer to the sandstone-mudstone transition as the base of the Colville Group.
- in the lower section, a featureless gamma-ray signal representing prodelta shales when present
- in the upper section, a serrated pattern on the gamma-ray and resistivity logs representing interbedded sandstones and shales (Plates 6 and 7)
- for the Undifferentiated Colville and Sagavanirktok, a thickness ranging from 1,912 to 3,971 feet

Canning Formation

The Canning Formation consists of prodelta shales which grade upward into the Sagavanirktok Formation. We use a stratigraphic cutoff based on the pinch-out of the Nanushuk to differentiate between the shale of the Colville Group and the Canning Formation (Plates 2, 3, and 7). The Canning Formation is characterized by:
- featureless gamma-ray and resistivity curves
- a thickness ranging from 1,800 to 7,000 feet (Plate 5)

Sagavanirktok Formation

The Sagavanirktok Formation is a shallow marine to nonmarine sequence of interbedded sandstones and shales (Plate 2). In this study we have included the younger, unconsolidated Gubik Formation in the Sagavanirktok because the Gubik is not recognizable on either the well logs or the seismic data. The Sagavanirktok is characterized by:
- a serrated pattern on both the gamma-ray and resistivity logs
- a thickness ranging from 4,720 to 8,058 feet east of the Colville River delta (Plate 4)

Permafrost

The borehole logs for some of the wells on Plates 3 through 8 show evidence of permafrost. In other wells, either logs were not run in the section where the permafrost might occur or the permafrost is absent. Plate 8 shows the permafrost thinning markedly seaward. Using the borehole log responses described in Scott et al. (1986), permafrost in the study area is characterized by:
- a high resistivity on the resistivity logs (Plate 4)
5. SEISMIC CORRELATIONS

Twenty-four CDP seismic reflection lines are presented in Plates 9 through 19. These lines are tied to 27 of the 28 wells shown in the geologic cross sections (Plates 3 to 8) in order to illustrate structural and stratigraphic relations near the wells. (Plate 1 shows the seismic line and well locations.)

Tying geophysical borehole logs to seismic lines involves a number of steps. A time-depth function is calculated for each well using the sonic logs and borehole velocity surveys. This function then is used to scale the borehole log to match the time scale on the seismic line. Synthetic seismograms are made for each well from the edited sonic log. The character of the synthetic seismogram, regional seismic correlations, and the borehole log correlations help specify each seismic boundary.

Using proprietary CDP data, the seismic lines are correlated between each well, though the intervening seismic lines used for these correlations are not shown in this report. The seismic sequence boundaries in this study, from deepest to shallowest, are:

- top of acoustic basement
- top of Ellesmerian
- top of Beaufortian
- top of Prodelta
- top of Colville/Nanushuk
- surface of seafloor/top of Sagavanirktok

These boundaries are used to define the seismic sequences described below. The stratigraphic chart, Plate 2, shows the relation of the seismic sequences to the geologic formations on the cross sections. The seismic stratigraphy terminology used follows Mitchum (1977).
Acoustic Basement

The top-of-acoustic-basement seismic boundary is coincident with the top of the basement complex and is delineated by unconformities of different ages. Bright reflectors can be seen below the top of acoustic basement (Plate 9) but cannot be mapped regionally. The top-of-acoustic-basement seismic boundary is:

- the deepest regional seismic reflector
- a bright reflector below which no regionally continuous reflectors occur
- downdropped to the north by normal faults (Plate 14)
- locally, a demonstrable angular unconformity (Plate 17)

Ellesmerian Seismic Sequence

The Ellesmerian seismic sequence consists of rocks of the Endicott, Lisburne, and Sadlerochit Groups and the Shublik and Sag River Formations (Plate 2). The Ellesmerian seismic sequence has:

- the bright, acoustic-basement seismic boundary at the base
- either a low-angle angular unconformity or a bright coherent reflector at the top
- concordant, bright internal reflectors representing the major geologic groups and formations within the sequence
- up to 0.5 seconds (3,200 feet) of section

Examples of these features are shown on Plates 10, 11, 12, and 13.

Beaufortian Seismic Sequence

The Beaufortian seismic sequence consists of the marine shales and minor sands of the Kingak and Miluveach Formations and the sands of the Kuparuk Formation. Characteristics of the Beaufortian seismic sequence include:

- at the base, either an angular unconformity (Plate 13), the bright coherent reflector of the Ellesmerian seismic boundary, or the acoustic-basement seismic boundary
- at the top, a bright regional reflector usually representing the HRZ (Plate 12) or a low-angle angular unconformity that is usually the LCU (Plate 10)
Prodelta Seismic Sequence

The Prodelta seismic sequence represents three time-transgressive prodelta shales—the Torok Formation, the shale of the Colville Group, and the Canning Formation.

