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Geology, Play Descriptions, and Petroleum Resources of the Alaskan North Slope (Petroleum Provinces 58-60)

by

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INTRODUCTION

The North Slope occurs at the northern extension of the Rocky Mountains and Great Plains provinces. It is one of the six most prolific petroleum producing areas of North America (Bird, 1989) and currently provides about 25 percent of U.S. oil production. This region spans the entire width of northern Alaska (Fig. 1) and encompasses a total area of about 200,000 km^2. Petroleum-prospective rocks extend offshore where they comprise an area similar in size to the onshore. The North Slope includes the northern part of the Brooks Range, the Foothills, and the Coastal Plain physiographic provinces. These provinces are approximately the same as those by the same name that were assessed for oil and gas ressources. The name North Slope is interchangeable with Arctic Slope.

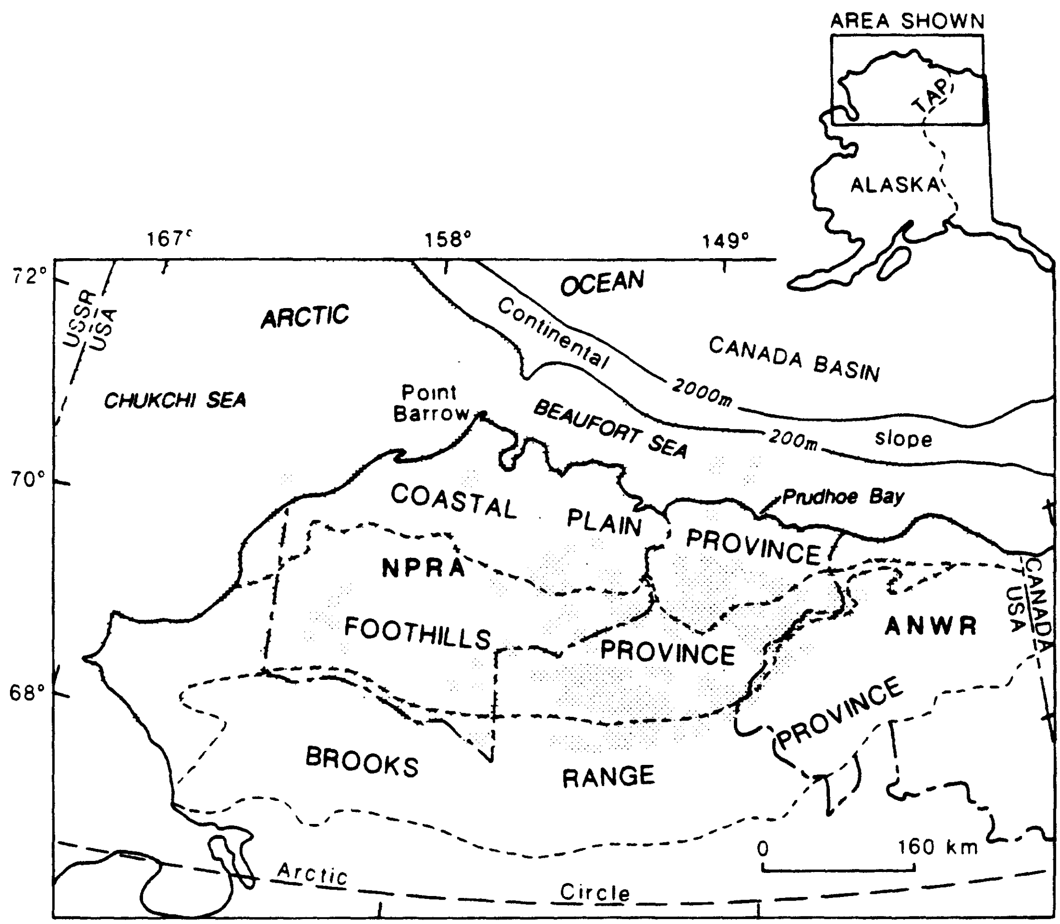

Figure 1. Index map showing the location of the onshore and offshore North Slope petroleum province (shaded area) and physiographic provinces. NPRA, National Petroleum Reserve in Alaska. ANWR, Arctic National Wildlife Refuge. TAP, trans-Alaska pipeline.

