Chapter GG

GEOGRAPHIC AND GEOLOGIC SETTING

by Kenneth J. Bird[1]

in The Oil and Gas Resource Potential of the 1002 Area, Arctic National Wildlife Refuge, Alaska, by ANWR Assessment Team, U. S. Geological Survey Open File Report 98-34.

1999

1 U.S. Geological Survey, MS 969, Menlo Park, CA 94025

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards (or with the North American Stratigraphic Code). Use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U. S. Geological Survey.

TABLE OF CONTENTS

FIGURES

PLATES

ABSTRACT

The 1002 area comprises the northernmost eight percent of the 19 million acre Arctic National Wildlife Refuge (ANWR). This part of the ANWR lies in the coastal plain between the Arctic Ocean and the Brooks Range. It is a treeless, tundra-covered wetland characterized by rolling hills and numerous northward-flowing braided streams. Native Alaskans own land within the 1002 area and about 200 individuals live in the village of Kaktovik located on the coast.

Bedrock geologic exposures are limited within the 1002 area because of extensive Quaternary surficial deposits. Information on the bedrock geology comes mainly from surface exposures in the mountains to the south, from wells to the west and offshore, and from geophysical data within the 1002 area that provide images of the subsurface geology.

The 1002 area is part of the North Slope geologic province, in which petroleum prospective rocks are restricted mostly to Mississippian and younger strata. The same geologic units that are oil-productive at Prudhoe Bay and oil- and gas-bearing in the Mackenzie Delta region of Canada are found in the 1002 area. The North Slope province is part of a continental microplate whose origin is still the subject of debate. The geologic history of this microplate includes development of (1) a Devonian to Triassic south-facing (in present-day coordinates) passive continental margin; (2) a Jurassic to Early Cretaceous northern rifted margin; and (3) a Jurassic to Recent southern orogenic margin with a related foreland basin and fold- and thrust-belt.

Structures within the 1002 area consist of closely-spaced folds and faults (thin-skinned deformation) within foreland basin strata and broad, domal faulted structures (thick-skinned deformation) in pre-foreland basin and basement strata. These structures formed in one or more episodes of Brooks Range-related deformation during Cenozoic time. Devonian and perhaps older structures are also known in this area, and the grain of these structures has controlled the orientation of some younger Cenozoic structures.

This part of the North Slope geologic province is an unusual area of converging regional geologic trends. This convergence has produced a geologic complexity that is greater than that found elsewhere in northern Alaska. This is where the youngest foreland basin strata were deposited on a rifted margin and where the Brooks Range fold- and thrust-belt intersects and incorporates pre-Mississippian basement rocks, rift related strata, and passive margin strata. Deformation has frequently been synchronous with deposition in Tertiary time and continues to the present-day.

INTRODUCTION

In the northeastern corner of Alaska, just west of the Canadian border and north of the Brooks Range lies the 1.5-million-acre parcel of land known as the 1002 area of the Arctic National Wildlife Refuge (Fig. AO1). This is the northernmost part of the 19-million acre Arctic National Wildlife Refuge. The 1002 area is about 105 miles across from east to west, and varies from 16 to 40 miles across in a north-south direction. The area is bounded on the west by the Canning and Staines Rivers, on the north by the Beaufort Sea, and on the east by the Aichilik River. The south boundary follows township lines and approximates the 1000-foot elevation contour (Plate GG1). For more than 100 miles south of the 1002 area, the land between the Canning River and the Canadian border, an area of about 8 million acres, is designated as wilderness (Fig. AO1). Within the northern part of the 1002 area, approximately 100,000 acres are Alaskan Native lands belonging to the Kaktovik Inupiat Corporation. The village of Kaktovik, population about 200, is located within this area on Barter Island. Kaktovik is one of eight villages in northern Alaska and is the only one within the refuge.

The geologic history of this region includes development of a Devonian to Triassic south-facing (in present-day coordinates) passive continental margin. That margin in its northern part was rifted in Jurassic to Early Cretaceous time away from its (unknown) parent continent. Co-eval with rifting in the north, an arc-continent collision occurred in the south, producing an orogenic landmass and adjacent foreland basin. As the foreland basin filled, continuing deformation resulted in a foreland fold- and thrust-belt. The 1002 area is located in the eastern part of this province where one finds the youngest foreland basin sediments, where the fold- and thrust-belt intersects and overrides the earlier-formed rift margin, and where deformation and related sedimentation continues to the present. The 1002 area is, therefore, an area of convergence of regional geologic trends and this results in a geologic complexity that is greater than that found elsewhere in northern Alaska.

The 1002 area is part of the North Slope geologic province, a region in which petroleum-prospective rocks are restricted mostly to Mississippian and younger rocks. The same geologic units that are oil-productive at Prudhoe Bay and oil- and gas-bearing in the Mackenzie Delta region of Canada are also found in the 1002 area. This chapter describes the geographic and geologic setting of the 1002 area and places it in a regional context.

GEOGRAPHY

The 1.5-million acre 1002 area of the Arctic National Wildlife Refuge lies mostly within the Arctic Coastal Plain physiographic province; a small part along the southern margin, constituting less than 5 percent of the area, lies within the Arctic Foothills physiographic province (Wahrhaftig, 1965). Most of the Arctic National Wildlife Refuge outside of the 1002 area is part of the Brooks Range physiographic province, a continuation of the Rocky Mountain system, and the Porcupine Plateau physiographic province, a continuation of the North American intermontane plateaus system. Similar to most lands north of the Brooks Range, the 1002 area is treeless, tundra-covered, and 99 percent wetland according to the Fish and Wildlife Service classification scheme (Cowardin and others, 1979).

The proportion of landform types within the 1002 area are foothills (45%), river floodplains (25%), hilly coastal plains (22%), lagoons and ocean (5%), thaw lake plains (3%), and mountains (<1%) (Clough and others, 1987). The coastal 1002 area is characterized by beaches, low bluffs, barrier islands, shallow lagoons, and river deltas. South of the coast, rolling hills gradually rise to elevations of more than 1000 feet. Cutting through these hills are numerous northward-flowing streams and rivers, most of them braided. The larger streams have their headwaters in the mountains south of the 1002 area where one encounters the highest peaks of the Brooks Range which have elevations of slightly more than 9000 feet. Panoramic photomontages by Takahashi (Chap. IG) provide views of most of these physiographic features within and adjacent to the 1002 area.

Additional information on the 1002 area relating to the physiography, climate, permafrost, soils, water resources, seismicity, erosion, mass movement, noise, and air quality can be found in the report by Brewer (1987) and the report to the Congress of the United States (Clough and others, 1987). In this report, Wang (Chap. SA) provides an updated summary of the water resources literature and describes new analyses of water quality from Hue Creek in the Ignek Valley and from the Sadlerochit and Red Hill springs in the Sadlerochit Mountains area.

PLATE TECTONIC SETTING

Northern Alaska is considered part of a small continental fragment, called the Arctic Alaska microplate by Hubbard and others (1987), the boundaries of which are only approximately known (Fig. GG1). This microplate includes the North Slope and its continental shelves, most of the Brooks Range and its extension into Canada, and part of northeastern Siberia. Smith (1987) envisioned the Arctic Alaska microplate as composed of two smaller continental fragments, the Seward-Chukotka microplate and a North Alaska microplate (Fig. GG1), both of which were originally part of a much larger (Barents) plate. These and other fragments of the Barents plate are postulated to comprise most of the lands now bordering the Arctic Ocean exclusive of Canada and Greenland.

The plate tectonic history of northern Alaska remains a controversial topic with many competing hypotheses, most of which have been summarized by Lawver and Scotese (1990). Cretaceous rifting and the opening of the oceanic Canada basin of the Arctic Ocean is a key event in most prevailing hypotheses. But the nature of Cretaceous rifting and pre-rift geography is not well known. Although many stratigraphic and structural similarities exist between northern Alaska and other lands bordering the Arctic Ocean, the absence of clear magnetic seafloor stripes in the Canada basin precludes a unique solution to the plate history of this region.

The most common plate tectonic interpretation for northern Alaska is the rotational hypothesis (Carey, 1958; Tailleur, 1973; Grantz and others, 1998). In this hypothesis, northern Alaska originally lay in a position adjacent to the Canadian Arctic Islands (Fig. GG1). Cretaceous rifting resulted in a rotational opening of the Canada basin by which northern Alaska moved counter clockwise, away from Canada through a 60-degree arc, about a pole of rotation located in the general area of the Mackenzie delta. Some recent papers challenge this hypothesis (Lane, 1997) and others support it (Grantz and others, 1998). Although these papers offer significantly different plate histories, a common theme is that opening of the Canada basin was more complex in both plate geometry and plate trajectory than proposed in earlier models.

SURFACE GEOLOGY

More than 95 percent of the 1002 area is covered by a veneer of unconsolidated, frozen sediments of late Cenozoic (mostly Quaternary) age, generally less than 100 ft thick (Carter and others, 1986). Despite the arctic climate prevailing during the Pleistocene epoch, only about 10 percent of the area was glaciated as indicated by morainal deposits which generally extend only a few miles into the southernmost parts of the 1002 area. Surficial deposits of the 1002 area consist of silt- to gravel-sized sediments mostly of nonmarine origin. The regional distribution of surficial deposits, including their offshore extent, age, stratigraphy, and composition are described in Dinter and others (1990).

A bedrock geologic map of the 1002 area and adjacent areas is provided in Plate GG1. This map is an updated version of that previously compiled by Bader and Bird (1986). It emphasizes the petroleum-prospective rocks and generalizes those rocks considered to have little petroleum potential. Accordingly, all surficial deposits are shown by a single map unit, and the multitudinous (more than 60) pre-Mississippian rock units mapped by Reiser and others (1971, 1980) are shown by only three map units. Within the 1002 area, bedrock exposures are mostly Tertiary deposits of the Sagavanirktok, Jago River, and Canning Formations and a few small exposures of

Cretaceous or Jurassic deposits of Hue Shale, pebble shale unit, and Kingak Shale in the Niguanak area. The oldest bedrock exposures are Mississippian Lisburne Group limestones found in the southernmost part of the 1002 area near the eastern end of the Sadlerochit Mountains (Plate GG1).

For limited parts of the region south of the 1002 area, detailed geologic maps are also available. One of the most significant of these is the mile-per-inch-scale geologic map of the Sadlerochit and Shublik Mountains (Robinson and others, 1989). This map region is important in that it documents some of the best exposures and critical stratigraphic relations of rocks that lie beneath the North Slope, including formations that are oil-producing in the Prudhoe Bay area, 90 miles to the northwest. Elsewhere, detailed geologic maps of small areas have been produced by the State Division of Geologic and Geophysical Surveys in collaboration with the University of Alaska (e.g., Anderson, 1991; Camber and Mull, 1986; Hanks, 1988, 1989; and Ziegler, 1988).

SUBSURFACE GEOLOGY

The subsurface geology of the 1002 area and area to the west is summarized in two well correlation sections (Plates GG2 and GG3). These sections are similar to those in USGS Bulletin 1778 (Plate 1 in Bird and Magoon, 1987), but have been updated with several new wells and extended offshore using reflection seismic data. The section in Plate GG2 trends from Camden Bay, within the 1002 area, westward about 70 miles along the coast to Prudhoe Bay; the section in Plate GG3 trends from the latitude of the Sadlerochit Mountains, less than 10 miles west of the 1002 area, northward along the Canning River and offshore to the Galahad well.

Each section has been restored to show its stratigraphic development at various stages in time. These time-slice restorations were accomplished by using regional unconformities or the uppermost surface of delta plain deposits as approximate horizontal datums. Such restorations remove structural deformation, show original stratigraphic relations, and allow estimation of amounts of eroded strata in areas of uplift or missing section. In addition to the present-day setting, both sections show restorations at 130 Ma (mid-Hauterivian) on the regional Lower Cretaceous unconformity. The coastal section (Plate GG2) shows a restoration at ~55 Ma (Eocene-Paleocene boundary) near the top of the Staines Tongue of the Sagavanirktok Formation. The Canning River section (Plate GG3) also shows restorations at ~60 Ma (mid Paleocene), at the top of an unnamed tongue of sandstone within the Sagavanirktok Formation, and at ~40 Ma (middle Eocene), at the top of the Mikkelson Tongue of the Canning Formation. The geochronology followed in this paper is that of Harland and others (1990) for the pre-Mesozoic, Gradstein and others (1994) for the Mesozoic, and Berggren and others (1995) for the Cenozoic.

STRUCTURE

At least two generations of compressional folding and faulting are represented in this region, and normal faulting related to rifting and to slope failure is also present. Structures in this region have been studied by a large number of workers many of whom are referenced in this report in chapters BC, BD, NA, and SM. Regional structural summaries have been presented by Wallace and Hanks (1990) for the onshore area and by Grantz and others (1987; 1990) for the offshore area.

The northeast Brooks Range north of about 69-degrees latitude and the 1002 area south and east of the Marsh Creek anticline (Plate GG1) are part of the Brooks Range fold- and thrust-belt. Here, deformation occurred episodically throughout Cenozoic time. Brookian structures in this region have either an east-northeast-trend, such as the Marsh Creek anticline, or an east-trend such as the Sadlerochit and Shublik Mountains. East-northeast structural trends probably are normal to the direction of Cenozoic tectonic transport. East-trends are probably controlled by the pre-Mississippian structural grain and are the result of a deepening or stepping-down of the level of structural detachment into the pre-Mississippian basement rocks. Regional zones of detachment occur in Jurassic to Cretaceous shales, Mississippian shales, and at some unknown horizon deep within the pre-Mississippian basement rocks.

Structural style varies with the rocks involved. Structure in the Brooks Range is dominated by a series of broad, regional-scale anticlinoria, each with a central core of pre-Mississippian rocks and a Mississippian and younger cover deformed into shorter wavelength folds. The pre-Mississippian rocks display north-vergent duplex structures, whereas the Mississippian and younger cover rocks display a variable sense of vergence and relatively few thrust faults compared to the rest of the Brooks Range. Structure north of the Brooks Range is characterized by closely-spaced folds and faults, described as thin-skinned deformation, that are developed in Cenozoic and Mesozoic strata above a detachment in Cretaceous or Jurassic shales. At depth, several broad domal structures are present that are believed to have developed mostly in pre-Mississippian rocks and are therefore similar to those structures exposed in the Brooks Range.

Structures involving only pre-Mississippian rocks are also present in this region. They have been recognized in the Brooks Range, in seismic images beneath the western 1002 area, and in well penetrations along the coast as far west as Point Barrow. These structures may represent more than one pre-Mississippian deformational event, but they are usually ascribed to the Devonian Ellesmerian orogeny. In outcrop, these structures are characterized by penetrative cleavage and folding of incompetent units, low-grade metamorphism, and regional faulting. They lie beneath a regional unconformity referred to here as the pre-Mississippian unconformity (Fig. GG2). In the subsurface, long-wavelength antiforms and synforms are imaged on seismic records and steep dips and small-scale faults in argillite and phyllite are observed in well core samples. Most, but not all, workers interpret these structures as north vergent, similar to the younger Cenozoic Brooks Range deformation.

Across the North Slope west of the 1002 area and beneath the continental shelves, Mississippian age normal faulting and development of basins and half-grabens is widespread (Hubbard and others, 1987; Grantz and others, 1990). In the coastal region and offshore northern Alaska, normal faulting related to Jurassic and Early Cretaceous rifting and to massive slope failure of the Beaufort passive margin in Tertiary time is well documented by Grantz and May (1983) and Hubbard and others (1987). Examples of these normal faults are illustrated in the cross sections in Plates GG2 and GG3.

Click here or on this symbol
in the toolbar to return.

STRATIGRAPHY AND TECTONICS

In 1973, Lerand provided a comprehensive review of the Phanerozoic stratigraphy and tectonics of the Canadian and Alaskan Arctic. In that review he offered a synthesis, elegant in its simplicity, based on tectonics and sediment source-area location. He summarized the 550 m.y. stratigraphic record of this region in three sequences: Franklinian (Cambrian through Devonian); Ellesmerian (Mississippian through Jurassic); and Brookian (Cretaceous and Tertiary). Later, to emphasize those strata deposited during Mesozoic rifting in northern Alaska, other workers proposed a fourth sequence, referring the Jurassic and earliest Cretaceous part of the Ellesmerian sequence to the Beaufortian sequence.

Lerand's sequences have provided a unifying concept and a useful way of synthesizing large volumes of data. Figure GG2 summarizes the sequence subdivision of the stratigraphic column and provides schematic sections that illustrate the post-Devonian tectonic development of northern Alaska. Figure GG3 illustrates the areal distribution of rocks comprising these sequences and the major tectonic features of northern Alaska and nearby parts of Canada. I refer to Lerand's subdivisions as "tectono-stratigraphic sequences" to distinguish them from "sequences" which have come to mean seismic-stratigraphic sequences in the now widely-used method of analysis pioneered by Vail and others (1977). Houseknecht and Schenk (Chap. BS) provide a seismic sequence stratigraphic analysis of Brookian rocks in the 1002 area.

Franklinian Sequence

Franklinian rocks of northeastern Alaska and adjacent parts of Canada consist of a thick succession of variously deformed and metamorphosed sedimentary strata with locally significant amounts of volcanic and intrusive igneous rocks. They lie beneath a regional unconformity often referred to as the pre-Mississippian unconformity. These rocks are extensively exposed in the northeastern Brooks Range and its Canadian extension, the British Mountains; they are penetrated by numerous wells along the coast west of the 1002 area, and they are seismically imaged in the western part of the 1002 area (Fisher and Bruns, 1987; Cole and others, Chap. SM; Kelley, Chap.

Click here or on this symbol in the toolbar to return.

BR). Ages, stratigraphic relations, and thicknesses of these rocks are, for the most part, only approximately known.

Lerand's (1973) Franklinian sequence included strata of middle Cambrian to Devonian age and did not include Proterozoic strata, which are also present in many areas. As used in Alaska, however, this term has generally included all pre-Mississippian rocks, a succession that includes not only early Paleozoic rocks, but also probable Proterozoic rocks. This term is now little used in Canada and some investigators have questioned whether Franklinian rocks represent a single, genetically related sequence (Moore and others, 1987). Two distinct assemblages of lithofacies exist within the Franklinian sequence of northeastern Alaska—a shallow marine facies composed mainly of carbonate rocks and a deeper marine facies composed of clastic deposits, chert, thinly-bedded carbonate rocks, and volcanic rocks. Both assemblages appear to span approximately the same time interval, Proterozoic to Devonian.

The shallow marine carbonate facies is best known in the Sadlerochit and Shublik Mountains area where the succession consists of more than 12,000 ft of dolomite and limestone. These rocks are assigned to the Katakturuk Dolomite of probable Proterozoic age, the Nanook Limestone of Cambrian, Ordovician and possible Proterozoic age, and the Mount Copleston Limestone of Lower Devonian age. No Silurian strata have been identified, and unconformities, some with angular relations of as much as 15 degrees, separate each of the formations. Clough (1989) interpreted these rocks as representing a long-lasting, south-facing (in present-day coordinates) carbonate bank environment. The carbonate facies, structurally and perhaps stratigraphically, overlies several hundred meters of quartzite, argillite, and undated tholeiitic basalt in the Shublik Mountains (Moore, 1987) and interbedded sandstone and shale intruded by 700 to 800 Ma diabase in the Sadlerochit Mountains (Clough and others, 1990).

The deeper marine facies is more areally widespread than the carbonate facies, but is less well understood. Rocks of this facies are exposed throughout the Romanzof and British Mountains where they have been studied by Reed (1968), Moore (1987), Lane (1991), Mull and Anderson (1991), Kelley and

Click here or on this symbol
in the toolbar to return.

others (1994), and Lane and others (1995). Rock types include quartzite, quartz wackes, conglomerate, phyllite, argillite, limestone, chert, granite, and volcanic rocks including tuffs, flows, and volcaniclastic rocks.

The geologic history of these rocks is complex and includes multiple deformation events. Intense imbrication makes it difficult to distinguish between intact stratigraphy and structural repetition (Lane and others, 1995). Fossils indicate that Cambrian through Devonian strata are present; Proterozoic strata are inferred to be present by stratal position below Cambrian rocks. Similarities have been noted between the Franklinian succession in this region and that of the Selwyn Basin, 1000 km to the southeast in Canada. As envisioned by Lane (1991 and references therein), Franklinian paleogeography of this region consisted of a complex of carbonate banks and deepwater troughs or basins on the northwestern margin of cratonic North America. The origin of the coarser-grained clastic rocks is unknown.