The palynological ages on Plates 5, 18, and 19 suggest that rocks of similar age as those in the Prodelta seismic sequence probably extend at least as far east as Corona No. 1, but structural complexities prevent a confident seismic correlation between Hammerhead No. 1 and Corona No. 1.

The seismic stratigraphy of this sequence is characterized by:
- downlapping reflectors at the base (Plate 12)
- toplap reflectors against the overlying Colville/Nanushuk or Sagavanirktok seismic sequence (Plate 9), or the boundary between the discontinuous, indistinct seismic signature of the prodelta shales and the bright, continuous reflectors of the deltaic sands
- discordant and tangential oblique internal reflectors (Plate 10)
- up to 1.35 seconds (7,200 feet) of section (Plate 17)

Colville/Nanushuk Seismic Sequence

The Colville/Nanushuk seismic sequence consists of prograding deltaic sands and shales. The Colville/Nanushuk sequence pinches out eastward at its distal facies near the Colville River delta. On some seismic lines, the top of the Colville/Nanushuk seismic sequence boundary cannot be confidently interpreted because it is near the top of the seismic section (Plate 10). Age data must be used in some areas to help define the top of this seismic sequence because the sands and shales of the Colville Group and the Sagavanirktok Formation are indistinguishable on seismic data.

The Colville/Nanushuk seismic sequence has the following characteristics:
- the Prodelta seismic boundary at the base
- toplapping reflectors of the Colville/Nanushuk seismic sequence (Plate 11) and/or the Tertiary-Cretaceous boundary
Sagavanirktok Seismic Sequence

The Sagavanirktok seismic sequence consists of prograding deltaic sands and shales. As mentioned previously, in some areas age data from wells must be used to help define the boundary between the Colville/Nanushuk sequence and the Sagavanirktok seismic sequence (Table 2). The palynological tops on Plates 5, 18, and 19 suggest that rocks of similar age to those in the Sagavanirktok seismic sequence probably extend eastward to the Corona No. 1 well, but structural complexities prevent a confident seismic correlation between Hammerhead No. 1 and Corona No. 1.

The characteristics of the Sagavanirktok seismic sequence include:
- at the base, the Colville/Nanushuk seismic boundary west of the Colville delta and the Prodelta seismic boundary east of the Colville delta (Plate 12)
- at the top, the seafloor or land surface (Plate 11)
- bright, internally concordant reflectors (Plate 14)
- up to 2.1 seconds (8,400 feet) of section (Plate 16)

### TABLE 2: TERTIARY-CRETACEOUS BOUNDARY

Based on palynological analysis from the Bujak Davies Group, Calgary, Alberta, Canada

<table>
<thead>
<tr>
<th>WELL NAME and OCS NUMBER</th>
<th>DEPTH (FEET) (TVSS)¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antares No. 1 Y-0280</td>
<td>1,100</td>
</tr>
<tr>
<td>Mars No. 1 Y-0302</td>
<td>1,300</td>
</tr>
<tr>
<td>Mukluk No. 1 Y-0334</td>
<td>2,450</td>
</tr>
</tbody>
</table>

¹TVSS - True vertical subsea depth.
SUMMARY

The combination of well log data and seismic CDP data used in this study provides a graphic illustration of an extension of North Slope geology into the outer continental shelf. The report also demonstrates some of the attendant problems of nomenclature currently faced by workers in this area.

Our interpretation depicts four major tectonic sequences in northern Alaska—the basement complex with varied lithologies, the south-facing trailing-margin Ellesmerian, the rift-associated Beaufortian, and the northerly prograding Brookian. Each sequence represents different, internally complex, cycles of basin development and depositional geometries.

The first stratigraphic-nomenclature problem encountered in the study area is the delineation of the basal Brookian shales, a problem compounded by the Pebble Shale/HRZ/Hue Shale nomenclatural morass. A consistent correlation can be made in the wells by picking the top of the Pebble Shale/HRZ unit at the first prominent increase in gamma-ray log values above the LCU. We called the unit the HRZ. It is composed of a time-transgressive, condensed, distal-basin facies.

Several correlation problems exist in the Brookian sequence between the onshore and offshore stratigraphy. The onshore Brookian sequence, where the stratigraphic nomenclature was developed, consists mostly of nonmarine to shallow marine facies, interbedded with marine facies. This nomenclature does not apply well to the distal-delta facies encountered along the coast and offshore.

The main correlation problem is the identification or separation of the different prodelta shales. Paleontological age data are used to define the termination of the Torok Formation near the Colville River delta. However, we must use a stratigraphic cutoff, based on the pinch-out of the Nanushuk Group, to differentiate between the shale of the Colville and the Brookian sequences.
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