The North Slope is primarily a composite basin of Paleozoic to Cenozoic age. The northern edge of the composite basin includes Cretaceous and Tertiary passive margin deposits, which form the southern flank of the modern Canada basin (Fig. 2). The composite basin includes late Paleozoic and Mesozoic south-facing continental margin deposits overlain by late Mesozoic and Cenozoic north-facing foreland basin deposits. Beginning in the Late Jurassic, north-verging compressional tectonism resulted in the uplift of the ancestral Brooks Range as a fold and thrust belt with a foredeep basin (Colville basin) to the north. Since the Early Cretaceous opening of the Canada basin, crustal shortening in the south has been occurring simultaneously with crustal extension in the north. The Chukchi and Arctic platforms, relatively stable areas characterized by nearly flat-lying strata, lie north of the fold and thrust belt. The Barrow arch, a broad, subsurface basement ridge, marks the boundary between the downwarped and downfaulted northern rifted margin and the gently south-dipping continental margin deposits.

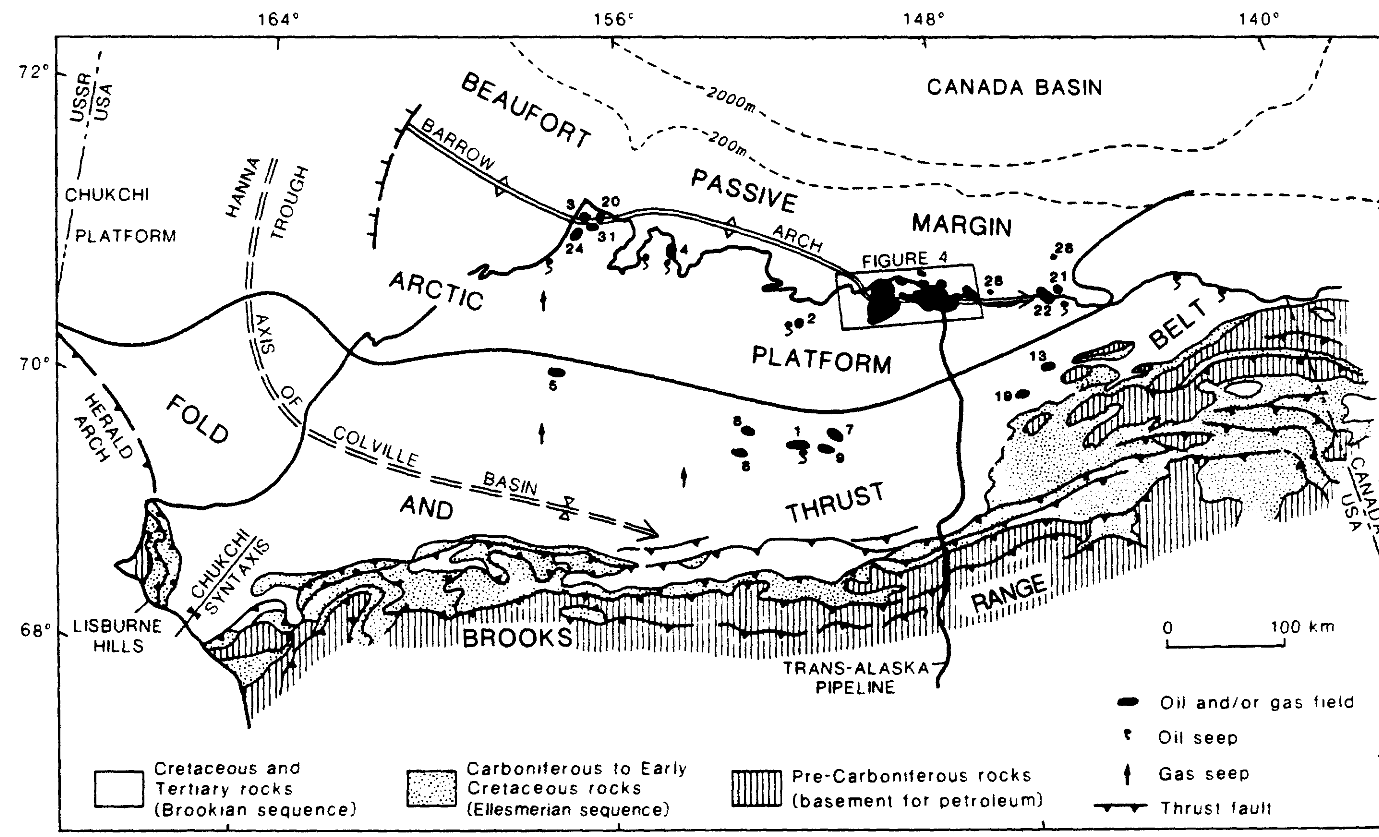

Figure 2. Generalized geologic map of North Slope showing locations of oil and gas fields, hydrocarbon seepages, and major tectonic elements. The northern edge of the Brooks Range generally coincides with the limit of pre-Cretaceous rocks, while the foothills-coastal plain boundary coincides with the northern edge of fold and thrust belt. Numbers coincide with oil and gas fields listed in Table 1.