Compressional deformation, uplift, and erosion ascribed to the Ellesmerian orogeny resulted in a regional unconformity, which marks the end of Franklinian sequence deposition in northeastern Alaska. The timing of deformation, constrained by the age of strata above and below the regional unconformity, appears to be limited to about 5 m.y. between late Early and early Middle Devonian. That age is bracketed by the Early Devonian (Emsian) Mount Copleston Limestone (Blodgett and others, 1992) below the unconformity and early Middle Devonian (Eifelian) Ulungarat formation (Anderson and others, 1994) above the unconformity. A 380 Ma (Middle Devonian) cooling age from the Okpilak batholith, interpreted as post-orogenic (Dillon and others, 1987), seems consistent with the stratigraphic age constraints placed on the deformation. Devonian compressional deformation is interpreted by some workers as north vergent, similar to younger Brookian deformation (Reed, 1968; Mull and Anderson, 1991; Kelley and others, 1994; and Lane and others, 1995; Cole and others, Chap. SM of this publication) and by others as south vergent (Oldow and others 1987).

An unusual feature of the Franklinian rocks in the subsurface of the western part of the ANWR 1002 area is that they are reflective in seismic images (Fisher and Bruns, 1987; Cole and others, Chap. SM; Kelley, Chap. BR). Elsewhere on the North Slope, reflections from within these rocks are nonexistent or rare (e.g., Kirschner and Rycerski, 1988). Cole and others (Chap. SM) interpret these seismically reflective Franklinian rocks in the western part of the 1002 area as part of a north-vergent thrust belt. It may be noteworthy that Proterozoic and early Paleozoic rocks in the Mackenzie Delta region are also seismically reflective and that this is the general area to which the ANWR 1002 area would restore in the rotational hypothesis for opening of the Canada basin. Seismic images in the Mackenzie Delta area are interpreted as imaging the margin of a south-vergent thrust belt of Late Devonian age (Coflin and others, 1990).

Ellesmerian Sequence

The Ellesmerian sequence as described in this report consists of marine and nonmarine clastic strata and marine carbonate rocks of Middle Devonian to Triassic age that, taken together, are thousands of feet thick. The sequence rests on a regional unconformity, the erosion surface related to the Early/Middle Devonian (Ellesmerian) orogeny. A characteristic of the Ellesmerian sequence in northern Alaska and adjacent parts of Canada is an overall northward-onlapping trend. This trend is illustrated in map view (Fig. GG4) and in cross sections (Fig. GG5). Overall sediment characteristics, patterns of stratal onlap, and extensional faulting suggest a south-facing passive margin origin for the Ellesmerian sequence (Moore and others, 1994). In the Brooks Range, the Middle Devonian Ulungarat formation (Anderson and others, 1994) evidently dates the onset of extension and rifting and thick Late Devonian formations (Beaucoup Formation, Hunt Fork Shale, and Kanayut Conglomerate) are interpreted as recording the main episode of rift-margin deposition. None of these rocks are present in the 1002 area; they are found to the south (Fig. GG3, shown by the yellow conglomerate pattern) and are allochthonous. Predeformational reconstructions place them even farther south where they form basins that lap-out northward. Ellesmerian rocks are absent from a broad area extending from just east of Prudhoe Bay southeastward across the western part of the 1002 area; their absence is the

Click here or on this symbol
in the toolbar to return.

product of erosion by the Lower Cretaceous unconformity (Fig. GG6; Plates GG2, GG3).

The Endicott Group is the basal unit of the Ellesmerian sequence in most areas (Figs. GG4, GG5). In the Brooks Range southwest of the 1002 area, the Endicott Group consists of more than 10,000 feet of Late Devonian rift-margin deposits. However, immediately south of the 1002 area and in the North Slope subsurface, these rocks are generally not present. Instead, the Endicott Group consists of Mississippian coal-bearing sandstone, conglomerate, and shale of the Kekiktuk Conglomerate and transitional to marine shale of the Kayak Shale (Brosgé and others, 1962). In the Prudhoe Bay area subsurface (Plate GG2), the Kayak grades laterally and upward into a redbed facies known as the Itkilyariak Formation (Mull and Mangus, 1972). In the northeast Brooks Range, the Kekiktuk and Kayak units are documented as filling in paleotopography on the regional unconformity (LePain and others, 1994). In the subsurface west of the 1002 area, these units locally occupy basins and half-grabens where thicknesses are generally much greater than observed in most outcrops (Plate GG2). Kelley and Brosgé (1995) interpreted these basins as Devonian and Mississippian in age, although Devonian strata have not been sampled in any of these basins. The Kekiktuk is an oil-bearing reservoir in the Endicott and the Tern Island/Liberty oil fields (Plate GG2). In the northeast Brooks Range, the Kayak Shale is a zone of structural detachment (Wallace and Hanks, 1990; Kelley and Foland, 1987; Cole and others, Chap. SM).

In Mississippian and Pennsylvanian time, clastic sedimentation in northern Alaska was largely replaced by deposition of limestone and dolomite of the Lisburne Group, resulting in development of a broad carbonate platform. Carbonate rock thicknesses are generally 1500 to 3000 feet (Bird and others, 1987, fig. 7.6). In most areas, the Lisburne Group gradationally overlies the Kayak Shale or Itkilyariak Formation, but in up-dip basin margin positions, the Lisburne may lie directly on Franklinian rocks (Figs. GG4, GG5). A relative sea level fall sometime during Middle Pennsylvanian to Early Permian time produced a regional erosional unconformity that separates the Lisburne from the overlying Sadlerochit Group. Domoulin (Chap. CC) summarizes the Lisburne Group in northeastern Alaska and Jameson (1994) provides details of the Lisburne in the subsurface of the Prudhoe Bay area where it produces oil and gas.

The Sadlerochit Group, about 1000 feet of Permian and Early Triassic strata, represents renewed subsidence of the basin and uplift of the northern landmass. Transgressive marine sandstone and siltstone (Echooka Formation) at the base of the group records this subsidence. The overlying Ivishak Formation records the deposition of offshore muds followed by regressive deltaic deposits composed of sandstone and conglomerate that indicates uplift in the source area. The uppermost part of the Ivishak records a change of deposition from deltaic sandstone to finer grained marine siltstone and sandstone indicating continued subsidence and or a wearing down of the source area. The Sadlerochit Group crops out throughout the northeast Brooks Range (Detterman and others, 1975; McMillen and Colvin, 1987; Crowder, 1990) and is found in the subsurface to the west (Bird and others, 1987, fig. 7.8). The Ledge Sandstone Member of the Ivishak Formation is the main oil-producing reservoir in the Prudhoe Bay oil field (Morgridge and Smith, 1972; Jones and Speers, 1976; Nelson and Bird, Chap. FP; Plate GG2).

The Shublik Formation of Middle and Late Triassic age is a distinctive dark-colored unit consisting of fossiliferous limestone and calcareous shale. It represents continued subsidence of the basin following Sadlerochit deposition, limited influx of clastic sediment, and significant carbonate production. It conformably overlies the Sadlerochit Group, except in basin margin areas where it becomes unconformable, overstepping older units northward (Figs. GG4, GG5). The Shublik has an irregular thickness pattern (Plate PS2), ranging from less than 100 feet in the Prudhoe Bay area to more than 500 feet south of the 1002 area. The Shublik is rich in organic carbon and is considered to be an important source rock for Prudhoe Bay oil (Seifert and others, 1980; Magoon and others, Chap. PS; Lillis and others, Chap. OA).

The Karen Creek Sandstone is a Late Triassic quartzose, very fine to silty sandstone that is discontinuous in occurrence; it is as much as 125 feet thick in outcrop south of the 1002 area (Bird and others, 1987, fig. 7.10). The Sag

River Sandstone is the subsurface unit with which the Karen Creek is correlative and is oil-productive in the Prudhoe Bay area (Nelson and Bird, Chap. FP) and contains gas in the Kavik field (Plate PS5). Marine transgression followed deposition of the Karen Creek Sandstone, marking the end of Ellesmerian sequence deposition and, with deposition of the overlying Kingak Shale, the beginning of the Beaufortian sequence.

Beaufortian Sequence

Jurassic and Early Cretaceous strata represent a change in the tectonic regime of northern Alaska, from slowly subsiding passive margin to an active rift margin. Therefore, the corresponding upper part of Lerand's Ellesmerian sequence was re-designated as the Barrovian sequence (Carman and Hardwick, 1983), the Beaufortian sequence (Hubbard and others, 1987) or Upper Ellesmerian sequence (Moore and others, 1994). The term Beaufortian is used here (Fig. GG2).

Jurassic and Early Cretaceous normal faulting, a defining characteristic of the Beaufortian, is limited to the coastal and offshore areas of northern Alaska. The Dinkum graben is the most prominent feature formed by this faulting (Fig. GG3). Northward onlap, a characteristic of the Ellesmerian sequence, is also a feature of the Beaufortian, but is sometimes obscured by faulting and later erosion (Figs. GG4, GG5). In the coastal area, sediment thicknesses are highly variable with more than 10,000 feet estimated for the Dinkum graben (Hubbard and others, 1987). Well penetrations indicate that sediments deposited in this area consist of marine shale (Kingak Shale and Mileuveach Formation) and local sandstone units, the most important of which is the Kuparuk River Sandstone (Carman and Hardwick, 1983). The Kuparuk River is a discontinuous, multi-storied, Early Cretaceous sandstone that hosts several oil accumulations, including the Kuparuk River, Milne Point, Cascade, Point McIntyre, and Niakuk oil fields. Recently, oil was discovered in Late Jurassic sandstones (Alpine and Nuiqsut sandstones) in the Colville River delta area (Kornbrath and others, 1997).

South of the area that contains Jurassic-Cretaceous normal faults, Beaufortian sediments are mostly mudstones of shelfal and deeper marine origin (Kingak

Shale) that reach a maximum thicknesses of about 3500 feet (Bird, 1987). The Kingak Shale is present south of the 1002 area and in limited exposures in the Niguanak area and just north of the eastern end of the Sadlerochit Mountains (Plate GG1). In these areas, the Kingak is a zone of detachment for thrust faults (Kelley and Foland, 1987; Wallace and Hanks, 1990; Chaps. SM, BD, NA). Other details of the Kingak in these areas can be found in Detterman and others (1975) and Bird and Molenaar (1987). Nearly 1900 feet of Kingak Shale and a Kuparuk River-like sandstone are present just east of the 1002 area in the Aurora well (Banet, 1992; Paul and others, 1994; Keller and others, Chap. SR). A Beaufortian section similar to that penetrated in the Aurora well was also penetrated in the Roland Bay and Spring River wells (Fig. GG6), 100 miles to the southeast in Canada. Here, the Beaufortian rests directly on Franklinian rocks (J. Dixon, Geological Survey of Canada, personal communication).

Uplift along the rift margin in Early Cretaceous time produced the regional Lower Cretaceous unconformity or LCU. This unconformity extends 50 miles or more south of the present-day coastline where it dies out into a conformable sedimentary section. A subcrop map showing the distribution of rock units beneath this unconformity is presented in Figure GG6. It shows a complex pattern of erosion and preservation of Ellesmerian and Beaufortian deposits in the coastal area. To the south, the map shows uniformly Beaufortian deposits. Significant amounts of erosion occurred locally along this margin. The most prominent area is that extending southeast of Prudhoe Bay and into the western part of the 1002 area where several thousand feet of Ellesmerian and Beaufortian strata were removed (Fig. GG6; Plates GG2, GG3). The LCU is the most areally widespread and easily recognizable unconformity in northern Alaska and is considered the break-up unconformity for the Early Cretaceous opening of the Canada basin (Grantz and May, 1983).

Subsidence of the rift margin resulted in a northward transgression of the sea across the LCU with deposition of local sand bodies (Kemik Sandstone, Thomson sand, etc.) and several hundred feet of marine shale, the pebble shale unit (Macquaker and others, Chap. SS). Together these units seldom exceed a thickness of 500 feet. Although separated from the underlying

Kingak Shale by a regional unconformity, the Kemik and related sandstones and the pebble shale unit are included in the Beaufortian sequence because they have generally northern, but local sources. As the rift margin became completely submerged, local sources ceased to exist and Beaufortian sequence deposition ended. Hemipelagic clays and bentonites comprising the overlying Hue Shale are considered in this report as part of the southern-sourced Brookian sequence.

The rift shoulder remains a broad subsurface structural feature known as the Barrow arch. It separates gently southward-dipping Ellesmerian and Beaufortian deposits and thick Cretaceous-Tertiary foreland basin deposits on the south from limited Ellesmerian deposits, locally thick Beaufortian deposits (e.g., Dinkum graben), and thick Cretaceous and Tertiary deposits of the Beaufort passive margin on the north (Figs. GG2, GG3; Plate GG3). The Barrow arch and the stratigraphic complexity related to rifting are key elements in the migration and trapping of the large volumes of oil in northern Alaska (Bird, 1987; Hubbard and others, 1987). The Kingak Shale and pebble shale unit are source rocks for some oil in the Prudhoe Bay area (Morgridge and Smith, 1972; Jones and Speers, 1976; Seifert and others, 1980) and for gas in the 1002 area (Chaps. OA, PS).

Regional Relations and the Niguanak/Aurora Area. The answer to the question of whether Ellesmerian strata with Prudhoe Bay-type reservoirs are present in the eastern part of the 1002 area and specifically on the two large structures in the northeastern part of this area (the Niguanak High and Aurora Dome, Figs. GG4, GG6) is of considerable importance to the oil and gas potential of this area. This is a long-running question that has yet to be unequivocally answered by reflection seismic or other geophysical methods (Chaps. NA, AM, GR). It is mainly the presence of Beaufortian rocks (Kingak Shale) on the surface in the Niguanak area and in the lowermost 1200 feet of the Aurora well that offers the possibility of Ellesmerian strata being present. These occurrences are markedly different than stratigraphic relations observed in the western part of the 1002 area where Early Cretaceous deposits (Kemik Sandstone and pebble shale unit) rest unconformably on Franklinian rocks (Fig. GG6, Plate GG3).

Consideration of regional characteristics of the Ellesmerian and Beaufortian sequences such as onlap, normal faulting, and erosion related to rift-margin uplift offers insight and some constraints on the range of possibilities. In Figure GG7 these regional characteristics and their implications are illustrated in a schematic cross section extending from the Brooks Range northward across the Niguanak/Aurora area. It is concluded from this analysis that regional onlap trends make it likely that if Ellesmerian strata are present at all they are probably thin and represent only the upper part of the sequence; this might include Sadlerochit, Shublik, and Karen Creek units. The observed occurrences of Kingak Shale, described above, may be explained by insignificant erosion on the LCU and little or no normal faulting (Fig. GG7A) or by significant erosion on the LCU, normal faulting, and development of north- or south-dipping half grabens (Fig. GG7B-D).

Brookian Sequence

In northern Alaska, the Brookian sequence consists of thick, northeasterly-prograding clastic deposits derived from the ancestral Brooks Range orogenic belt to the south and southwest. These deposits filled the Colville foreland basin adjacent to the orogenic belt and spilled northward across the subsiding rift shoulder (Barrow arch) to accumulate in the ancestral Arctic Ocean forming the Beaufort passive margin (Fig. GG3; Plate GG3). Brookian deposits have different names and ages in different areas (Bird and Molenaar, 1992), but generally show a similar succession everywhere. That succession is complex in detail but simple in gross aspect. It consists of a basal condensed facies, a deep-water shale and turbidite sandstone (flysch) facies, and a deltaic sandstone and shale (molasse) facies.

The Colville basin filled longitudinally. Figure GG8, modified from Moore and others (1994), shows three depocenters—Early Cretaceous, Late Cretaceous, and Tertiary—that record the progressive west to east filling of the basin. Seismic mapping in the central part of the 1002 area suggests that as much as 30,000 ft of Tertiary fill is present in the youngest depocenter (Chaps. NA and BD). This figure also illustrates the degree to which the eastern part of the Brooks Range orogen has migrated northward, overriding the Early Cretaceous rift margin and disrupting the passive margin. Figure

GG3 shows that in this area, the fold- and thrust-belt extends far offshore and eastward as far as the Mackenzie delta in Canada.

The basal unit of the Brookian sequence in the 1002 area and to the west is a black fissile shale and bentonite unit as much as 1000 feet thick known as the Hue Shale (Molenaar and others, 1987). The Hue Shale is a distal condensed shale facies deposited on the north side of the Colville basin, on the Barrow arch, and to the north of the arch. The Hue represents about 50 m.y. of time (Aptian to Maestrichtian) and an average rate of accumulation of about 20 ft/m.y. (calculated using the compacted thickness). Age-equivalent strata in the central part of the Colville basin accumulated at least 15 times faster than the Hue Shale. The Hue Shale is organic-carbon rich and is considered a good to excellent oil-prone source rock (Magoon and others, Chap. PS; Lillis and others, Chap. OA; and Keller and others, Chap. SR).

The Canning Formation (Molenaar and others, 1987) is a thick, dominantly shale unit that conformably overlies the Hue Shale and underlies thick, deltaic deposits of the Sagavanirktok Formation. Thickness of the Canning is 6000 feet or more (Plate GG2, GG3). Within the Canning, two facies are recognized: a basinal and lower-slope shale and turbidite sandstone facies and a thick upper-slope and shelf shale facies. Water depths of several thousand feet for the turbidite facies are calculated from seismically-imaged clinoform bedding. With improved resolution of seismic records, stratigraphic details including mounds, channels, slumps, and scours have been observed (Houseknecht and Schenk, Chap. BS). Seismic records also reveal a number of slump or scour surfaces that locally remove significant amounts of strata, including part or all of the underlying Hue Shale (Plates GG2, GG3; and Chap. BS). Canning turbidite sandstones are reservoirs for oil in the Badami oil field and in many wells in the Point Thomson area (Plate PS4).

The Sagavanirktok Formation is a thick, deltaic shallow marine and nonmarine unit overlying and intertonguing with the Canning Formation. Total thickness of the Sagavanirktok in northeastern Alaska, including tongues of Canning Formation, is more than 8000 feet (Bird and others, 1987, fig. 7.12; Plates GG2, GG3). Regionally, the Sagavanirktok-Canning formation boundary is time transgressive, ranging from Late Cretaceous southwest of the 1002 area to Oligocene offshore (Molenaar and others, 1987; Plates GG2, GG3). Some of the youngest exposures of the Sagavanirktok have been studied on the north flank of the Marsh Creek anticline (Plate GG1) by Fouch and others (1990). Here, the Nuwok Member of the Sagavanirktok (Detterman and others, 1975) consists of more than 600 feet of silty to pebbly marine sandstone that is variously reported as Oligocene, Miocene, and possibly as young as Pliocene (McNeil and Miller, 1990; Marincovich and others, 1991; Brouwers, 1994). Sagavanirktok sandstones are reservoirs for oil in the Hammerhead and Kuvlum oil accumulations (Fig. AO2). A synclinal remnant of the Sagavanirktok Formation, the Jago River Formation of Buckingham (1987), is located in the south-central part of the 1002 area (Plate GG1). The Jago River Formation is reportedly more than 10,000 feet thick and Late Cretaceous and Paleocene in age. Seismic interpretation (Potter and others, Chap. BD) suggests that it was deposited in part in a contemporaneously growing syncline, a piggyback basin.

PALEOGEOGRAPHIC RECONSTRUCTIONS

A series of six maps have been prepared in collaboration with D. Houseknecht to summarize the Brookian paleogeography and present-day structural features of northeastern Alaska (Plate GG4). These maps are made possible by new information gathered over the last 10 years, including biostratigraphic control from outcrops and wells, improved seismic records, ties between onshore and offshore seismic, and mapping of seismic sequences (Houseknecht and Schenk, Chap. BS). The maps show inferred positions of tectonic and stratigraphic features for six time slices: Albian, Paleocene, Eocene, Oligocene, Miocene, and Holocene. Together, they illustrate the progradational filling of the Colville basin and the accompanying tectonic deformation during the last 100 m.y. in northeastern Alaska.