The petroleum-prospective rocks of the North Slope are predominantly clastic deposits. The Colville basin and laterally equivalent passive margin deposits are composed of clastic sedimentary rocks derived from a southern source, the Brooks Range orogen. These rocks, known as the Brookian sequence, overlie Mississippian to Early Cretaceous continental margin deposits known as the Ellesmerian sequence. The Ellesmerian is composed of both clastic (~75 %) and carbonate (~25 %) rocks that were deposited on the south-facing margin (in present-day coordinates) of a stable continental land mass. Together, the Brookian and Ellesmerian sequences, names coined by Lerand (1973), make up the composite basin deposits; they unconformably overlie metamorphosed and deformed sedimentary and igneous rocks of Proterozoic to Devonian age that form the basement for petroleum exploration in this region.

With one critical difference, the North Slope basin is similar to the numerous intracontinental composite basins located along the east side of the American Cordillera (Klemme, 1981). Whereas these basins display an asymmetric basin profile, with the longer, tapering limb toward the continental interior (the foreland), the Paleozoic through Mesozoic section of the North Slope is unique in that the foreland side of the basin is truncated by rifting, and the expected continental interior is replaced by the Arctic Ocean basin. Pre-rift rocks of the North Slope, in fact, show that a continent once lay to the north (in present-day coordinates). The continental connection was severed in Early Cretaceous time, and the whereabouts of that connection is a point of ongoing debate and one of the main reasons that northern Alaska is considered a suspect terrane (Coney and Jones, 1985).

This report summarizes the petroleum geology of the North Slope, including its exploration history, principal petroleum plays, and the methodology and results of the assessment of undiscovered oil and gas resources. This assessment was part of the 1987 national assessment reported by Mast and others (1989). The treatment of the structure, stratigraphy, and tectonic development of this region is generalized from the more detailed presentation by Moore and others (in press) and Grantz and others (1990). An earlier version of this report, without the assessment details, was published in the Decade of North American Geology series (Bird, in press).

EXPLORATION HISTORY AND TECHNIQUES

Intermittent petroleum exploration of the North Slope can be documented for 50 of the last 70 years, and the role of government in these efforts makes this region unique. Details of North Slope petroleum exploration history provided by Reed (1958), Gryc (1970, 1988), Jamison and others (1980), Bird (1981), and Tailleur and Weimer (1987) show that government exploration was conducted intermittently beginning in 1923 and that industry exploration has been continuous since 1958.

Standard petroleum exploration methods are employed on the North Slope. However, its Arctic environment and frontier setting dictate modification of some techniques. For example, the near-roadless nature of the region often necessitates air transport of equipment and supplies for exploratory drilling at remote sites. Furthermore, the marshy terrain of the coastal plain makes summertime surface activities difficult and potentially disruptive of the tundra; therefore, most onshore seismic surveys and exploratory drilling are conducted during the winter months when the ground surface is frozen and snow covered, thus minimizing the environmental impact of these activities. Temporary (single season) airstrips and roads are usually constructed of ice, and offshore, at shallow-water locations, islands have been constructed of either ice or gravel to serve as drilling platforms for one-season exploratory wells (Oil and Gas Journal, 1989). Schindler (1988) describes many of the logistical and engineering details related to Arctic exploration.

Government exploration of the North Slope was conducted in three phases. The initial phase, following World War I, was prompted by a perceived shortage of oil for the Navy. About one-half of the prospective area of the North Slope was set aside by the U.S. government in 1923, under the jurisdiction of the Navy. This area, initially known as Naval Petroleum Reserve No. 4 (NPR-4), is now known as the National Petroleum Reserve in Alaska (NPRA; Fig. 1). Exploration was conducted here during four consecutive seasons (1923 to 1926) by geologic-topographic parties from the U.S. Geological Survey (Smith and Mertie, 1930). Between 1926 and 1943, no further exploration of the North Slope was undertaken either by the government or by private industry.

The second phase of exploration began during World War II (1944), when the U.S. government mounted a full-scale petroleum exploration program known as Pet-4. It was focused on NPR-4 but was not limited to it. This program, described in detail by Reed (1958), lasted ten years; it utilized all of the petroleum exploration techniques then available and introduced new ones. Extensive and far-ranging geologic studies were conducted by the U.S. Geological Survey (USGS). A full complement of geophysical surveys was conducted, including seismic, gravity, and aeromagnetic. A total of 36 test wells and 45 shallow core tests were drilled, resulting in the discovery of three oil fields and five gas fields (Table 1, Fig. 2). All petroleum discoveries were subeconomic, although accumulation sizes are only approximately known. The South Barrow gas field was developed for local usage. Most discoveries were made on anticlinal structures in Cretaceous sandstone reservoirs, although two of the three oil accumulations (Fish Creek and Simpson, numbers 2 and 4 on Fig. 2) were discovered by drilling near surface oil seepages in the absence of anticlinal structures.

The third and final phase of government exploration was stimulated by the discovery of the Prudhoe Bay oil field (1967), and the Arab oil embargo (1973). Initiated in 1974 and concluded in 1982, this program was limited to the NPRA. It was a comprehensive exploration effort, including geologic, geochemical, and geophysical surveys as well as exploratory drilling.

Table 1. Summary of selected details for North Slope oil and gas accumulations. (For additional details see table in Magoon, in press). [Map numbers correspond to locations shown in Figures 2 and 4; Disc, discovery; Reservoir, main hydrocarbon-bearing rock unit; see Figure 7 for age and lithology; In place, reported values or rounded estimates based on assumed recovery factors of about 30 percent (oil) and 80 percent (gas); oil, reported in BBO (10^9 barrels, $159x10^8$ m^3) or MBO (10^6 barrels, $159x10^3$ m^3)(barrel = 42 U.S. gallons = 0.159 m^3); gas, reported in TCF (10^{12} ft^3, $283x10^8$ m^3) or BCF (10^9 ft^3, $283x10^5$ m^3); Cum prod, cumulative production through 12-31-87; Reserves, remaining reserves as of 12-31-87; Data source, see references keyed to numbers at bottom of table; ?, amount of resource unknown; -, resource not present; *, midpoint of range].

Map No.	Field or Accumulation Name	Disc Date	Reservoir	In place OIL (BBO)	In place GAS (TCF)	Cum prod OIL (MBO)	Cum prod GAS (BCF)	Reserves OIL (MBO)	Reserves GAS (BCF)	Data Source
1	Umiat	1946	Nanushuk	<1	<<1	-	-	70	?	1
2	Fish Creek	1949	Nanushuk	<<1	-	-	-	?	?	2
3	South Barrow	1949	Barrow	-	<<1	-	18	-	7	3
4	Simpson	1950	Nanushuk	<<1	<<1	-	-	12	?	2
5	Meade	1950	Nanushuk	-	<<1	-	-	-	20	2
6	Wolf Creek	1951	Nanushuk	-	<<1	-	-	-	?	2
7	Gubik	1951	Colville	-	<1	-	-	-	295	2
8	Square Lake	1952	Colville	-	<<1	-	-	-	58	2
9	East Umiat	1963	Nanushuk	-	<1	-	-	-	?	4
10	Prudhoe Bay	1967	Sadlerochit	23	27	5,507	7,652	4,219	23,441	5
11	Lisburne	1967	Lisburne	3	3	22	76	143	406	6
12	Kuparuk River	1969	Kuparuk	~4	~2	398	470	1,105	634	7
13	Kavik	1969	Sadlerochit	-	<1	-	-	-	?	8
14	West Sak	1969	Sagavanirktok	20*	<<1	-	-	-	-	9
15	Ugnu	1969	Sagavanirktok	15*	-	-	-	-	-	9
16	Milne Point	1969	Kuparuk	<1	<<1	5	2	95	?	8
17	Gwydyr Bay	1969	Sadlerochit	<1	<<1	-	-	60	?	10
18	North Prudhoe	1970	Sadlerochit	<1	<<1	-	-	75	?	10
19	Kemik	1972	Shublik	-	<1	-	-	-	?	8
20	East Barrow	1974	Barrow	-	<<1	-	4	-	8	3
21	Flaxman Island	1975	Canning	?	?	-	-	?	?	4
22	Point Thomson	1977	Thomson	<1	6	-	-	350	5,000	11
23	Endicott	1978	Kekiktuk	1	<2	9	8	366	907	12
24	Walakpa	1980	Walakpa	-	<<1	-	-	-	?	13
25	Niakuk	1981	Kuparuk	<1	<<1	-	-	58	30	14
26	Tern Island	1982	Kekiktuk	?	?	-	-	?	?	15
27	Seal Island	1984	Sadlerochit	<1	<1	-	-	150	?	16
28	Hammerhead	1985	Sagavanirktok	?	?	-	-	?	?	15
29	Colville Delta	1985	Kuparuk?	?	?	-	-	?	?	16
30	Sandpiper	1986	Sadlerochit	?	?	-	-	?	?	15
31	Sikulik	1988	Barrow	-	<<1	-	-	-	?	4
32	Point McIntyre	1988	Kuparuk	1	?	-	-	~300	?	17
TOTALS				~69	~40	5,941	8,230	7,003	30,791	