The map of Albian paleogeography (Plate GG4) shows the eastern part of the now completely filled Early Cretaceous depocenter of Figure GG8 and the deep marine conditions that prevailed to the east of the depocenter. This time slice shows the inferred area of deposition of (1) the condensed facies represented by the Hue Shale gamma-ray zone and the Boundary Creek

Formation in Canada and (2) the flysch facies represented by the Arctic Creek facies (Molenaar and others, 1987; Mull and Decker, 1993), the Bathtub Greywacke (Detterman and others, 1975), and the Albian flysch of the Rapid Depression in Canada (Dixon, 1996). In the Aurora well, foraminiferal-bearing Albian strata are present (Keller and others, Chap. SR) but they display only moderate to low gamma-ray log response. We note that this is anomalous, being only 25 miles northeast of (thrust-faulted) outcrops of the gamma-ray zone on the Jago River (Bird and Molenaar, 1987, fig. 5.8E).

The map of Paleocene paleogeography shows that northward progradation of Brookian strata since Albian time had reached the 1002 area. Plate GG3 shows the considerable thickness and stratigraphic complexity of Paleocene deposits just west of the 1002 area. The shelf-edge trend represents that of the latest Paleocene Staines Tongue of the Sagavanirktok Formation. In the eastern part of the 1002 area, deposition was synchronous with thrusting; the Jago River Formation was deposited in the Sabbath Creek sub-basin adjacent to the growing Aichilik high. To the south, uplift and erosion (cooling) is indicated by fission-track analysis in the Bathtub syncline area (O'Sullivan and others, 1993). West of the 1002 area, significant coal deposits formed at this time (Roberts, 1991; Roberts and others, 1992).

The map of Eocene paleogeography shows continuing syndepositional deformation in the eastern part of the 1002 area and offshore with the development of a series of sub-basins and ridges. Fission track analysis (O'Sullivan and others, 1993) demonstrates uplift and erosion (cooling) in the Sadlerochit Mountains and Leffingwell Ridge areas. To the south, significant crustal loading is suggested by an early or middle Eocene transgression which flooded the late Paleocene and early Eocene delta plain (Staines Tongue), resulting in a southward shifting of the shoreline by more than 30 miles. Progradation resumed with deposition of the Mikkelsen Tongue of the Canning Formation, a southward thickening wedge that probably records the maximum burial of strata in the Sadlerochit Mountains area (see Plate GG3 restoration at ~40 Ma). In the eastern part of the 1002 area, northward propagating thrusting reached as far north as the Jago Ridge area.

Click here or on this symbol in the toolbar to return.

The map of Oligocene paleogeography shows continuing and northward-expanding syndepositional deformation in the eastern part of the 1002 area and offshore. The Camden anticline and Barter sub-basin began to form during this time as did the Marsh Creek anticline. Fission track analysis (O'Sullivan and others, 1993) shows additional uplift and erosion (cooling) in the Sadlerochit Mountains. Oligocene was a time of major clastic influx, progradation, and development offshore of growth faults. During this time the Brookian sequence completely filled the old foreland basin, overtopped the Barrow arch, and built a northward-thickening wedge forming a major part of the Beaufort passive margin (Plate GG3).

The map of Miocene paleogeography shows continuing syndepositional deformation in the eastern part of the 1002 area, the offshore, and the Marsh Creek anticline area. The shelf edge position was strongly controlled by uplifted areas such as the Camden and Belcher anticlines and by subsiding areas such as the Barter sub-basin, a shelf edge re-entrant.

The Holocene map shows the present-day location of the coastline, shelf edge, sub-basins, ridges, and areas of growth faulting. Pleistocene and Holocene sediment thickness variations on the shelf, warped terrace deposits onshore, and earthquake epicenters (recorded between 1966 to 1978) all attest to continuing contractional deformation in this area (Grantz and others, 1987). Sedimentation continues to be active with modern fan deltas being built from the south into the Demarcation subbasin.

SUMMARY

The 1.5-million acre 1002 area of the Arctic National Wildlife Refuge is a treeless, tundra-covered wetland situated between the Brooks Range and the Arctic Ocean. It lies mainly within the Arctic Coastal Plain physiographic province which, in this area, is characterized by rolling hills cut by numerous northward-flowing braided streams. The 1002 area is mantled by a thin veneer of frozen surficial deposits, which nearly completely mask the bedrock geology in most areas. Our understanding of the bedrock geology comes primarily from geophysical remote sensing of the rocks beneath the 1002 area, from observations of surface exposures mostly in the mountains south of the area, and from well penetrations west and north of the area.

Northern Alaska is part of a small, poorly-defined continental fragment with a controversial plate tectonic history. At the heart of the controversy is the nature of Cretaceous rifting and the pre-rift geography. Many stratigraphic and structural similarities exist between northern Alaska and other lands bordering the Arctic Ocean; however, the lack of clear magnetic seafloor stripes in the oceanic Canada basin precludes a unique solution to the plate history of this region.

Structures within the 1002 area consist of closely-spaced folds and faults (thin-skinned deformation) within foreland basin strata and broad, domal faulted structures (thick-skinned deformation) in pre-foreland basin and basement strata. These structures formed in one or more episodes of Brooks Range-related deformation during Cenozoic time. Devonian and perhaps older structures are also known in this area, and the grain of these structures has controlled the orientation of some younger Cenozoic structures. Across the North Slope west of the 1002 area and beneath the continental shelves, normal faulting is related to rifting in Mississippian and Jurassic and Early Cretaceous time and to massive slope failure of the Beaufort passive margin in Tertiary time.

The sedimentologic history of northern Alaska can be summarized in four tectono-stratigraphic sequences. The oldest sequence is the Franklinian, which consists of a thick succession of metamorphosed sedimentary, volcanic, and igneous rocks of Proterozoic to Early Devonian age, all of which are generally considered non-prospective for petroleum. The overlying Ellesmerian sequence of Middle Devonian to Triassic age represents a south-facing passive margin which includes some of the main oil producing reservoirs in the Prudhoe Bay area. The Beaufortian sequence records Jurassic and Cretaceous rifting which severed the continental connection of northern Alaska and opened the Canada basin. All major north Alaskan oil accumulations owe their origin to geologic structures related to the rift margin. The Brookian sequence, Jurassic to Recent in age, consists of debris shed from a southern orogenic land mass, the ancestral and modern Brooks

Range, and deposited in foreland basin and passive margin settings. Brookian rocks provided the deep burial necessary to generate North Slope oil and gas and they are oil bearing in both deep- and shallow-marine reservoirs found in areas adjacent to the 1002 area.

The 1002 area is located in the eastern part of the North Slope geologic province, an unusual area of converging regional geologic trends. This convergence has produced a geologic complexity that is greater than that found elsewhere in northern Alaska. This is where the youngest foreland basin strata were deposited on a rifted margin and where the Brooks Range fold- and thrust-belt intersects and incorporates pre-Mississippian basement rocks, rift-related strata, and passive margin strata. Deformation has frequently been synchronous with deposition in Tertiary time and continues to the present-day.

ACKNOWLEDGMENTS

Thanks are extended to Kevin Evans, Heather Marshall, and Mike Sinor for the application of their considerable computer skills to producing the figures and plates and to reviewers, Frances Cole and Tom Moore, for their thoughtful comments and helpful suggestions.

REFERENCES

Anderson, A.V., 1991, Geologic map and cross-sections: Headwaters of the Kongakut and Aichilik Rivers, Demarcation Point (A-4) and Table Mountain (D-4) quadrangles, eastern Brooks Range, Alaska: Alaska Division of Geological and Geophysical Surveys 91-3, 23 p.

Anderson, A.V., Mull, C.G., and Crowder, R.K., 1993, Mississippian terrigenous clastic and volcaniclastic rocks of Ellesmerian sequence, upper Sheenjek River area, eastern Brooks Range, Alaska, *in* Solie, D.N., and Tannian, F., eds., Short notes on Alaskan geology 1993, Alaska Division of Geological and Geophysical Surveys Professional Report 113, p. 1-6.

Anderson, A.V., Wallace, W.K., and Mull, C.G., 1994, Depositional record of a major tectonic transition in northern Alaska: Middle Devonian to

Mississippian rift-basin margin deposits, upper Kongakut River region, eastern Brooks Range, Alaska, *in* Thurston, D.K., and Fujita, K., eds., 1992 Proceedings International Conference on Arctic Margins: Anchorage, Alaska, Minerals Management Service OCS Study MMS 94-0040.

Bader, J.W., and Bird, K.J., 1986, Geologic map of the Demarcation Point, Mt. Michelson, Flaxman Island, and Barter Island quadrangles, Alaska: U.G. Geological Survey Miscellaneous Investigations Map I-1791, scale 1:250,000, 1 sheet.

Banet, A.C., Jr., 1992, Log analysis of Aurora #1, OCS-Y-0943 well, offshore of the Arctic National Wildlife Refuge 1002 area, northeast Alaska: Anchorage, Alaska: USDOI, Bureau of Land Management-Alaska Technical Report No. 15, p. 37.

Berggren, W.A., Kent, D.V., Swisher, C.S., III, and Aubry, M., 1995, A revised Cenozoic chronology and chronostratigraphy, geochronology, time scales, and global stratigraphic correlation: Tulsa, OK, Society for Sedimentary Geology, SEPM Special Publication No. 54, p. 129-212.

Bird, K.J., 1987, The framework geology of the North Slope of Alaska as related to oil-source rock correlations, *in* Tailleur, I., and Weimer, P., eds., Alaskan North Slope Geology: Bakersfield, California, Pacific Section, Society of Economic Paleontologists and Mineralogists, p. 121–143.

Bird, K.J., and Molenaar, C.M., 1987, Stratigraphy, *in* Bird, K.J., and Magoon, L.B., eds., Petroleum geology of the northern part of the Arctic National Wildlife Refuge, northeastern Alaska, U.S. Geological Survey Bulletin 1778, p. 37–59.

Bird, K.J., and Molenaar, C.M., 1992, The North Slope foreland basin, Alaska, *in* Macqueen, R., and Leckie, D., eds., Foreland basins and foldbelts: American Association of Petroleum Geologists Memoir 55, p. 363-393.

Bird, K.J., Griscom, S.B., Bartsch-Winkler, S., and Giovannetti, D.M., 1987, Petroleum reservoir rocks, *in* Bird, K.J., and Magoon, L.B., eds., Petroleum geology of the northern part of the Arctic National Wildlife

Refuge, northeastern Alaska, U.S. Geological Survey Bulletin 1778, p. 79–99.

Blodgett, R.B., Clough, J.G., Harris, A.G., and Robinson, M.S., 1992, The Mount Copleston Limestone, a new Lower Devonian formation in the Shublik Mountains, northeastern Brooks Range, Alaska, *in* Bradley, D.C., and Ford, A.B., eds., Geologic studies in Alaska by the U.S. Geological Survey, 1990, U.S. Geological Survey Bulletin 1999, p. 3–7.

Brewer, M.C., 1987, Surficial geology, permafrost, and physical processes, *in* Bird, K.J., and Magoon, L.B., eds., Petroleum geology of the northern part of the Arctic National Wildlife Refuge, northeastern Alaska, U.S. Geological Survey Bulletin 1778, p. 27–36.

Brosgé, W.P., Dutro, J.T., Jr., Mangus, M.D., and Reiser, H.N., 1962, Paleozoic sequence in eastern Brooks Range, Alaska: American Association of Petroleum Geologists Bulletin, v. 46, no. 2, p. 2174-2198.

Brouwers, E.M., 1994, Late Pliocene paleoecologic reconstructions based on ostracode assemblages from the Sagavanirktok and Gubik Formations, Alaskan North Slope: Arctic, v. 47, no. 1, p. 16-33.

Camber, W., and Mull, C.G., 1986, Preliminary bedrock geologic map of part of the Demarcation Point A-3 and A-4 quadrangles, Bathtub Ridge, northeastern Alaska: Alaska Division of Geological and Geophysical Surveys 86-86c, 10 p.

Carey, S.W., 1958, A tectonic approach to continental drift, *in* Carey, S.W., ed., Continental drift, a symposium: Hobart, Tasmania, Tasmania University, p. 177-355.

Carter, L.D., Ferrians, O.J., Jr., and Galloway, J.P., 1986, Engineering-geologic maps of northern Alaska coastal plain and foothills of the Arctic National Wildlife Refuge: U.S. Geological Survey Open-File Report 86-334, 2 sheets, 9 p.

Clough, N.K., Patton, P.C., and Christiansen, A.C., editors, 1987, Arctic National Wildlife Refuge, Alaska, coastal plain resource

Click here or on this symbol in the toolbar to return.

assessment—Report and recommendation to the Congress of the United States and final legislative environmental impact statement: Washington, D.C., U.S. Fish and Wildlife Service, U.S. Geological Survey, and Bureau of Land Management, v. 1, 208 p.

Clough, J.G., 1989, General stratigraphy of the Katakturuk Dolomite in the Sadlerochit and Shublik Mountains, Arctic National Wildlife Refuge, northeastern Alaska: Alaska Division of Geological and Geophysical Surveys 89-4, 8 p.

Clough, J.G., Robinson, M.S., Pessel, G.H., Imm, T.A., Blodgett, R.B., Harris, A.G., Bergman, S.C., and Foland, K.A., 1990, Geology and age of Franklinian and older rocks in the Sadlerochit and Shublik Mountains, Arctic National Wildlife Refuge, Alaska [abs.]: Geological Association of Canada and Mineralogical Association of Canada Annual Meeting, Program with Abstracts, v. 15, p. A25.

Coflin, K.C., Cook, F.A., and Geis, W.T., 1990, Evidence for Ellesmerian convergence in the subsurface east of the Mackenzie Delta, *in* Weber, J.R., Forsyth, D.A., Embry, A.F., and Blasco, S.M., eds., Marine Geology Special Issue of Arctic Geoscience, vol. 93: Amsterdam, Elsevier, p. 289-301.

Cowardin, L.M., Carter, V., Golet, F.C., and LaRoe, E.T., 1979, Classification of wetlands and deepwater habitats of the United States: Washington, D.C., U.S. Fish and Wildlife Service FWS/OBS-79/31, 103 p.

Crowder, R.K., 1990, Permian and Triassic sedimentation in the northeastern Brooks Range, Alaska: Deposition of the Sadlerochit Group: American Association of Petroleum Geologists Bulletin, v. 74, no. 9, p. 1351–1370.

Detterman, R.L., Reiser, H.N., Brosge, W.P., and Dutro, J.T., Jr., 1975, Post-Carboniferous stratigraphy, northeastern Alaska: U.S. Geological Survey Professional Paper 886, 46 p.

Dillon, J.T., Tilton, G.R., Decker, J., and Kelley, M.J., 1987, Resource implications of magmatic and metamorphic ages for Devonian igneous rocks in the Brooks Range, *in* Tailleur, I., and Weimer, P., eds., Alaskan North Slope Geology: Bakersfield, California and Anchorage, Alaska, Pacific Section, Society of Economic Paleontologists and Mineralogists and Alaska Geological Society, p. 713-723.

Dinter, D.A., Carter, L.D., and Brigham-Grette, J., 1990, Late Cenozoic geologic evolution of the Alaskan North Slope and adjacent continental shelves, *in* Grantz, A., Johnson, L., and Sweeney, J.F., eds., The Arctic Ocean region: Boulder, Colorado, Geological Society of America, The Geology of North America, vol. L, p. 459-490.

Dixon, J., ed., 1996, Geological atlas of the Beaufort-Mackenzie area: Geological Survey of Canada Miscellaneous Report 59, 173 p.

Fisher, M.A., and Bruns, T.R., 1987, Structure of pre-Mississippian rocks beneath the coastal plain, *in* Bird, K.J., and Magoon, L.B., eds., Petroleum geology of the northern part of the Arctic National Wildlife Refuge, northeastern Alaska, U.S. Geological Survey Bulletin 1778, p. 245–254.

Fouch, T.D., Brouwers, E.M., McNeil, D.H., Marincovich, L., Bird, K.J., and Reick, H., 1990, Oligocene(?) and/or Neogene(?) Nuwok Member of Sagavanirktok Formation; implications for petroleum geology of the North Slope and Beaufort Sea: Evidence from the type section, Carter Creek, Arctic National Wildlife Refuge (ANWR), Alaska (abs.), *in* Carter, L.M.J., ed., USGS research on energy resources-1990, Program and Abstracts of the sixth V.E. McKelvey Forum on Mineral and Energy Resources:, U.S. Geological Survey Circular 1060, p. 30-31.

Fujita, K., Stone, D.B., Layer, P.W., Parfenov, L.M., and Koz'min, B.M., 1997, Cooperative program helps decipher tectonics of northeastern Russia: EOS, v. 78, no. 24, p. 245-253.

Gradstein, F.M., Agterberg, F.P., Ogg, J.G., Hardenbol, J., van Veen, P., Thierry, J., and Huang, Z., 1994, A Mesozoic time scale: Journal of Geophysical Research, v. 99, no. B12, p. 24,051–24,074.

Grantz, A., and May, S.D., 1983, Rifting history and structural development of the continental margin north of Alaska, *in* Watkins, J.S., and Drake, C.L., eds., Studies in continental margin geology: American Association of Petroleum Geologists Memoir 34, p. 77-100.

Grantz, A., Dinter, D.A., and Culotta, R.C., 1987, Structure of the continental shelf north of the Arctic National Wildlife Refuge, *in* Bird, K.J., and Magoon, L.B., eds., Petroleum geology of the northern part of the Arctic National Wildlife Refuge, northeastern Alaska, U.S. Geological Survey Bulletin 1778, p. 271–276.

Grantz, A., May, S.D., and Hart, P.E., 1990, Geology of the continental margin north of Alaska, *in* Grantz, A., Johnson, G.L., and Sweeney, J.F., eds., The Arctic Ocean region: Boulder, Colorado, Geological Society of America, The Geology of North America, vol. L, p. 257-288.

Grantz, A., May, S.D., Taylor, P.T., and Lawver, L.A., 1990, Canada basin, *in* Grantz, A., Johnson, G.L., and Sweeney, J.F., eds., The Arctic Ocean region: Boulder, Colorado, Geological Society of America, The Geology of North America, vol. L, p. 379-402.

Grantz, A., Clark, D.L., Phillips, R.L., and Srivastava, S.P., 1998, Phanerozoic stratigraphy of Northwind Ridge, magnetic anomalies in the Canada basin, and the geometry and timing of rifting in the Amerasia basin, Arctic Ocean: Geological Society of America Bulletin, v. 110, no. 6, p. 801 -820.

Hanks, C.L., 1988, Preliminary geologic map of eastern Leffingwell Ridge, northeastern Arctic National Wildlife Refuge, Brooks Range, Alaska: Alaska Division of Geological and Geophysical Surveys 88-6c, 13 p.

Hanks, C.L., 1989, Peliminary geology of the pre-Mississippian rocks of the Aichilik and Egaksrak River areas, northeastern Brooks Range, Alaska: Alaska Division of Gological and Geophysical Surveys 89-1a, 18 p.

Harland, W.B., Armstrong, R.L., Cox, A.V., Craig, L.E., Smith, A.G., and Smith, D.G., 1990, A geologic time scale 1989, Cambridge University Press, 263 p.

Hubbard, R.J., Edrich, S.P., and Rattey, R.P., 1987, Geologic evolution and hydrocarbon habitat of the 'Arctic Alaska Microplate', *in* Tailleur, I., and Weimer, P., eds., Alaskan North Slope Geology: Bakersfield, California and Anchorage, Alaska, Pacific Section, Society of Economic Paleontologists and Mineralogists and Alaska Geological Society, p. 797–830.

Jameson, J., 1994, Models of porosity formation and their impact on reservoir description, Lisburne Field, Prudhoe Bay, Alaska: American Association of Petroleum Geologists Bulletin, v. 78, no. 11, p. 1651-1678.

Jones, H.P., and Speers, R.G., 1976, Permo-Triassic reservoirs of Prudhoe Bay field, North Slope, Alaska, *in* Braunstein, J., ed., North American oil and gas fields: American Association of Petroleum Geologists Memoir 24, p. 23-50.

Kelley, J.S., and Brosgé, W.P., 1995, Geologic framework of a transect of the central Brooks Range: Regional relations and an alternative to the Endicott Mountains allochthon: American Association of Petroleum Geologists Bulletin, v. 79, no. 8, p. 1087-1116.

Kelley, J.S., and Foland, R.L., 1987, Structural style and framework geology of the coastal plain and adjacent Brooks Range, *in* Bird, K.J., and Magoon, L.B., eds., Petroleum geology of the northern part of the Arctic National Wildlife Refuge, northeastern Alaska, U.S. Geological Survey Bulletin 1778, p. 255–270.