Data source: 1. Molenaar, 1982; 2. Collins and Robinson, 1967; Reed, 1958; 3. Lantz, 1981; 4. Well file; 5. State of Alaska, 1977; 6. State of Alaska, 1984; 7. Carman and Hardwick, 1983; van Poollen and Associates and State of Alaska, 1978; 8. State of Alaska, 1985; 9. Werner, 1987; 10. Van Dyke, 1980; 11. Oil and Gas Journal, 1984; Bird and Magoon, 1987; Craig and others, 1985; 12. Woidneck and others, 1987; Harris, 1987; 13 Gryc, 1988; 14. Harris, 1988; 15. Minerals Management Service, 1988; 16. Alaska Report, 1989; 17. Williams, 1989.

Nearly 24,000 line-kilometers of reflection seismic data was collected and interpreted. A total of 28 test wells were drilled, primarily for pre-Cretaceous objectives similar to those developed at Prudhoe Bay. Two subcommercial gas accumulations were discovered (East Barrow and Walakpa, numbers 20 and 24 on Fig. 2), and indications of oil and/or gas were found in nearly all the test wells. Additional exploratory and development wells were drilled in the Barrow area to supplement the local gas supply. A summary of this program and results of studies may be found in Gryc (1988) and in various contractor reports that are available through the National Geophysical Data Center, NOAA, Boulder, Colorado 80303.

Industry exploration of the North Slope dates from 1958, when the government lifted a land freeze and offered acreage for lease. Until 1979, when the first offshore lease sale was held, industry exploration was restricted by land availability to the area between the NPRA and the Arctic National Wildlife Refuge (ANWR, Fig. 1). Since then, additional sales have been held, both offshore and onshore, including four sales in the NPRA and, most recently, the first sale in the Chukchi Sea. Limited exploration, including seismic surveys and surface geologic studies, was allowed on a part of the ANWR coastal plain in 1984 and 1985. Results of these studies, described in Bird and Magoon (1987), indicate that this is the most promising onshore area for petroleum exploration remaining on the North Slope. A decision about whether or not to allow leasing and drilling in the coastal plain of ANWR is now pending in Congress.

Industry drilling began in the foothills, testing Cretaceous anticlinal objectives, similar to those tested by the Navy in NPR-4; eight wells were drilled from 1964 to 1967. Although only one subcommercial gas field (East Umiat) was discovered, indications of oil and gas were encountered in every well. Exploration activity then shifted northward to the coastal plain, where pre-Cretaceous objectives could be tested at shallower depths than in the foothills, and where there was better opportunity to acquire solid lease-blocks on state-owned acreage. The third coastal plain well was drilled in 1967, when exploration activity on the North Slope was winding down toward a virtual standstill. This well, the eleventh industry attempt on the North Slope, resulted in the discovery of the Prudhoe Bay field, the largest commercial oil accumulation in North America. In the year or so following the Prudhoe Bay discovery, North Slope exploration activity blossomed, and the rate of oil and gas discovery shot upward. Since then, the rate has tapered off to one discovery every two years (Fig. 3).

Exploratory drilling by government and industry has been conducted for 45 years on the North Slope, resulting in the discovery of 32 oil and gas accumulations, which encompass both onshore and offshore areas. The rate of discovery is plotted in Figure 3, based on the tabulation in Table 1. The oil and gas accumulations are located in Figures 2 and 4. Although most of the oil and gas accumulations are noncommercial by current North Slope standards, five are now producing. Their total ultimate recovery (reserves plus produced) is estimated to be nearly 12 billion barrels (1.9×10^9 m^3) of oil. Even more indicative of the richness of this province are the total in-place resources shown in Table 1: nearly 70 billion barrels (11×10^9 m^3) of oil and 40 trillion cubic ft (1.13×10^{12} m^3) of gas, more than 95 percent of which are concentrated within a 65-km radius of Prudhoe Bay (Fig. 4).

Hydrocarbon production on the North Slope began in 1949, when the government produced natural gas for local use at Barrow. Commercial oil production began in 1977 from the Prudhoe Bay field when the trans-Alaska pipeline was completed--almost ten years after the field was discovered. Production from the Prudhoe Bay and Kuparuk River fields, currently the two leading U.S. oil producers, combined with that from three other North Slope fields (Endicott, Lisburne, and Milne Point), supplied about 2 million barrels (3.2×10^5 m^3) of oil per day in 1988, or about 25 percent of total U.S. production. North Slope production rates on a per-well basis are typical of frontier regions (Table 2). This tabulation of the United States' most important oil-producing states as of 1984 shows Alaskan production rates averaged nearly 2,000 barrels per day per well, about two orders of magnitude greater than per-well rates of any other state. Alaska's rates reflect the remarkable characteristics of the Sadlerochit reservoir at the Prudhoe Bay field--some wells produce nearly 20,000 barrels per day (Jamison and others, 1980)--and the economics of Arctic petroleum development. At least in part for lack of a transportation system, natural gas is not presently economic, even though large volumes of gas have been discovered. Some gas, however, is produced for use in the production facilities at Prudhoe Bay and nearby oil fields.

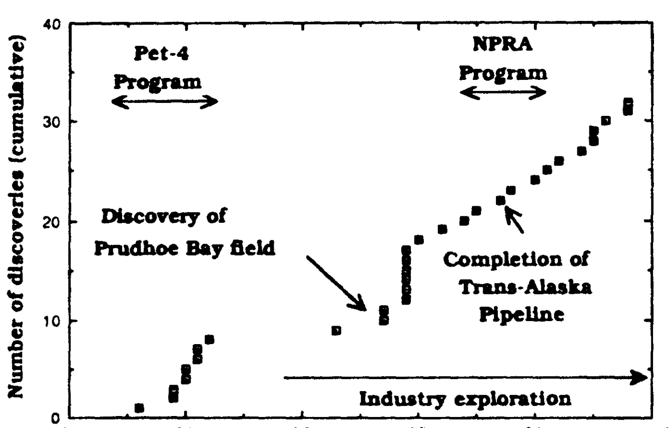

Figure 3. Summary of North Slope petroleum exploration history in terms of oil and gas discoveries, 1944 through 1989. Each square represents a single oil or gas accumulation. Most North Slope oil and gas accumulations are not economic or are not producing. Data from Table 1. Pet-4, Naval Petroleum Reserve No.4; NPRA, National Petroleum Reserve in Alaska.

Table 2. Ranking of the top ten oil-producing states as of 1984 showing Alaska's extremely high per-well production rate and its relatively small number of producing wells, reflections primarily of the economics of arctic oil production (adapted from Gerhard and others, 1988).

Rank	State	Daily Rate of Production		Number of Producing Wells
		Total (10^3 bbl)	Per well (barrels)	
1	Texas	2,435	12	209,040
2	**Alaska**	1,825	1,868	977
3	Louisiana	1,392	54	25,823
4	California	1,161	23	49,847
5	Oklahoma	446	4	103,000
6	Wyoming	352	29	12,038
7	New Mexico	215	12	18,697
8	Kansas	207	4	51,888
9	North Dakota	139	38	3,697
10	Utah	112	58	1,944