Kelley, J.S., Wrucke, C.T., and Lane, L.S., 1994, Pre-Mississippian rocks in the Clarence and Malcolm Rivers area, Alaska and Yukon Territory, *in* Thurston, D.K. and Fujita, K., eds., Proceedings of the 1992 International Conference on Arctic Margins: United States Department of the Interior, Minerals Management Service, OCS Study MMS94-0040, p. 59-64.

Kirschner, C.E., and Rycerski, B.A., 1988, Petroleum potential of representative stratigraphic and structural elements in the National petroleum Reserve in Alaska, *in* Gryc, G., ed., Geology and exploration of the National Petroleum Reserve in Alaska, 1974 to 1982, U.S. Geological Survey Professional Paper 1399, p. 191–208.

Kornbrath, R.W., Myers, M.D., Krouskop, D.L., Meyer, J.F., Houle, J.A., Ryherd, T.J., and Richter, K.N., 1997, Petroleum potential of the eastern National Petroleum Reserve–Alaska: Alaska Department of Natural Resources, Division of Oil and Gas, 30 p.

Lane, L.S., 1991, The pre-Mississippian "Neruokpuk Formation," northeastern Alaska and northwestern Yukon: Review and new regional correlations: Canadian Journal of Earth Science, v. 28, no. 10, p. 1521–1533.

Lane, L.S., Kelley, J.S., and Wrucke, C.T., 1995, Stratigraphy and structure of the Clarence River area, Yukon-Alaska north slope: a USGS-GSC co-operative project: in Current Research 1995-E, Geological Survey of Canada, p. 1-9.

Lane, L.S., 1997, Canada Basin, Arctic Ocean: Evidence against a rotational origin: Tectonics, v. 16, no. 3, p. 363-387.

Lawver, L.A., and Scotese, C.R., 1990, A review of tectonic models for the evolution of the Canada basin, *in* Grantz, A., Johnson, G.L., and Sweeney, J.F., eds., The Arctic Ocean region: Boulder, Colorado, Geological Society of America, The Geology of North America, vol. L, p. 593-618.

Laxon, S., and McAdoo, D., 1998, Satellites provide new insights into polar geophysics: EOS, v. 79, no. 6, p. 69-73.

Laxon, S., and McAdoo, D., 1994, Arctic Ocean gravity field derived from ERS-1 satellite altimetry: Science, v. 265, p. 621-624.

LePain, D.L., Crowder, R.K., and Wallace, W.K., 1994, Early Carboniferous transgression on a passive continental margin: Deposition of the Kekiktuk Conglomerate, northeastern Brooks Range, Alaska: American Association of Petroleum Geologists Bulletin, v. 78, no. 5, p. 679-699.

Lerand, M., 1973, Beaufort Sea, *in* McCrossan, R.G., ed., The future petroleum provinces of Canada—their geology and potential: Canadian Society of Petroleum Geology Memoir 1, p. 315-386.

Click here or on this symbol in the toolbar to return.

Marincovich, L., Jr., Brouwers, E.M., Hopkins, D.M., and McKenna, M.C., 1990, Late Mesozoic and Cenozoic paleogeographic and paleoclimatic history of the Arctic Ocean basin, based on shallow-water marine faunas and terrestrial vertebrates, *in* Grantz, A., Johnson, L., and Sweeney, J.F., eds., The Arctic Ocean region: Boulder, Colorado, Geological Society of America, The Geology of North America, vol. L, p. 403-426.

Marincovich, L., Jr., Powell, C.L., McNeil, D.H., and Miller, K.G., 1991, Comment and reply on "High-latitude application of 87Sr/86Sr: Correlation of Nuwok beds on North Slope, Alaska, to standard Oligocene chronostratigraphy": Geology, v. 19, p. 537-538.

McMillen, K.J., and Colvin, M.D., 1987, Facies correlation and basin analysis of the Ivishak Formation, Arctic National Wildlife Refuge, Alaska, *in* Tailleur, I., and Weimer, P., eds., Alaskan North Slope Geology: Bakersfield, California, Pacific Section SEPM, p. 381-390.

McNeil, D.H., and Miller, K.G., 1990, High-latitude application of 87Sr/86Sr: Correlation of Nuwok beds on North Slope, Alaska, to standard Oligocene chronostratigraphy: Geology, v. 18, p. 415-418.

Miall, A.D., 1973, Regional geology of northern Yukon: Bulletin of Canadian Petroleum Geology, v. 21, no. 1, p. 81-116.

Molenaar, C.M., 1983, Depositional relations of Cretaceous and lower Tertiary rocks, northeastern Alaska: American Association of Petroleum Geologists Bulletin, v. 67, no. 7, p. 1066-1080.

Molenaar, C.M., Bird, K.J., and Kirk, A.R., 1987, Cretaceous and Tertiary stratigraphy of northeastern Alaska, *in* Tailleur, I., and Weimer, P., eds., Alaskan North Slope Geology: Bakersfield, California, Pacific Section, Society of Economic Paleontologists and Mineralogists and Alaska Geological Society, p. 513–528.

Moore, T.E., 1987, Geochemistry and tectonic setting of some volcanic rocks of the Franklinian assemblage, central and eastern Brooks Range, *in* Tailleur, I., and Weimer, P., eds., Alaskan North Slope Geology: Bakersfield, California and Anchorage, Alaska, Pacific Section, Society of Economic Paleontologists and Mineralogists and Alaska Geological Society, p. 691-710.

Moore, T.E., Brosgé, W.P., Churkin, M., Jr., and Wallace, W.K., 1987, Pre-Mississippian accreted terranes of the northeastern Brooks Range, Alaska [abs], *in* Tailleur, I., and Weimer, P., eds., Alaskan North Slope Geology: Bakersfield, California and Anchorage, Alaska, Pacific Section, Society of Economic Paleontologists and Mineralogists and Alaska Geological Society, p. 711.

Moore, T.E., Wallace, W.K., Bird, K.J., Karl, S.M., Mull, C.G., and Dillon, J.T., 1994, Geology of northern Alaska, *in* Plafker, G., and Berg, H.C., eds., The Geology of Alaska: Boulder, Colorado, Geological Society of America, The Geology of North America, vol. G-1, p. 49-140.

Morgridge, D.L., and Smith, W.B., Jr., 1972, Geology and discovery of Prudhoe Bay field, eastern Arctic Slope, Alaska, *in* King, R.E., ed., Stratigraphic oil and gas fields—classification, exploration methods, and case histories, American Association of Petroleum Geologists Memoir 16, p. 489-501.

Mull, C.G., 1987, Kemik Sandstone, Arctic National Wildlife Refuge, northeastern Alaska, *in* Tailleur, I., and Weimer, P., eds., Alaskan North Slope Geology: Bakersfield, California and Anchorage, Alaska, Pacific Section, Society of Economic Paleontologists and Mineralogists and Alaska Geological Society, p. 405–431.

Mull, C.G., and Anderson, A.V., 1991, Franklinian lithotectonic domains, northeastern Brooks Range, Alaska: Alaska Division of Geological and Geophysical Surveys 91-5, 40 p.

Mull, C.G., and Decker, J., 1993, Organic-rich shale and bentonite in the Arctic Creek unit, Arctic National Wildlife Refuge: Implications for stratigraphic and structural interpretations, *in* Solie, D.N., and Tannian, F., eds., Short notes on Alaskan geology 1993, Alaska Division of Geological and Geophysical Surveys Professional Report 113, p. 41-49.

Mull, C.G., and Mangus, M.D., 1972, Itkilyariak Formation: new Mississippian formation of Endicott Group, Arctic Slope of Alaska:

Click here or on this symbol in the toolbar to return.

American Association of Petroleum Geologists Bulletin, v. 56, no. 8, p. 1364-1369.

Oldow, J.S., Ave Lallemant, H.G., Julian, F.E., and Seidensticker, C.M., 1987, Ellesmerian(?) and Brookian deformation in the Franklin Mountains, northeastern Brooks Range, Alaska, and its bearing on the origin of the Canada basin: Geology, v. 15, no. 1, p. 37-41.

O'Sullivan, P.B., Green, P.F., Bergman, S.C., Decker, J., Duddy, I.R., Gleadow, A.J.W., and Turner, D.L., 1993, Multiple phases of Tertiary uplift in the Arctic National Wildlife Refuge, Alaska, revealed by apatite fission track analysis: American Association of Petroleum Geologists Bulletin, v. 77, no. 3, p. 359-385.

Paul, L.E., Choromanski, D.R., Turner, R.F., and Flett, T.O., 1994, Geological, geochemical, and operational summary, Aurora well, OCS Y-0943-1, Beaufort Sea, Alaska: Minerals Management Service OCS Report MMS 94-0001, p. 71 p.

Plafker, G., and Berg, H.C., 1994, Overview of the geology and tectonic evolution of Alaska, *in* Plafker, G., and Berg, H.C., eds., The Geology of Alaska: Boulder, Colorado, Geological Society of America, The Geology of North America, vol. G-1, p. 989-1021.

Reed, B.L., 1968, Geology of the Lake Peters area northeastern Brooks Range, Alaska: U.S. Geological Survey Bulletin 1236, 132 p.

Reiser, H.N., Brosgé, W.P., Dutro, J.T., Jr., and Detterman, R.L., 1971, Preliminary geologic map of the Mt. Michelson quadrangle, Alaska: U.S. Geological Survey Open-File Report 71-237, scale 1:200,000.

Reiser, H.N., Brosgé, W.P., Dutro, J.T., Jr., and Detterman, R.L., 1980, Geologic map of the Demarcation Point quadrangle, Alaska: U.S. Geological Survey Miscellaneous Investigation Series Map I-1133, scale 1:250,000.

Roberts, S.B., 1991, Subsurface cross section showing coal beds in the Sagavanirktok Formation, vicinity of Prudhoe Bay, east-central North Slope, Alaska: U.S. Geological Survey Coal Investigations Map C-139A, 1 pl.

Roberts, S.B., Stricker, G.D., and Affolter, R.H., 1992, Reevaluation of coal resources in the Late Cretaceous Sagavanirktok Formation, North Slope, Alaska, *in* Bradley, D.C., and Ford, A.B., eds., Geologic studies in Alaska by the U.S. Geological Survey, 1990, U.S. Geological Survey Bulletin 1999, p. 196–203.

Robinson, M.S., Decker, J., Clough, J.G., Reifenstuhl, R.R., Dillon, J.T., Combellick, R.A., and Rawlinson, S.E., 1989, Geology of the Sadlerochit and Shublik Mountains Arctic National Wildlife Refuge, northeastern Alaska: Professional Report 100, Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys. 1 sheet, scale 1:63,360.

Seifert, W.K., Moldowan, J.M., and Jones, R.W., 1980, Application of biological marker chemistry to petroleum exploration: Proceedings of the 10th World Petroleum Congress, Bucharest, p. 425-440.

Sherwood, K.W., 1994, Stratigraphy, structure, and origin of the Franklinian, Northeast Chukchi Basin, Arctic Alaska Plate, *in* Thurston, D.K., and Fujita, K., eds., 1992 Proceedings International Conference on Arctic Margins: Anchorage, Alaska, Minerals Management Service OCS Study, MMS 94-0040, p. 245-250.

Smith, D.G., 1987, Late Paleozoic to Cenozoic Reconstructions of the Arctic, *in* Tailleur, I., and Weimer, P., eds., Alaskan North Slope Geology: Bakersfield, California and Anchorage, Alaska, Pacific Section, Society of Economic Paleontologists and Mineralogists and Alaska Geological Society, p. 785–795.

Tailleur, I.L., 1973, Probably rift origin of Canada basin, Arctic Ocean, *in* Pitcher, M.G., ed., Arctic geology, American Association of Petroleum Geologists Memoir 19, p. 526-535.

Vail, P.R., Mitchum, R.M., Jr. , Todd, R.G., Widmier, J.M., Thompson, S., III, Sangree, J.B., Bubb, J.N., and Hatlelid, W.G., 1977, Seismic stratigraphy and global changes in sea level in seismic stratigraphy, *in* Payton, C.E., ed., Seismic Stratigraphy -- applications to hydrocarbon exploration, American Association of Petroleum Geologists Memoir 26, p. 49-212.

Wahrhaftig, C., 1965, Physiographic divisions of Alaska: U.S. Geological Survey Professional Paper 482, 52 p.

Wallace, W.K., and Hanks, C.L., 1990, Structural provinces of the northeastern Brooks Range, Arctic National Wildlife Refuge, Alaska: American Association of Petroleum Geologists Bulletin, v. 74, no. 7, p. 1100-1118.

Woidneck, K., Behrman, P., Soule, C., and Wu, J., 1987, Reservoir description of the Endicott field, North Slope, Alaska, *in* Tailleur, I., and Weimer, P., eds., Alaskan North Slope Geology: Bakersfield, Calif., Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 43-59.

Ziegler, J.A., 1988, Preliminary geologic map of Franklin Mountains between forks of the Canning River, Arctic National Wildlife Refuge, northeastern Brooks Range, Alaska: Alaska Division of Geological and Geophysical Surveys 88-6b, 14 p.

USGS
science for a changing world

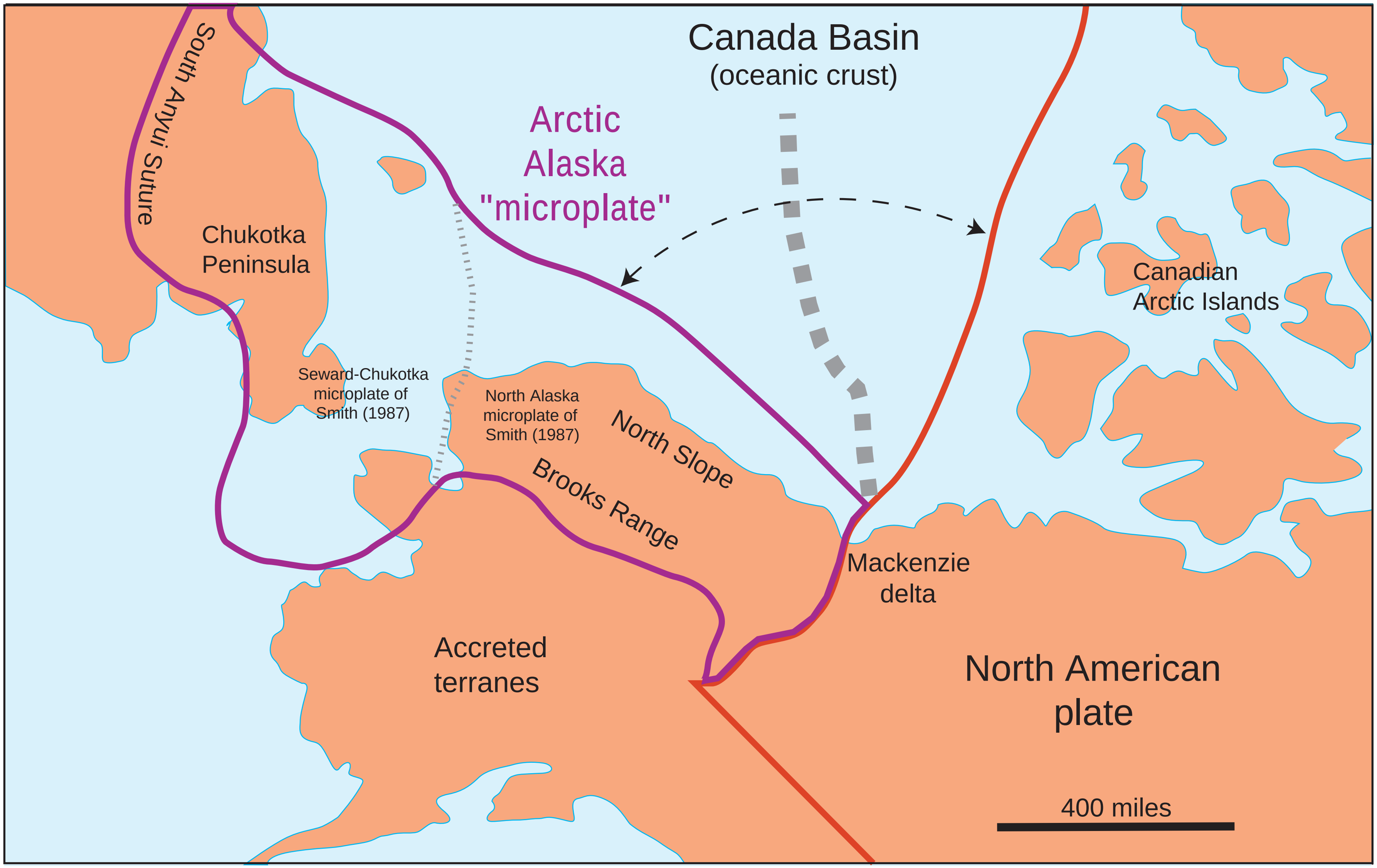


Figure GG1. Map showing major plate tectonic elements of the Alaskan arctic. Heavy dashed line in Canada basin is a gravity anomaly interpreted by Laxon and McAdoo (1994, 1998) to be an extinct seafloor spreading center about which northern Alaska, the Arctic Alaska microplate, rotated away from northern Canada during Early Cretaceous time.

Click here or on this symbol
in the toolbar to return.