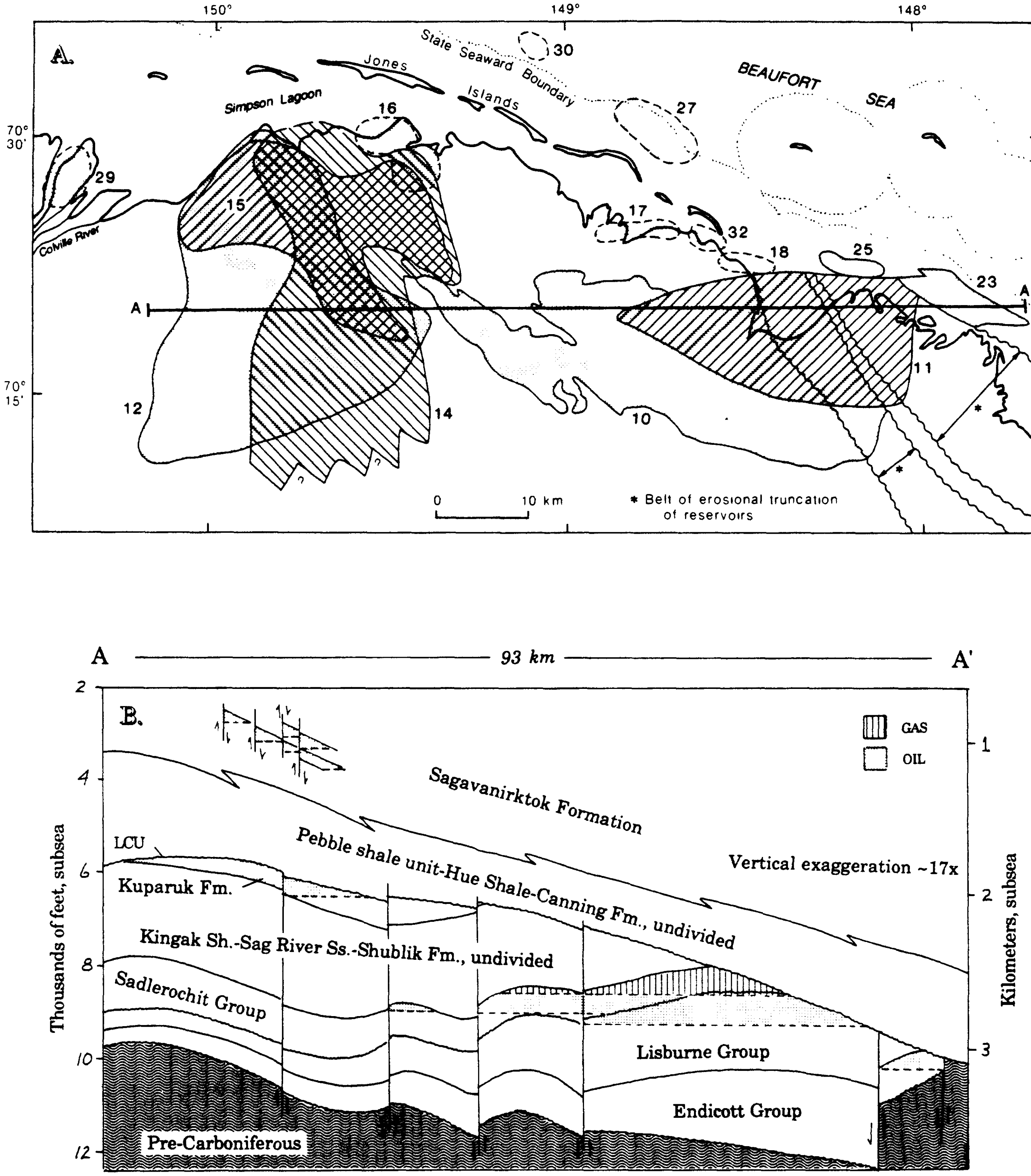

Figure 4. Prudhoe Bay area oil and gas accumulations. A. Map of the greater Prudhoe Bay area, where most North Slope oil and gas resources occur, showing the location and areal extent of fields and the truncation trends of producing reservoir units beneath the Lower Cretaceous unconformity. Numbers coincide with fields listed in Table 1. B. Cross section shows structural and stratigraphic details of Prudhoe-area oil and gas fields. Note the importance of the Lower Cretaceous unconformity (LCU) in truncating reservoirs and the overlying shale units in providing seals for accumulations.

STRUCTURAL SETTING

The complex history of basin evolution, foreland to rift-type basins, results in a complex structure contour pattern on the basement surface in the North Slope province (Fig. 5). Burial depth to pre-Carboniferous basement exceeds 10 km beneath the axis of the Colville basin and along the passive margin; minimum burial depths, some as shallow as 1 km, occur along the Barrow arch and on the Chukchi platform. Brooks Range thrusting and uplift interrupt these trends and bring basement rocks to the surface. As summarized below and in the north-south cross section (Fig. 6), most preserved North Slope structures formed in Cretaceous and Tertiary time in response to compressional forces in the south and extensional forces in the north.

The Brooks Range and the deformed rocks of the Foothills province compose a fold and thrust belt (Fig. 2). The Brooks Range is a continental (A-type) subduction orogenic belt (Bally and Snelson, 1980) more than 1,000 km long and as much as 300 km wide. In the western part of the North Slope, this orogenic belt makes a sharp bend (the Chukchi syntaxis), virtually doubling back on itself, and continues northward through the Lisburne Hills and northwestward offshore along the Herald arch (Fig. 2). Except for the area of the syntaxis, where structural trends oppose each other, the orogen is characterized by east-trending, north-vergent structures.

Important differences in structural style and time of deformation occur along the northern margin of the Brooks Range; faults are more steeply dipping and imbrications less numerous in the northeastern part of the range compared to the western part of the range (Moore and others, in press). West of 148° W , the northern margin of the range is made up of a stack of far-traveled thrust packages (allochthons) that are defined by distinctive sequences of stratified Late Devonian to Early Cretaceous rocks and characterized by complex folds and imbricate thrust faults. East of 148° W, where the front of the range extends far to the north and displays mostly northeast-trending structures, the range is dominated by anticlinoria cored by pre-Carboniferous rocks, reflecting regional north-vergent duplex structures. Basal thrusts lie in pre-Carboniferous basement rocks, and roof thrusts cut various stratigraphic levels in younger stratigraphic units.