USGS
science for a changing world

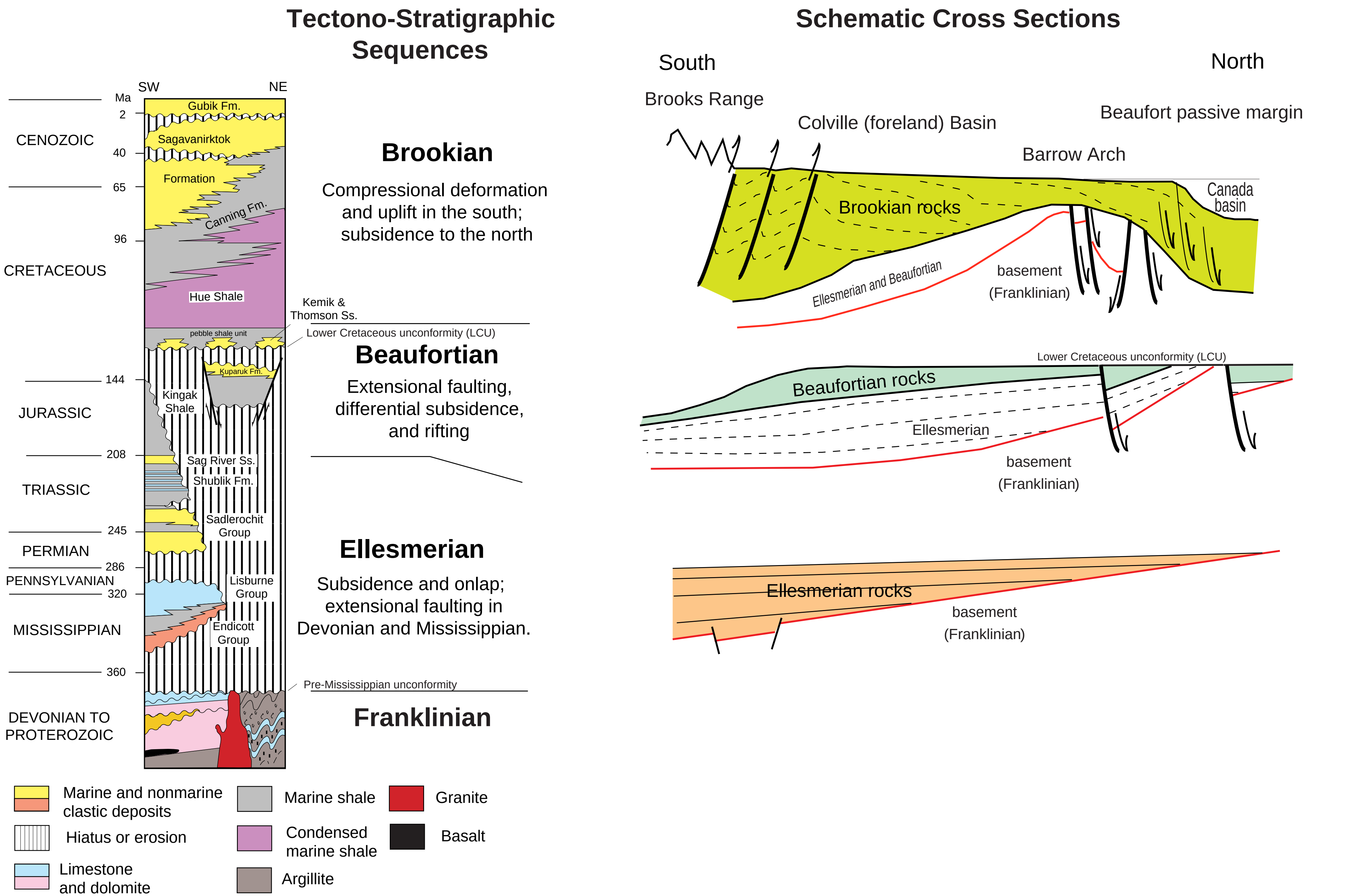
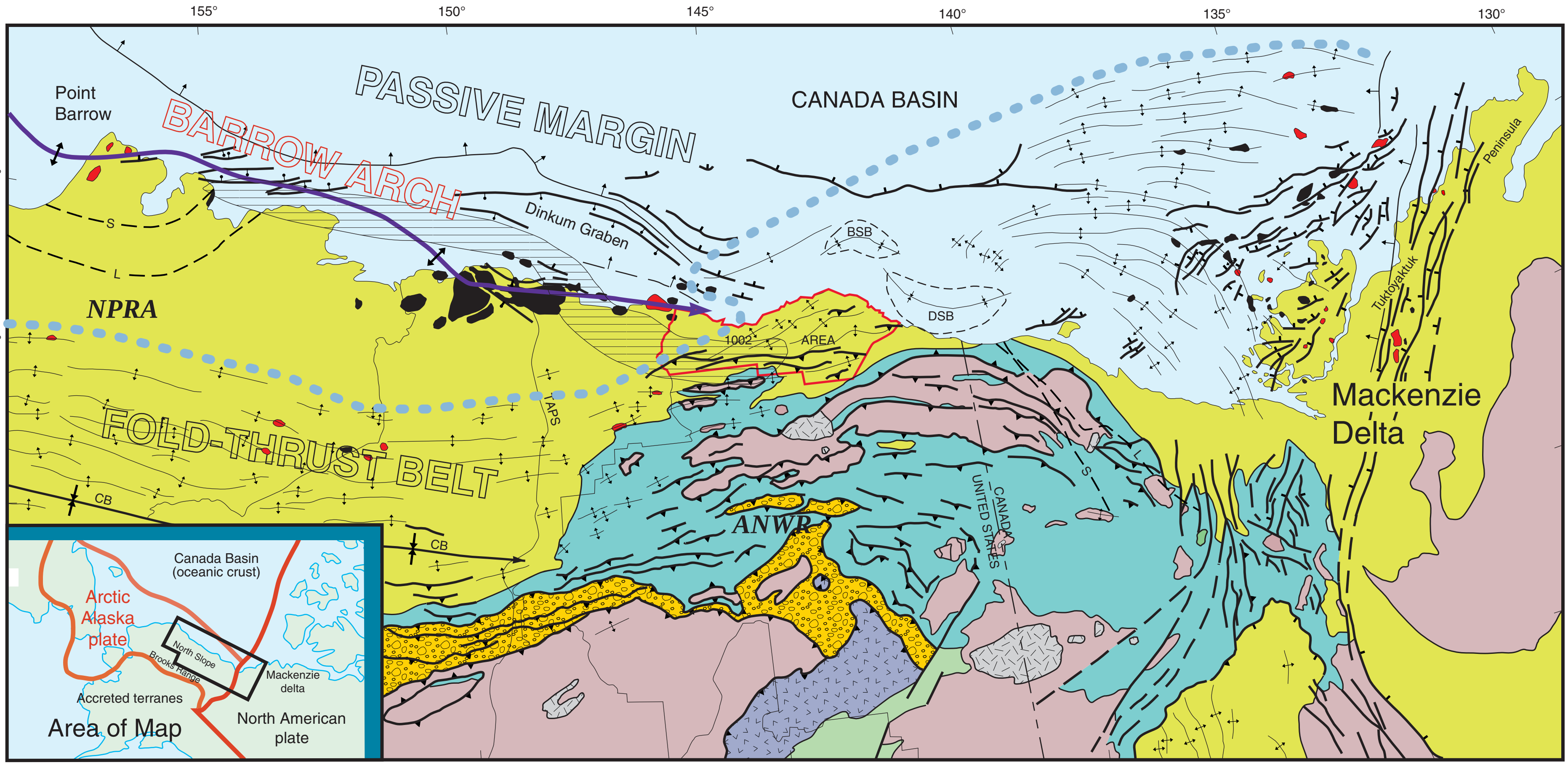


Figure GG2. Stratigraphic column for northeastern Alaska showing the tectono-stratigraphic subdivisions and schematic sections illustrating the post-Devonian geologic evolution of northern Alaska.

Click here or on this symbol in the toolbar to return.



Brookian (Cretaceous and Tertiary) rocks

Ellesmerian and Beaufortian (Middle Devonian to Early Cretaceous) rocks

Franklinian (Pre-Middle Devonian) rocks

Oil accumulation

Gas accumulation

Northern boundary of fold- and thrust-belt

Zone of truncation of Ellesmerian rocks by the Lower Cretaceous unconformity (LCU)

0 100 miles

Figure GG3. Map of part of northern Alaska and adjacent parts of Canada showing the regional tectonic setting of the ANWR 1002 area. BSB, Barter sub-basin. CB, Colville basin. DSB, Demarcation sub-basin. L, Northern onlap limit of Lisburne Group rocks. NPRA, National Petroleum Reserve, Alaska. S, Northern onlap limit of Sadlerochit Group rocks. TAPS, Trans-Alaska Pipeline System. Figure modified from Bird and Bader (1987).

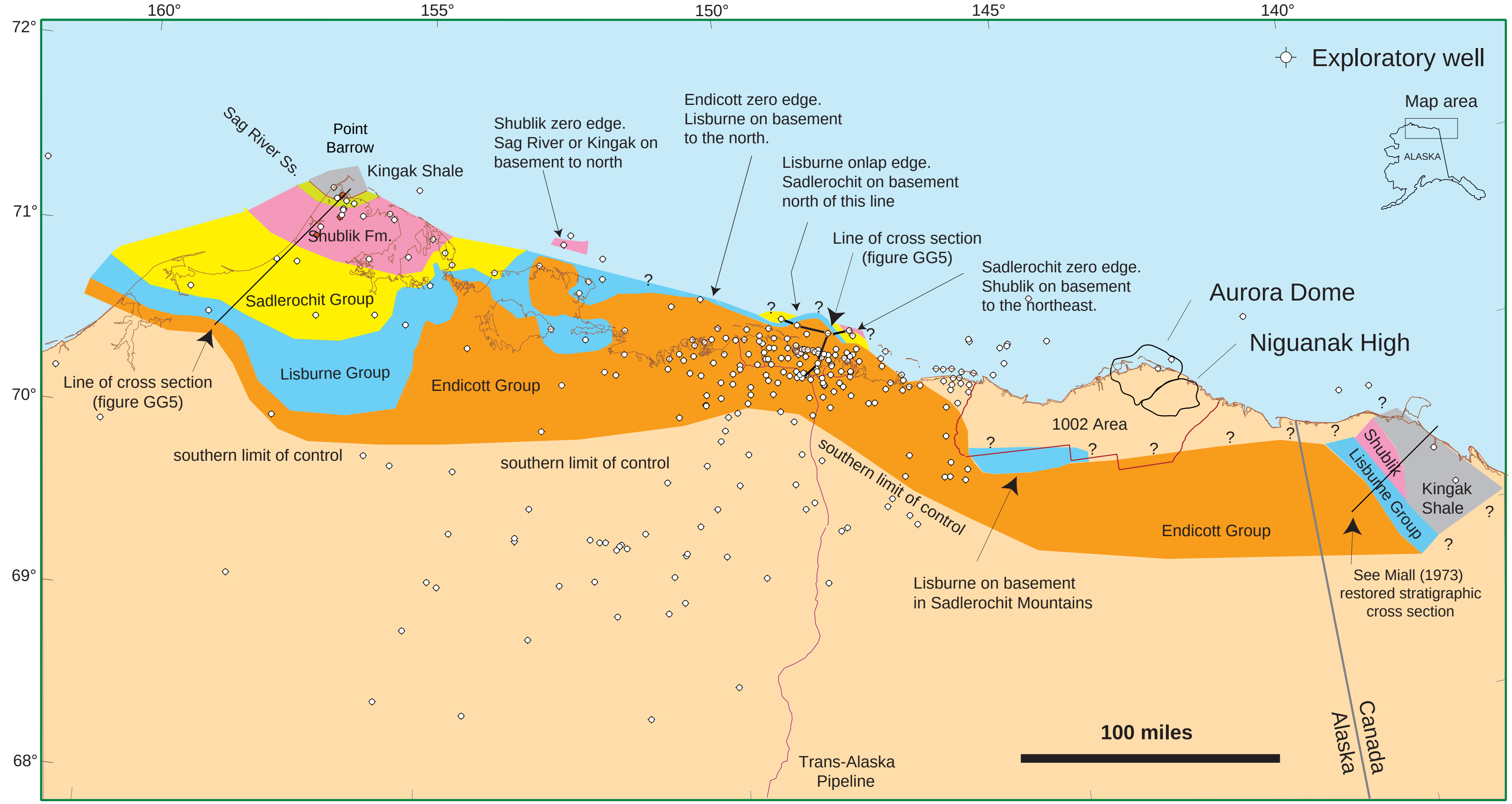


Figure GG4. Map showing the general, but irregular, northward onlap of successively younger Ellesmerian rock units onto pre-Mississippian basement rocks in northern Alaska and adjacent parts of Canada. Colors indicate which Ellesmerian rock unit directly overlies basement rocks. Stratigraphic relations in the western part of the ANWR 1002 Area and offshore westward to about 154 W. longitude are unknown because of stratigraphic section removed beneath the regional Lower Cretaceous unconformity.

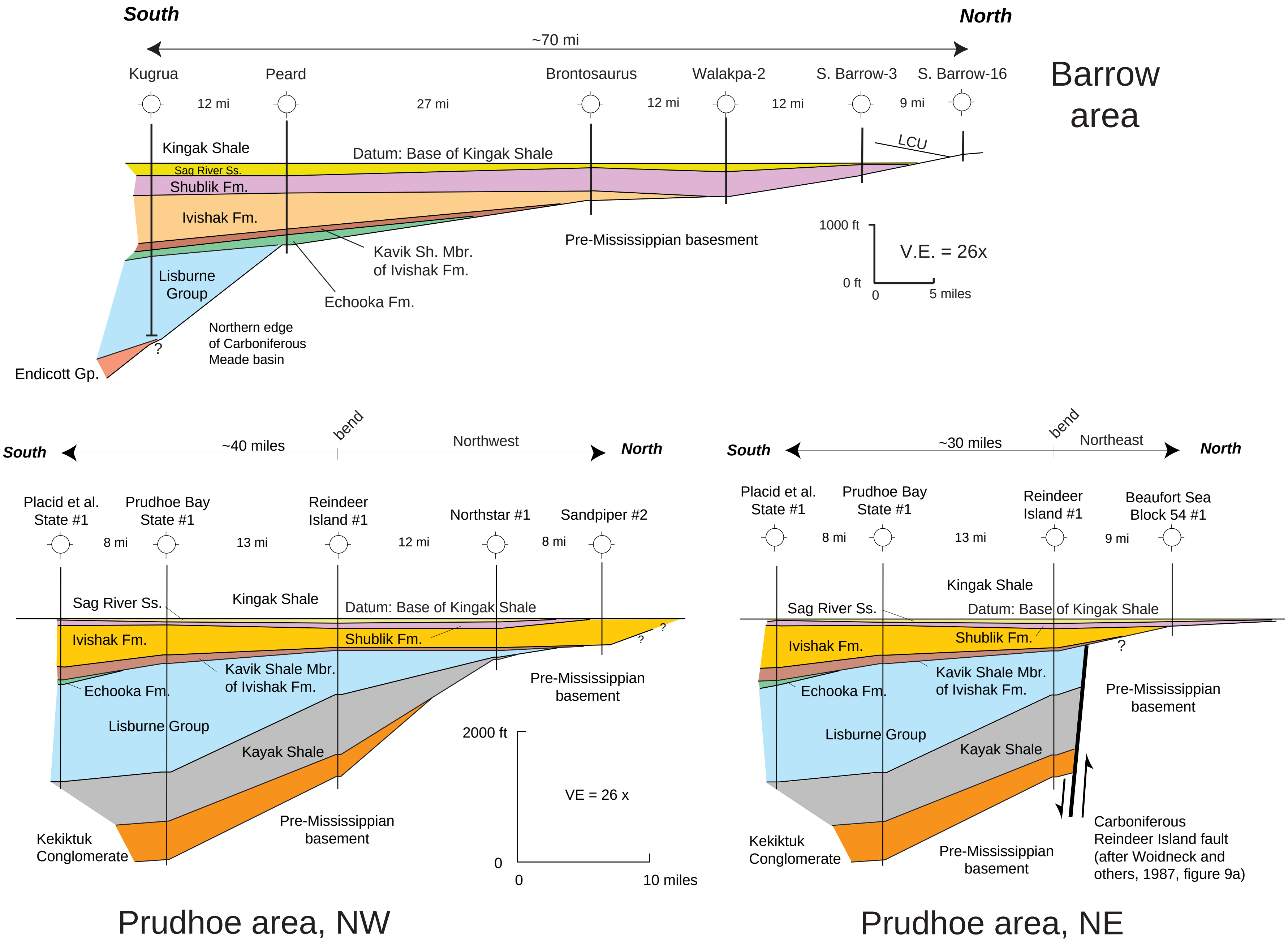


Figure GG5. Well correlation sections illustrating characteristics of Ellesmerian onlap relations in northern Alaska. See Figure GG4 for location of sections. See Miall (1973) for a similar section showing restored stratigraphic relations in northwestern Canada (Fig. GG4).

USGS
science for a changing world

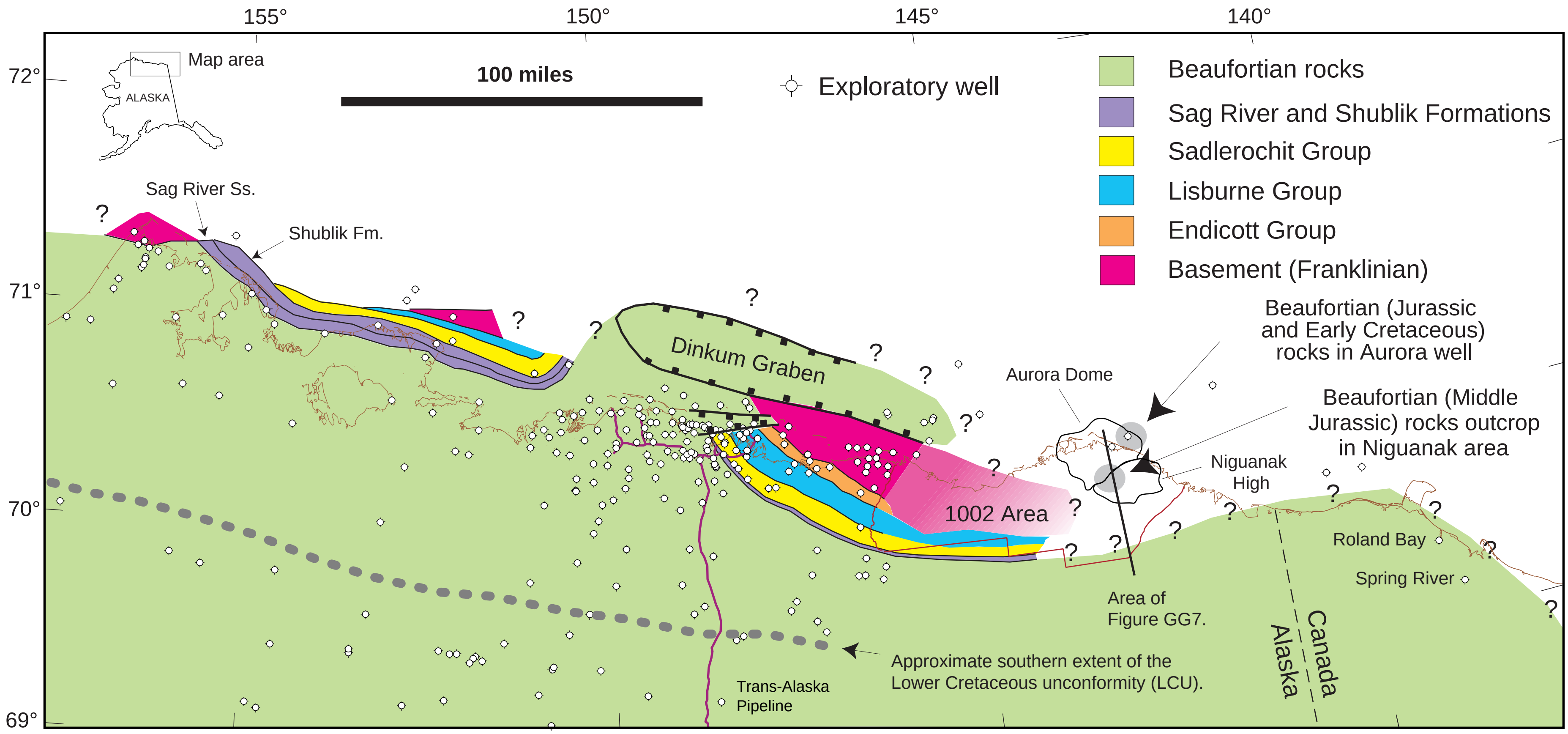
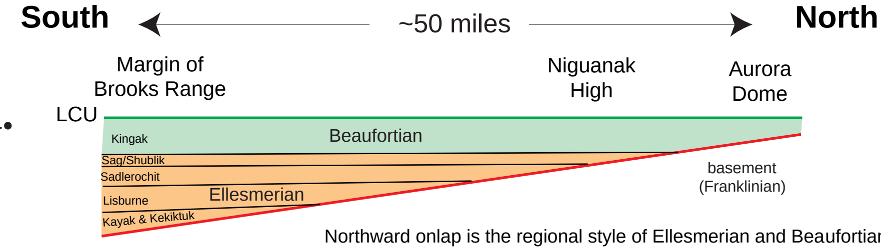


Figure GG6. Map showing rock units that subcrop beneath the regional Lower Cretaceous unconformity (LCU) in northern Alaska and adjacent parts of Canada. Colors indicate rock units that lie directly beneath the unconformity.

The Oil and Gas Resource Potential of the
Arctic National Wildlife Refuge 1002 Area, Alaska
Open File Report 98-34

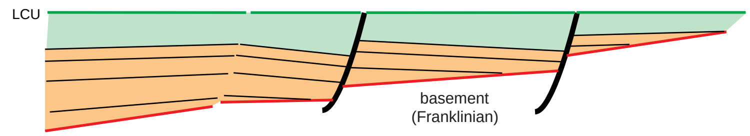
A.



ELLESMERIAN AND BEAUFORTIAN ONLAP

Northward onlap is the regional style of Ellesmerian and Beaufortian deposition. Where Carboniferous extensional faulting is present, abrupt differences are noted across faults, but only at the Endicott and Lisburne level. Regionally, rates of onlap vary significantly. Causes of variation are unknown.

B.

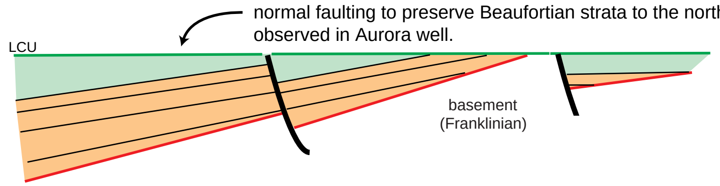


BEAUFORTIAN NORMAL FAULTING (south dipping)

Onlap relations are preserved and Beaufortian is present as northward-thickening wedges within each fault block. South-dipping normal faults would be more likely to be re-activated by later Brookian compressional deformation than north-dipping normal faults.

C.

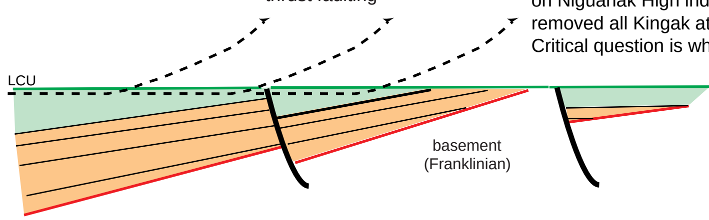
Truncation by the LCU in southern 1002-area structures requires normal faulting to preserve Beaufortian strata to the north as observed in Aurora well.



BEAUFORTIAN NORMAL FAULTING (north dipping)

D.

Outcrop of allochthonous mid-Jurassic (Kingak) strata on Niguanak High indicates that LCU-truncation had not removed all Kingak at the site of its original deposition. Critical question is where does the outcrop of Kingak restore to?



BROOKIAN COMPRESSIONAL DEFORMATION

Truncation by the LCU in southern 1002 area is incompatible with the presence of Beaufortian strata in the Aurora well without normal faulting. With a low rate of northward Ellesmerian onlap, one could have a nearly complete Ellesmerian section at Aurora Dome; with a high rate, one could have only Beaufortian strata. Carboniferous normal faulting would not affect the post-Lisburne Ellesmerian section and the analysis above would still apply to Sadlerochit and younger rocks.

Figure GG7. Regional stratigraphic and tectonic factors that bear on the distribution of Ellesmerian and Beaufortian rock units in the Niguanak High and Aurora Dome areas, notheastern 1002 area. Aurora well, located on the Aurora Dome, confirms the presence of Beaufortian strata at this location. See figure GG6 for location.

Click here or on this symbol
in the toolbar to return.

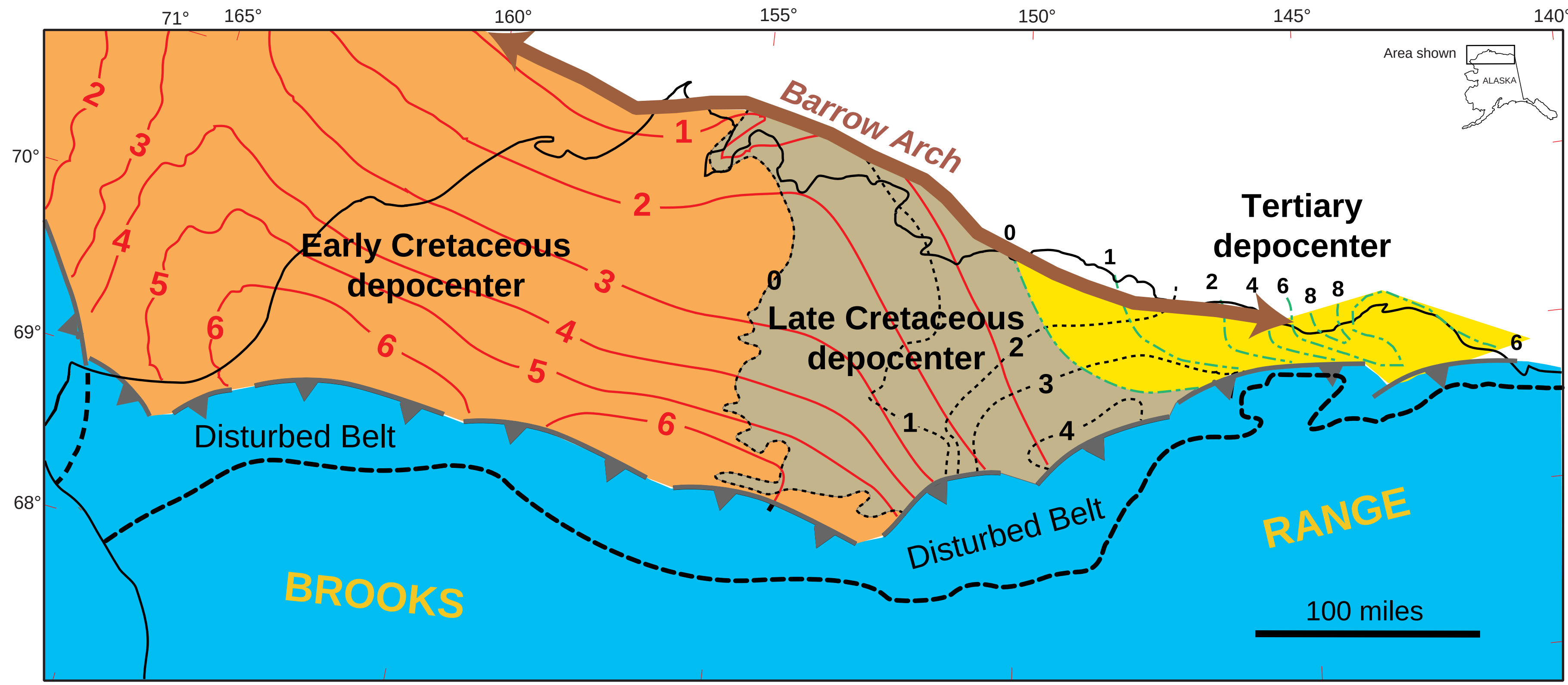
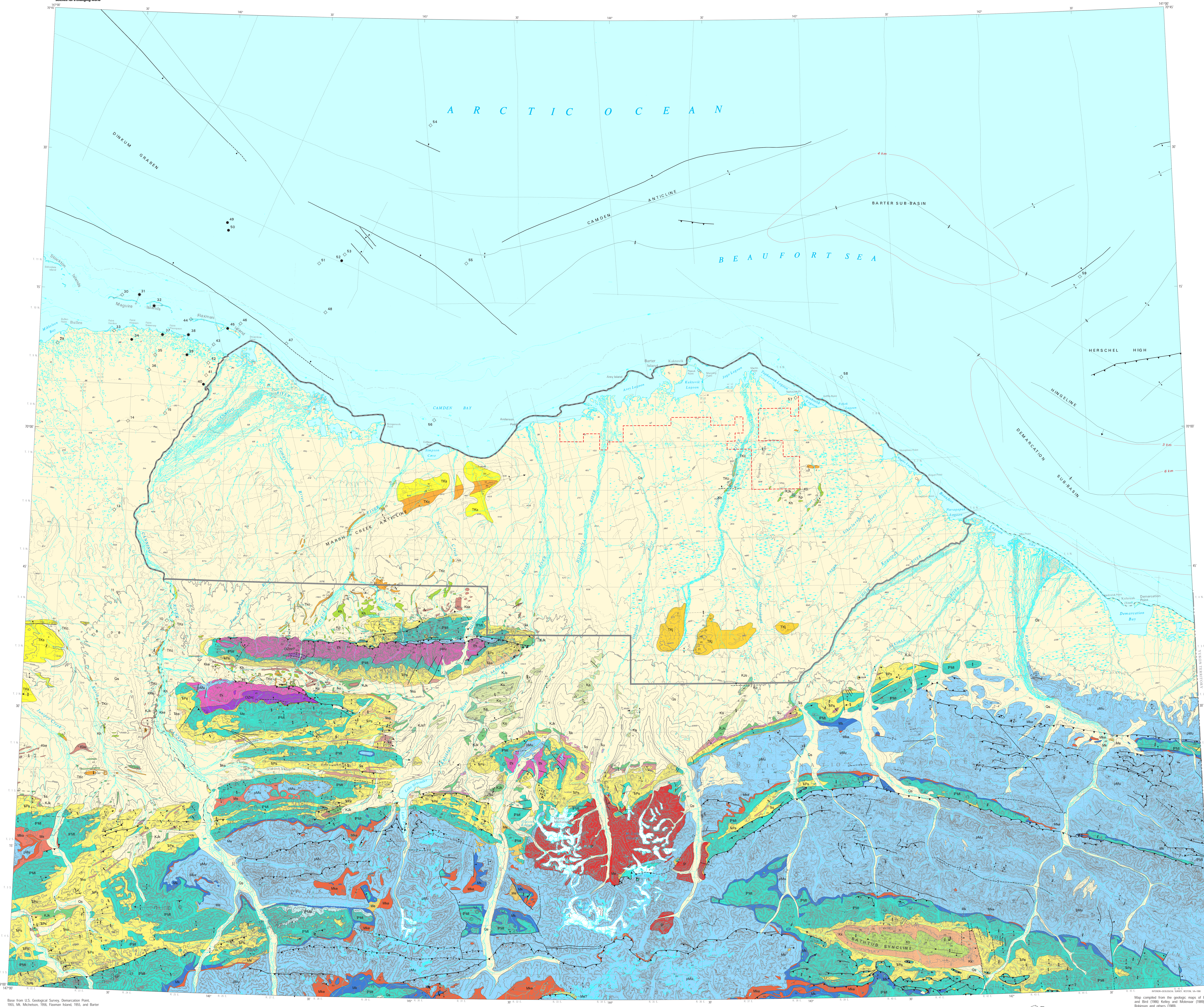


Figure GG8. Map illustrating the longitudinal west-to-east-filling of the Colville (foreland) basin. Isopachs (in km) showing present-day thicknesses reveal a pattern of successive eastward-shifting depocenter development through time. The Barrow Arch, a buried rift shoulder, marks the boundary between the Colville basin to the south and the Beaufort (passive) margin to the north.

USGS
science for a changing world

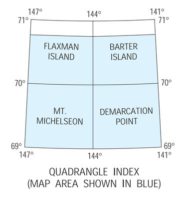
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

OPEN-FILE REPORT 98-34
PLATE GG1 (SHEET 1 OF 2)



Base from U.S. Geological Survey, Demarcation Point, 1955, Mt. Michelson, 1956, Flaxman Island, 1955, and Barter Island, 1959.

Universal Transverse Mercator Projection



QUADRANGLE INDEX
(MAP AREA SHOWN IN BLUE)

SCALE 1:250 000

CONTOUR INTERVAL 200 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

MAP LOCATION

Map compiled from the geologic maps of Bader and Bird (1986) Kelley and Molenaar (1989) and Robinson and others (1989).

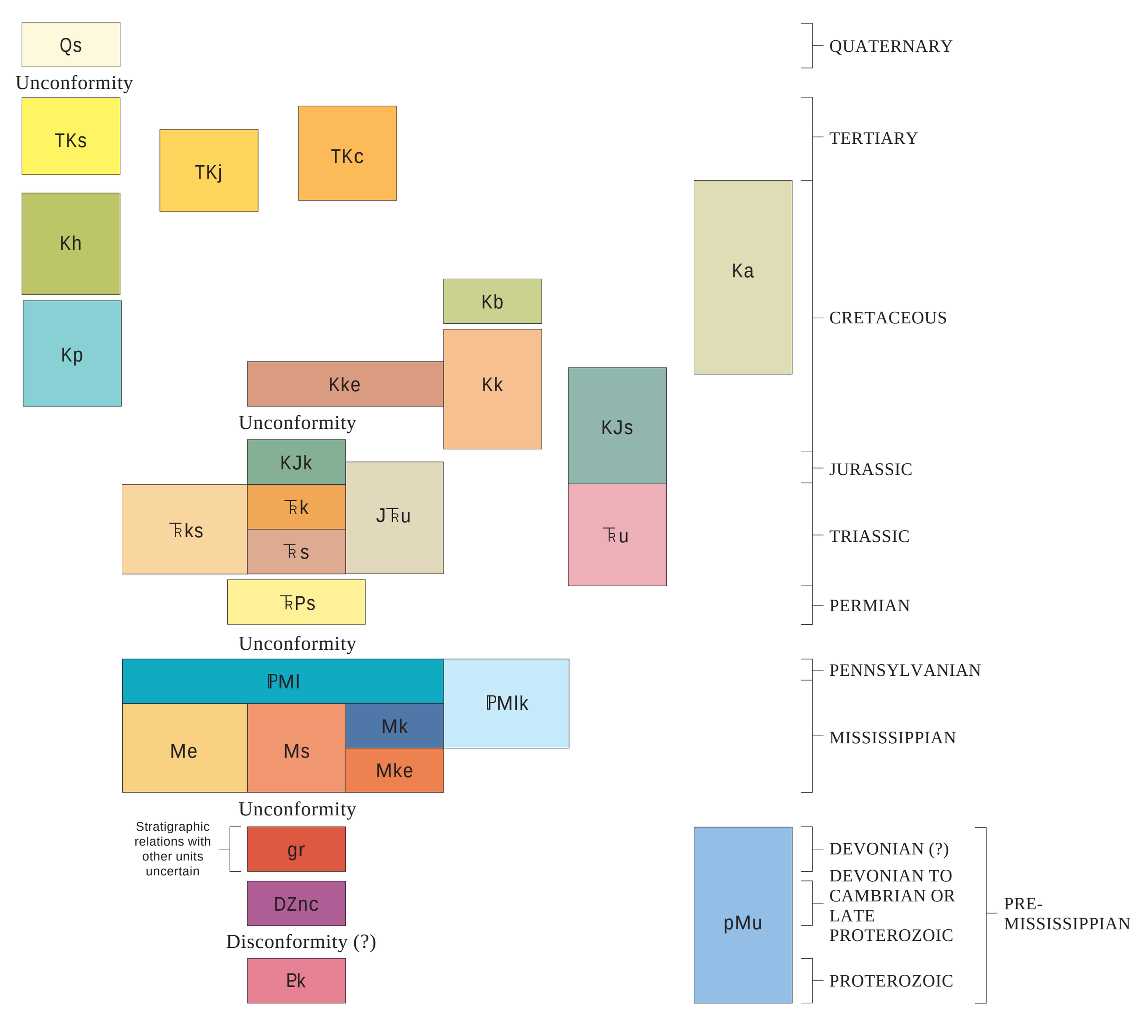
GEOLOGIC MAP OF THE DEMARCATION POINT, MT. MICHELSON, FLAXMAN ISLAND, AND BARTER ISLAND QUADRANGLES, NORTHEASTERN ALASKA

Digital compilation by
Heather A. Marshall, Michael S. Sinor, Kevin R. Evans, and Kenneth J. Bird

1998

Click here or on this symbol in the toolbar to return.

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

Description of map units modified from Reiser and others (1971, 1980), and stratigraphic units of Molenaar and others (1987). Includes units from unpublished mapping by C. M. Molenaar, A. R. Kirk, L. B. Magoon, and A. C. Huffman (1980, 1982-85).

Qs **Surficial deposits (Quaternary)-**Alluvium, beach deposits, colluvium, alluvial fans, terrace deposits, marine terrace deposits, glacial deposits, glacial fluvial deposits, and landslides. See maps by Reiser and others (1971, 1980) for descriptions and areal distribution of these units. In order to emphasize petroleum prospective rocks in this area, these rocks, which have been mapped in considerable detail by Reiser and others (1971, 1974, 1980), have been shown as single map unit.

TKs **Sagavanirktok Formation (Tertiary and Cretaceous)-**Poorly consolidated gray siltstone, mudstone, sandstone, and lesser amounts of conglomerate. As much as 1,500 m thick on north flank of Marsh Creek anticline and 2,300 m thick in wells near mouth of Canning River. Nonmarine and shallow marine deposits. Some shallow marine deposits are oil and gas bearing in the Hammerhead and Kuvlum wells offshore from the Point Thomson area.

TKc **Canning Formation (Tertiary and Cretaceous)-**Gray shale and siltstone containing interbeds of mostly thin-bedded, very fine to fine-grained lithic sandstone (turbidites). 1,500 to 1,800 m thick in wells west of Canning River. Common 'floating' chert pebbles in Tertiary marine shales. Deep-water marine deposits. Some turbidities are oil and gas bearing in wells near mouth of Canning river. Age is Cretaceous and early Tertiary.

TKj **Jago River Formation (Tertiary and Cretaceous)-**Well-indurated thick-bedded, fine- to coarse-grained, lithic sandstone, conglomerate, and minor amounts of coal and carbonaceous shale. Nonmarine and minor shallow marine deposits. Approximately 3,000 m thick in type section along Igilatvik (Sabbath) Creek. Age is latest Cretaceous and earliest Tertiary (Buckingham, 1987).

Kh **Hue Shale (Cretaceous)-**Dark-gray, bentonitic shale in which fine-grained pyroclastic rock fragments weather yellow, greenish gray, and in areas surrounding Sadlerochit Mountains, bright red. Unit is 220 m thick at Ignek Valley. The 40-m-thick, gamma-ray zone at base is Albian (?) in age. Rich oil-prone source rocks in lower part (Albian? to Santonian). As mapped in Ignek Valley, includes some interbedded shale and turbidite sandstone assigned to the Canning Formation. Deep-water marine deposits. Age is Early and Late Cretaceous in mapped area.

Ka **Arctic Creek facies (Cretaceous)-**Complexly folded, dark gray, and in part bentonitic shale and thin- to thick-bedded, very fine to fine-grained lithic sandstone (turbidities). Deep-water marine deposits. Probably Albian and younger in age.

Kp **Pebble shale unit (Cretaceous)-**Nonbentonitic shale containing matrix-supported, well-rounded, frosted quartz sand grains and common to rare chert and quartzite pebbles; about 100 m thick. Marine deposits. Age is Early Cretaceous (upper Neocomian).

Kb **Bathtub Graywacke (Cretaceous)-**Greenish-gray, mostly thick-bedded, fine-grained lithic sandstone (graywacke). Contains common bimodal medium to coarse sand grains and minor amounts of conglomerate. Sandstone units are separated by thick to thin, dark-gray, silty shale units. Measured unit is 750+ m thick (top not exposed). Exposed only at Bathtub Ridge in T. 4 S., Rs. 39-41E. Deep-water marine deposits. Age is Early Cretaceous, possibly as young as Albian.

Kk **Kongakut Formation (Cretaceous)-**Restricted on this map to exposures in Bathtub Ridge area. Lower part is mostly dark-gray, locally fossiliferous (Valanginian) shale (clay shale member or correlative with upper part of Kingak Shale), which is overlain by thin discontinuous, very fine grained, quartzose sandstone beds (Kemik Sandstone Member), which in turn is overlain by manganiferous shale containing rare chert and quartzite pebbles (pebble shale member). Upper part is dark-gray silty shale in which lower half is more resistant to erosion (siltstone member). Part below pebble shale member is 350-400 m thick and is part of the northerly derived Ellesmerian sequence. Part above pebble shale member is about 700 m thick, is part of the southerly derived Brookian sequence and is not recognized in foothills and coastal plain. Age is Early Cretaceous.

Kke **Kemik Sandstone (Cretaceous)-**Resistant, ridge-forming, medium- to light-gray, very fine to fine-grained quartzose sandstone containing tripolitic chert grains. As much as 30 m thick. North of Sadlerochit Mountains in T. 4 N., areas mapped as Kemik Sandstone consist of fault repetitions involving the Kemik and parts of adjacent pebble shale unit and Kingak Shale (Kelley and Molenaar, 1988). Its absence in outcrops generally east of Sadlerochit River and north of Bathtub Ridge is thought to result from nondeposition. Shallow marine deposits. In subsurface, near mouth of Canning River, the stratigraphically equivalent, informally designated Thomson sand is present in some wells and is the main gas- and oil-bearing reservoir of Point Thomson field. Age is Early Cretaceous (Hauterivian).

KJs **Shale (Cretaceous and Jurassic)-**Dark-gray. Lower part is the Jurassic and Lower Cretaceous Kingak Shale and upper part, which contains rounded, frosted quartz sand grains and rare chert and quartzite pebbles, is the informally designated pebble shale unit. These two units are not easily distinguished when the Kemik Sandstone, which separates them, is missing. As much as 550 m thick. Marine deposits. Age is Jurassic and earliest Cretaceous.

KJk **Kingak Shale (Cretaceous and Jurassic)-**Dark-gray, nonbentonitic shale containing common ironstone concretions. As much as 450 m thick. Marine deposits. Age is Jurassic and Early Cretaceous (early Neocomian) in this area.

JTRu **Kingak Shale (part) (Cretaceous and Jurassic), Shublik Formation (Jurassic), and Karen Creek Sandstone (Triassic), undivided-**As much as 650 m thick.

TRk **Karen Creek Sandstone (Triassic)-**Dark-gray, very fine grained, quartzitic sandstone and siltstone. Locally calcareous or dolomitic. Phosphatic nodules common. Unit absent in Bathtub Ridge area because of possible structural complexities. As much as 38 m thick. Age is Late Triassic.

TRs **Shublik Formation (Triassic)-**Interbedded black shale, black calcareous siltstone, and black limestone. Abundantly fossiliferous. Rich oil-prone source rock, but overmature in outcrop belt. Unit mostly absent in Bathtub Ridge area because of possible structural complexities. As much as 140 m thick. The Shublik is gas bearing in Kemik field and oil and gas bearing in Prudhoe Bay field.

TRks **Karen Creek Sandstone and Shublik Formation, undivided (Triassic)-**As much as 170 m thick.

TRu **Sedimentary rocks, undivided (Triassic)**

TRPs **Sadlerochit Group, undivided (Triassic and Permian)-**Composed of the Ivishak and Echooka Formations. These formations are readily recognized in field (e.g., Robinson and others, 1989) but are mapped here as Sadlerochit Group, undivided owing to limits of scale and field control: Ivishak Formation, (Lower Triassic) consists of three lithologic units. Upper unit, Fire Creek Siltstone Member, medium-dark-gray, thin bedded to massive, commonly laminated siliceous siltstone, minor silty shale, and argillaceous sandstone. Contains middle Early Triassic (Smithian) fossils. As much as 135 m thick. Middle unit, Ledge Sandstone Member, clean, light-gray, massive sandstone. Weathers red to reddish brown. Locally conglomeratic. As much as 134 m thick. This is main oil-producing reservoir in Prudhoe Bay field. It is gas bearing in Kavik field. Lower unit, Kavik Member, dark-colored, laminated to thin bedded silty shale and siltstone with minor argillaceous sandstone beds. Fossils of Early Triassic (Griesbachian) age collected from this unit (Detterman and others, 1975). As much as 200 m thick. Echooka Formation (Upper and Lower Permian) consists of two lithologic units. Upper unit, Ikiakpaurak Member, red-weathering resistant ferruginous orthoquartzite, quartzitic sandstone, and siltstone. Contains Late Permian (Guadalupian) fossils at base of upper unit, probably equivalent in age to top of lower unit, south of Demarcation Point quadrangle. Thickness of upper unit 50 to 110 m; thins to north. Lower unit, Joe Creek Member, almost entirely restricted to extreme southern part of Demarcation Point quadrangle. Best exposed in ridge north of Joe Creek, 3 km south of map area. Top of lower unit is thin- to medium-bedded quartzose calcarenite and limestone that includes brachiopod coquinas. Thickness approximately 20 m. Top of lower unit underlain by about 25 m of medium- to thick-bedded chert and siliceous siltstone. Base of lower unit is dusky yellow, thin-bedded limy mudstone and calcareous siltstone. Thickness approximately 50 m. Lower unit yields Early and Late Permian (Wolfcampian to Guadalupian) fossils. Total thickness for lower unit about 100 m; thins rapidly to northwest (Detterman and others, 1975).

PMl **Lisburne Group (Pennsylvanian and Mississippian)-**Upper unit (Wahoo Limestone) fine-grained limestone and oolitic limestone, some glauconite and minor dolomite. Weathers characteristic light gray to yellowish cream. Contains megafauna and microfauna of Morrowan and Atokan (Early and Middle Pennsylvanian) age. Thickness of upper unit variable owing to erosion, 0 to about 375 m. Lower unit (Alapah Limestone) gray bioclastic limestone, dolomite, and black chert. Weathers gray to dark gray. Contains megafauna and microfauna of Meramecian and Chesterian (Late Mississippian) age. Thickness of lower unit 275 to 655 m. In extreme south-central part of Demarcation Point quadrangle, unit includes unmapped areas of Joe Creek Member of Echooka Formation (Lower Permian). In southern part of Mt. Michelson quadrangle, lower part of unit is shaly and basal contact is obscure. Dolomite reservoirs in the Lisburne are oil and gas bearing in Prudhoe Bay field.

PMlk **Lisburne Group (Pennsylvanian and Mississippian) and Kayak Shale (Mississippian), undivided**

Me **Endicott Group, undivided (Mississippian)-**In this area consists of Kayak Shale, Itkilyariak Formation, Kekiktuk Conglomerate, and unnamed siltstone. Locally not differentiated from Lisburne Group. As much as 380 m thick. The Kekiktuk is oil and gas bearing in Endicott field. Locally divided into:

Ms **Siltstone-**Dark-gray phyllitic siltstone with laminae and knots of red-weathering ferruginous siltstone. Locally contains anthracite. Distinguished only in southwestern part of Mt. Michelson quadrangle.

Mk **Kayak Shale-**Dark gray to black. Locally interbedded with gray- to red-weathering limestone. Locally contains anthracite at base. Includes unmapped area of Itkilyariak (?) Formation in secs. 2 and 12, T. 1 S., R. 39 E. and in secs 13 and 16, T. 1 N., R. 44 E. As much as 250 m thick.

Mke **Kekiktuk Conglomerate-**Resistant massive quartzite and granule to cobble conglomerate. Quartzite is generally light gray, clean, and weathers light gray; locally iron stained. Conglomerate is interbedded and lenticular within quartzite; clasts predominantly of quartz and chert. Locally contains anthracite. Thickness variable, 0-130 m. The Kekiktuk is oil and gas bearing in Endicott field.

gr **Granite (Devonian?)-**Granitic rocks, predominantly quartz monzonite. Muscovite and biotite common accessory minerals within main pluton (Okpilak batholith) and in stock (Jago stock) in T. 2 S., R. 35 E. Hornblende abundant but restricted to small stock at head of Jago River in Tps. 3 and 4 S., R. 35 E. Potassium-argon age of 431 ± 13 Ma on hornblende. Lead-alpha ages of 310 ± 25 and 405 ± 45 Ma on zircon and potassium- argon ages of 125 and 128 Ma on biotite from Okpilak batholith (Sable, 1965, 1977). Alteration of Mississippian (?) rocks in contact with granitic rocks indicate post-Mississippian (Cretaceous?) remobilization.

DZnc **Nanook Limestone and Mount Copleston Limestone, undivided (Devonian to Cambrian or Late Proterozoic)-**The Mount Copleston Limestone (Blodgett and others, 1992) consists of thin- to medium-bedded dark gray limestone as much as 72 m thick. Limited to the Shublik Mountains. Formerly, these rocks were included in the uppermost part of the Nanook Limestone. Unconformably overlain by the Kekiktuk Conglomerate. Disconformably overlies Nanook Limestone. Age is Early Devonian. Nanook Limestone consists of thin- to thick-bedded limestone, silicified limestone, and vuggy dolomite with minor amounts of siltstone and shale. More than 1,220 m thick (Clough and others, 1990). Unconformably overlain by either Mount Copleston Limestone or Ellesmerian sequence. Age is Ordovician to Cambrian or Late Proterozoic.

Pk **Katakturuk Dolomite (Proterozoic)-**Predominantly dolomite with minor amounts of nodular chert. Dolomite is crossbedded, oolitic, stromatolitic, pisolitic, and vuggy. Silty shale in lower part. More than 1,035 m thick. Lies disconformably (?) beneath Nanook Limestone and conformably (?) above unnamed, white, vuggy dolomite. Age is Proterozoic based on stratigraphic relations with overlying Nanook Limestone (Blodgett and others, 1986)

pMu **Igneous, metamorphic, and sedimentary rocks, undivided (pre-Mississippian)-**Greater than 3,000 m thick. In order to emphasize the petroleum prospective rocks in the area, these rocks, which have been mapped in considerable detail by Reiser and others, (1970, 1971, 1974, 1980), have been shown as a single map unit.

Contact-Dashed where approximately located; dotted where concealed; queried where uncertain

Fault-Dashed where approximately located; dotted where concealed; queried where uncertain

Thrust fault-Dashed where approximately located; dotted where concealed; queried where uncertain

High-angle fault-Ball and bar on downthrown side; dashed where approximately located; dotted where concealed; queried where uncertain

Anticline-Dashed where approximately located; dotted where concealed

Overturned anticline-Dashed where approximately located; dotted where concealed; showing direction of dip of limbs

Syncline-Dashed where approximately located; dotted where concealed

Overturned syncline-Dashed where approximately located; dotted where concealed; showing direction of dip of limbs

Strike and dip of strata-Arrow indicates aerial or distant evaluation

20 70 **Inclined**

70 20 **Overturned**

Horizontal

Vertical

3 km **Depth to Eocene unconformity-**Depth in kilometers; from Grantz and May, 1983

Tectonic hingeline-Arrow on downwarped side

Seismic line

19 **Oil well-**Showing surface hole location (SHL) and bottom hole location (BHL)

20 **Oil and gas well-**Number refers to figure 1

21 **Gas well**

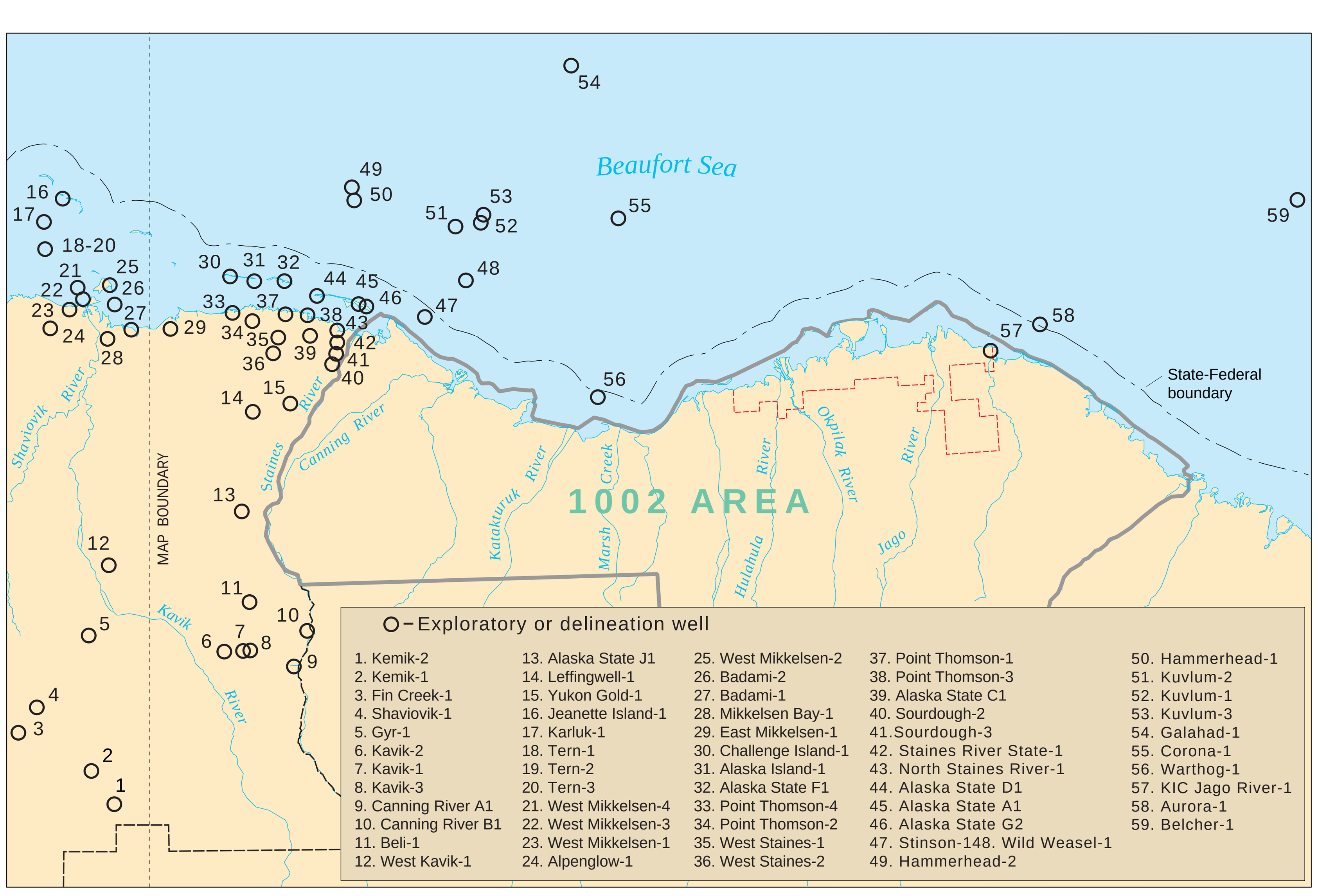
22 **Dry or unknown well**

Oil seep, oil-stained rock, or oil-soaked tundra

Boundary of the Arctic National Wildlife Refuge

Boundary of the Section 1002 area of the Alaska National Interest Lands Conservation Act (ANILCA); includes all lagoons within boundary

Boundary of the Kaktovik Inupiat Corporation; includes all islands within boundary



Index map showing location of wells near the Arctic National Wildlife Refuge 1002 area.

REFERENCES CITED

Alaska Department of Natural Resources, 1983, Geothermal resources of Alaska: Alaska E Series Map, scale 1:2,500,000, 1 sheet.

Bader, J.W., and Bird, K.J. 1986, Geologic Map of the Demarcation Point, Mt. Michelson, Flaxman Island, and Barter Island Quadrangles: U.S. Geological Survey Miscellaneous Investigations Series Map I-1791, scale 1:250,000, 1 sheet.

Blodgett, R.B., Clough, J.G., Dutro, J.T., Jr., Ormiston, A.R., Palmer, A.R., and Taylor, M.E., 1986. Age revisions for the Nanook Limestone and Katakturuk Dolomite, northeastern Brooks Range, Alaska, *in* Bartsch-Winkler, Susan, and Reed, K.M., eds., Geologic studies in Alaska by the U.S. Geological Survey during 1985: U.S. Geological Survey Circular 978, p. 5-10.

Blodgett, R.B., Clough, J.G., Harris, A.G., and Robinson, M.S., 1992, The Mount Copleston Limestone, a new Lower Devonian formation in the Shublik Mountains, northeastern Brooks Range, Alaska, *in* Bradley, D.C., and Ford, A.B., eds., Geologic studies in Alaska by the U.S. Geological Survey, 1990: U.S. Geological Survey Bulletin 1999, p. 3-7.

Buckingham, M.L., 1987, Fluvio-deltaic sedimentation patterns of the upper Cretaceous to lower Tertiary Jago River Formation, Arctic National Wildlife Refuge (ANWR), northeastern Alaska, *in* Tailleur, I., and Weimer, P., eds., Alaskan North Slope Geology: Bakersfield, California and Anchorage, Alaska, Pacific Section, Society of Economic Paleontologists and Mineralogists and Alaska Geological Society, p. 529-540.

Clough, J.G., Robinson, M.S., Pessel, G.H., Imm, T.A., Blodgett, R.B., Harris, A.G., Bergman, S.C., and Foland, K.A., 1990, Geology and age of Franklinian and older rocks in the Sadlerochit and Shublik Mountains, Arctic National Wildlife Refuge, Alaska [abs.]: Geological Association of Canada and Mineralogical Association of Canada Annual Meeting, Program with Abstracts, v. 15, p. A25.

Detterman, R.L., Reiser, H.N., Brosge', W.P., and Dutro, J.T, Jr., 1975, Post-Carboniferous stratigraphy, northeastern Alaska: U.S. Geological Survey Professional Paper 886, 46 p.

Ebbley, Norman, Jr., 1944, Oil seepages on the Alaskan Arctic slope: Mining and Metallurgy, v. 25, p. 415-419.

Grantz, Arthur, Dinter, D.A., and Biswas,N.N.,1983, Map, cross sections, and chart showing late Quaternary faults, folds, and earthquake epicenters on the Alaskan Beaufort shelf: U.S. Geological Survey Miscellaneous Investigations Series Map I-1182-C, scale 1:500,000, 3 sheets.

Grantz, Arthur, and May, S.D., 1983, Rifting history and structural development of the continental margin north of Alaska, *in* Watkins, J.S., and Drake, C.L., eds., Studies in continental margin geology: American Association of Petroleum Geologists Memoir 34, p. 77-100.

Hanna, G.D., 1963, Oil seepages on the Arctic coastal plain, Alaska: Occasional Papers of the California Academy of Sciences, no. 38, 18 p.

Kelley, J.S., and Molenaar, C.M., 1989, Geologic map of the north flank of the Sadlerochit Mountains, Mount Michelson C-1, C-2, C-3 quadrangles, northeastern Alaska: U.S. Geological Survey Open-File Report 89-11, scale 1:63,360, 1 sheet.

Leffingwell, E. de K., 1919, The Canning River region, northern Alaska: U.S. Geological Survey Professional Paper 109, 251 p.

MacNeil, F.S., 1957, Cenozoic megafossils of northern Alaska, *in* Shorter contributions to General geology 1956: U.S. Geological Survey Professional Paper 294-C, p. 99-123.

Molenaar, C.M., Bird, K.J., and Kirk, A.R., 1987, Cretaceous and Tertiary stratigraphy of northeastern Alaska, *in* Tailleur, I.L., and Weimer, Paul, eds., Alaska North Slope Geology: Pacific Section Society of Economic Paleontologists and Mineralogists, p. 513- 528.

Reiser, H.N., Dutro, J.T., Jr., Brosge', W.P., Armstrong, A.K., and Detterman, R.L., 1970, Progress map, geology of the Sadlerochit and Shublik Mountains, Mt. Michelson C-1, C-2, C-3 and C-4 quadrangles, Alaska: U.S. Geological Survey Open-File Report 70-273, scale 1:63,360, 5 sheets.

Reiser, H.N., Brosge', W.P., Dutro, J.T., Jr., and Detterman, R.L., 1971, Preliminary geologic map, Mt. Michelson quadrangle, Alaska: U.S. Geological Survey Open-File Report 70-273, scale 1:200,000 2 sheets.

--------1974, Preliminary geologic map of the Demarcation Point quadrangle, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-610, scale 1:200,000, 1 sheet.

--------1980, Geologic map of the Demarcation Point quadrangle, Alaska: U.S. Geological Survey Miscellaneous Investigations Series Map I-1133, scale 1:250,000, 1 sheet.

Robinson, M.S., Decker, J., Clough, J.G., Reifenstuhl, R.R., Dillon, J.T., Combellick, R.A., and Rawlinson, S.E., 1989, Geology of the Sadlerochit and Shublik Mountains Arctic National Wildlife Refuge, northeastern Alaska: Professional Report 100, Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys, scale 1:63,360, 1 sheet.

Sable, E.G., 1965, Geology of the Romanzof Mountains, Brooks Range, northeastern Alaska: U.S. Geological Survey Open-File Report 65-141, 218 p.

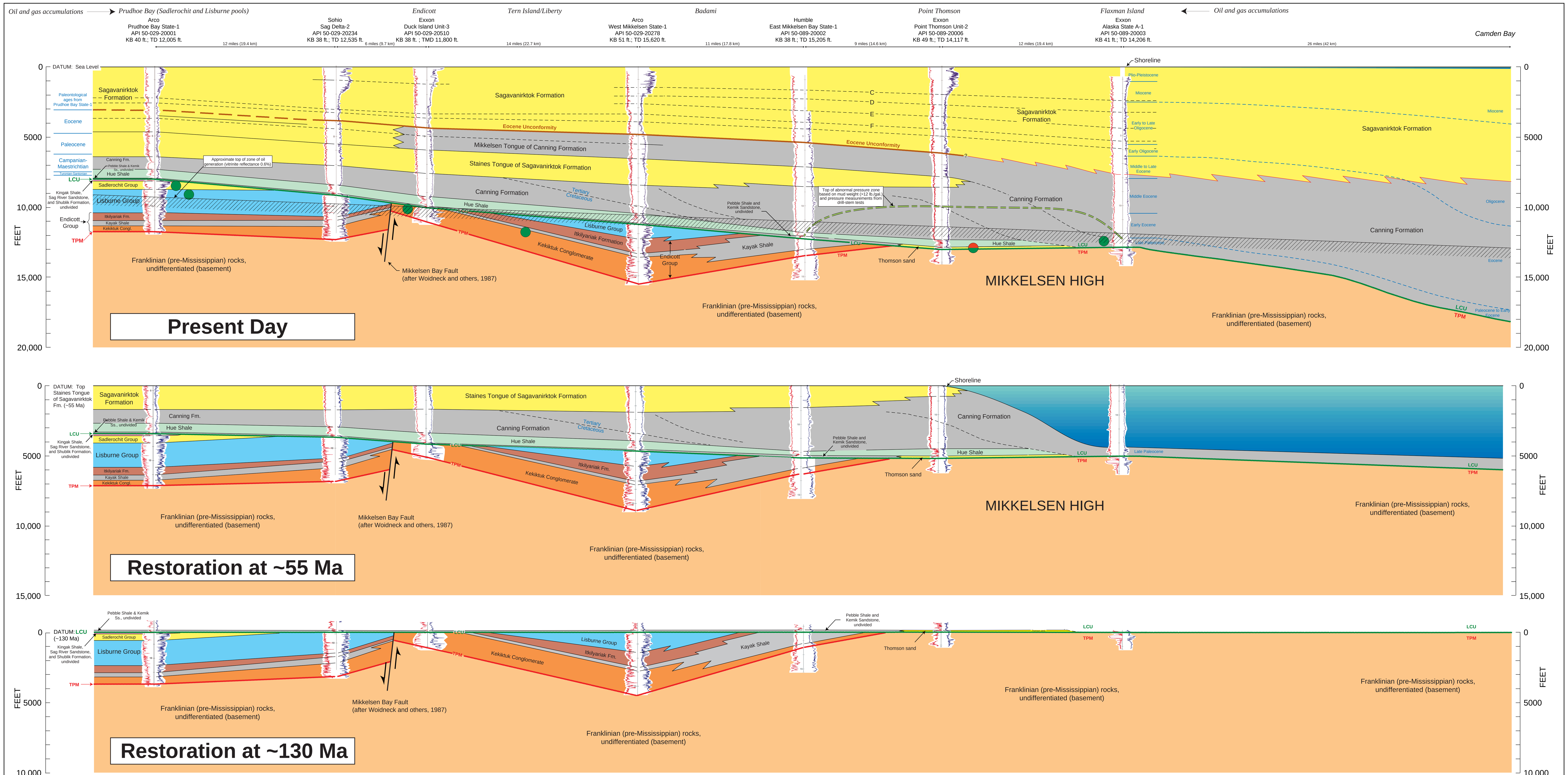
-------1977, Geology of the Romanzof Mountains, Brooks Range, northeastern Alaska: U.S. Geological Survey Professional Paper 897, 84 p.

U.S. Department of the Interior-Alaska Planning Group, 1974, Proposed Arctic National Wildlife Refuge, Alaska-Final environmental statement: U.S. Department of the Interior, 668 p.

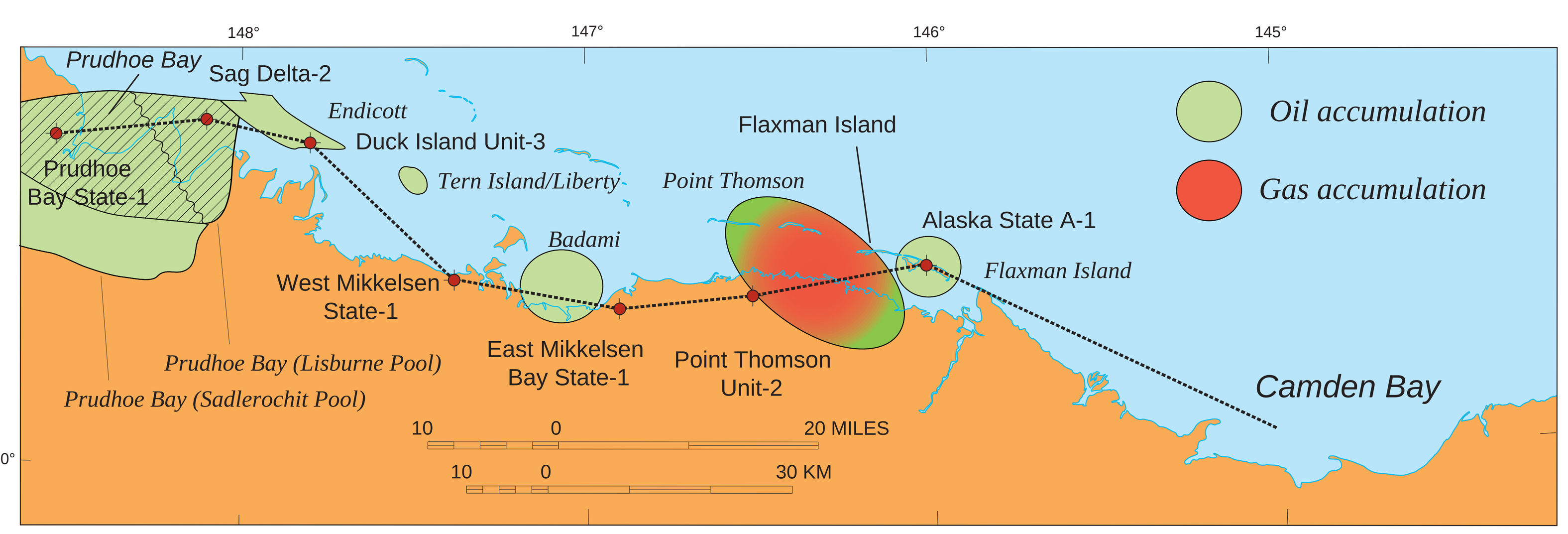
U.S. Department of the Interior, 1983, Proposed oil and gas exploration within the coastal plain of the Arctic National Wildlife Refuge, Alaska-Final environmental impact statement and preliminary final regulations: U.S. Department of the Interior, 463 p., 3 plates.

USGS
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

OPEN-FILE REPORT 98-34
PLATE GG2



EXPLANATION



- Carbonate rocks
- Sandstone and Conglomerate
- Shale
- Shaly carbonate rocks
- Metasedimentary rocks
- Eocene Unconformity
- LCU — Lower Cretaceous Unconformity
- TPM — Top Pre-Mississippian Unconformity
- Paleontological ages
- Log correlation lines
- Lithofacies boundary
- Seismic reflectors

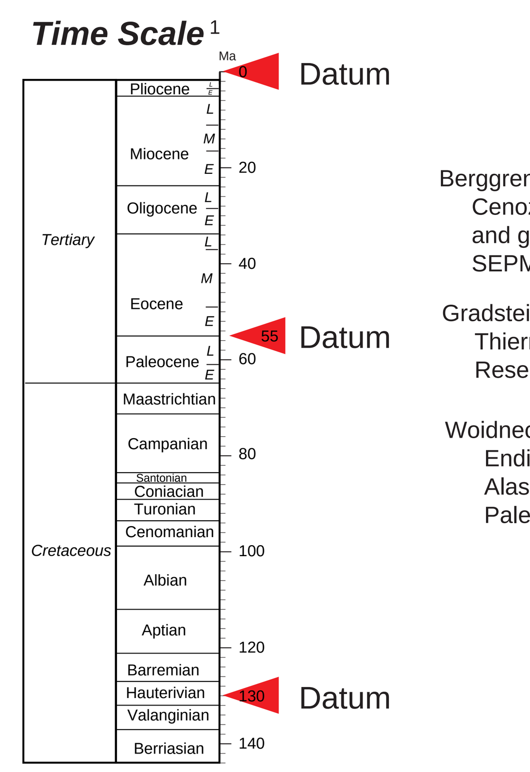
Horizontal Scale: 0 5 10 15 km; 0 4 8 mi

Vertical Scale: Meters 0, 500, 1000, 1500; Feet 0, 5000

VERTICAL EXAGGERATION = X5

ANGULAR RELATIONS: 0°, 2°, 5°, 10°

Time Scale[1]



1. Based on Berggren and others (1995) and Gradstein and others (1994).

References Cited

Berggren, W.A., Kent, D.V., Swisher, C.C., III, and Aubry, M 1995, A revised Cenozoic chronology and chronostratigraphy, in Geochronology, time scales, and global stratigraphic correlation: Tulsa, OK, Society for Sedimentary Geology, SEPM Special Publication No. 54, p. 129-212.

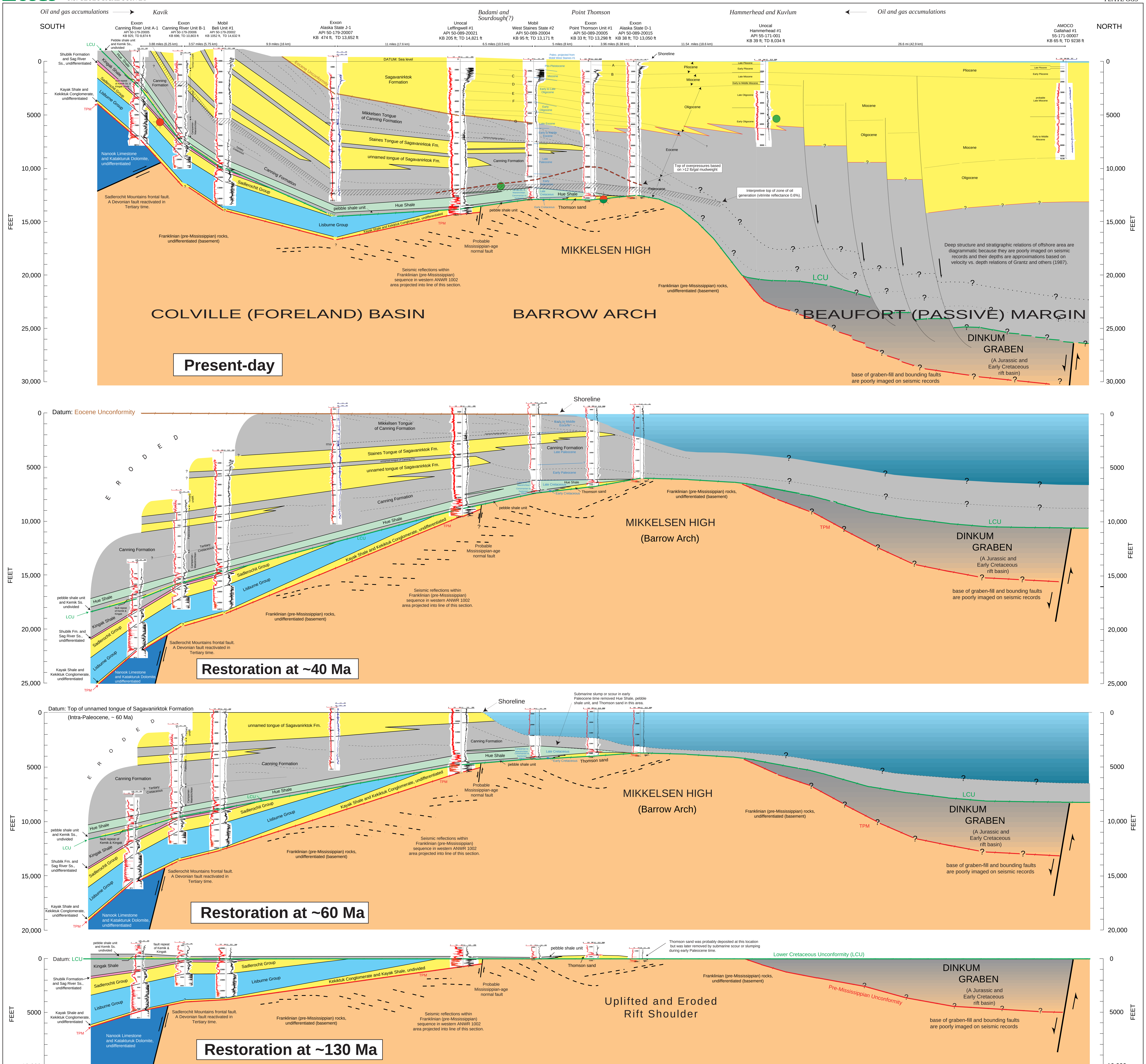
Gradstein, F.M., Agterberg, F.P., Ogg, J.G., Hardenbol, J.van Veen, P., Thierry, J., and Huang, Z., 1994, A Mesozoic time scale: Journal of Geophysical Research, v. 99, no. B12, p. 24,051-24,074.

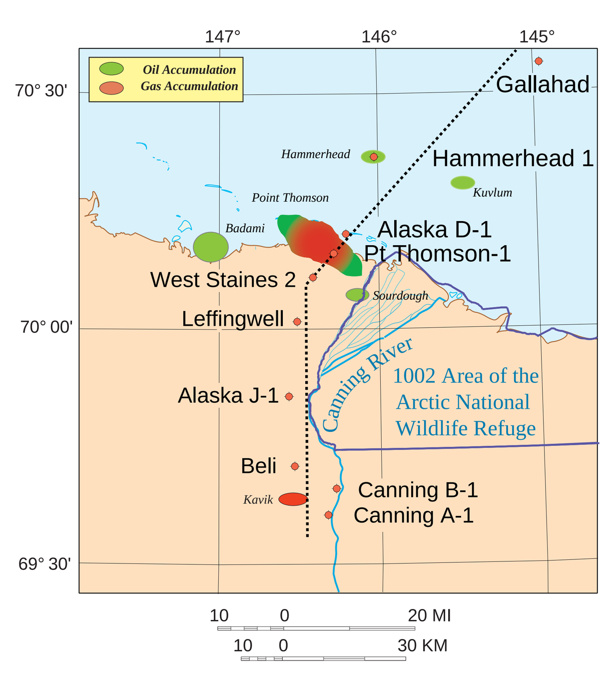
Woidneck, K., Behrman, P., Soule, C., and Wu, J., 1987, Reservoir description of the Endicott field, North Slope, Alaska, in Tailleur, I.,and Weimer, P., eds., Alaskan North Slope Geology: Bakersfield, Calif., Society of Economic Paleontologists and Mineralogists, Pacific Section, p.43-59.

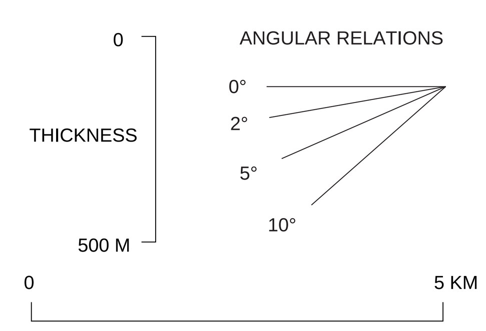
PRUDHOE BAY TO CAMDEN BAY WELL CORRELATION SECTION AND GEOLOGIC RESTORATIONS

by
Kenneth J. Bird

Click here or on this symbol in the toolbar to return.





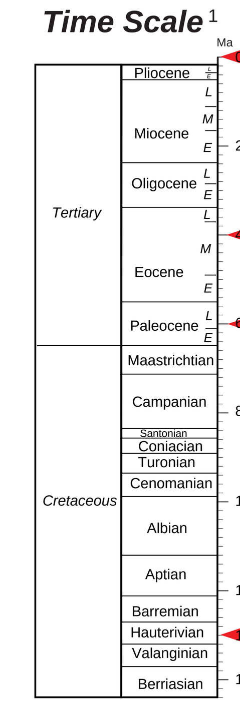


CROSS-SECTION VERTICAL EXAGGERATION = X5

EXPLANATION

- Carbonate rocks
- Sandstone and Conglomerate
- Shale
- Shaly carbonate rocks
- Metasedimentary rocks
- Eocene Unconformity
- LCU — Lower Cretaceous Unconformity
- TPM — Top Pre-Mississippian Unconformity
- Projected paleontological ages
- Log correlation lines
- Seismic reflectors

Time Scale[1]



1. Based on Berggren and others (1995) and Gradstein and others (1994).

References Cited

Berggren, W.A., Kent, D.V., Swisher, C.S., III, and Aubry, M, 1995, A revised Cenozoic chronology and chronostratigraphy, in Geochronology, time scales, and global stratigraphic correlation: Tulsa, OK, Society for Sedimentary Geology, SEPM Special Publication No. 54, p. 129-212.

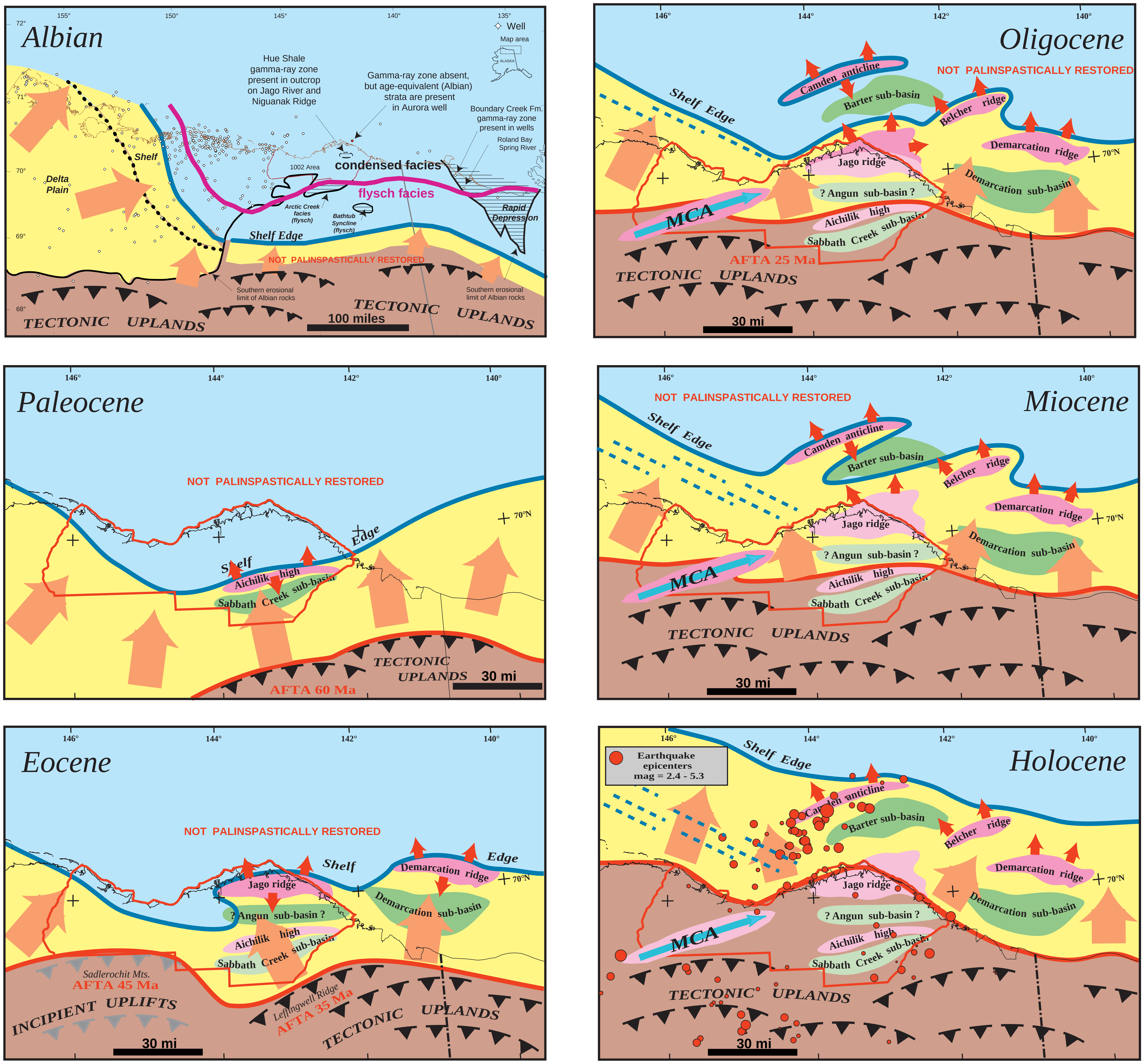
Gradstein, F.M., Agterberg, F.P., Ogg, J.G., Hardenbol, J., van Veen, P., Thierry, J., and Huang, Z., 1994, A Mesozoic time scale: Journal of Geophysical Research, v. 99, no. B12, p. 24,051-24,074.

Grantz, A., Dinter, D.A., and Culotta, R.C., 1987, Structure of the continental shelf north of the Arctic National Wildlife Refuge, in Bird, K.J., and Magoon, L.B., eds., Petroleum geology of the northern part of the Arctic National Wildlife Refuge, northeastern Alaska, U.S. Geological Survey Bulletin 1778, p. 271-276.

CANNING RIVER AND OFFSHORE WELL CORRELATION SECTION AND GEOLOGIC RESTORATIONS

by
Kenneth J. Bird

Click here or on this symbol in the toolbar to return.



EXPLANATION

Depositional Systems

Fluvial, Deltaic, & Marine Shelf

Marine Slope & Deep Basin

Sediment Transport Direction

Predominant

Minor

Structural Features

MCA Marsh Creek Anticline

Positive Structures

Negative Structures

N-Dipping Growth Faults

PALEOGEOGRAPHIC RECONSTRUCTIONS AND PRESENT-DAY STRUCTURAL FEATURES OF NORTHEASTERN ALASKA

by
Kenneth J. Bird

Click here or on this symbol in the toolbar to return.