Two phases of thrusting are recognized in the Brooks Range: (1) an early phase of displacement during Late Jurassic to Neocomian time, and (2) a late phase of displacements from mid-Cretaceous to Tertiary time. The latter deformational episode resulted in uplift of the range and development of many of its conspicuous structures, as well as deformation of foredeep deposits in the foothills province. Patterns of development and filling of the foredeep basin suggest that the latter deformational event was diachronous, being older in the west and becoming progressively younger in the east. Earthquake epicenters and deformed terrace deposits suggest that deformation continues in the northern ANWR and offshore in the eastern Beaufort Sea (Grantz and others, 1988).

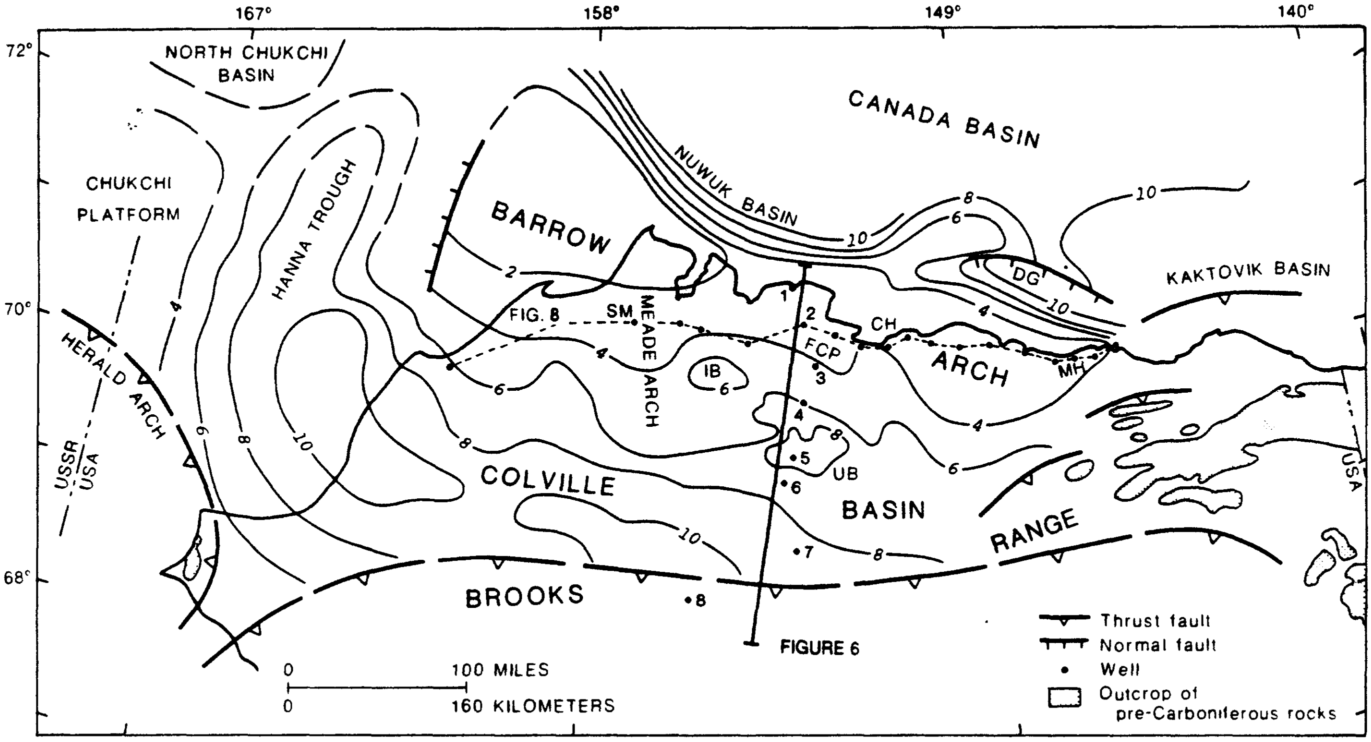

Figure 5. Structure contour map of the North Slope petroleum province showing depth (in kilometers subsea) to pre-Carboniferous basement. Offshore contours generalized from Grantz and May (1988) and Grantz and others (1988). Geologic features: CH, Colville high; DG, Dinkum graben; FCP, Fish Creek platform; IB, Ikpikpuk basin; MH, Mikkelsen high; SM, South Meade; UB, Umiat basin. Wells: 1. J.W. Dalton-1; 2. East Teshekpuk-1; 3. North Inigok-1; 4. Inigok-1; 5. Square Lake-1; 6. Wolf Creek-3; 7. East Kurupa-1; 8. Lisburne-1.

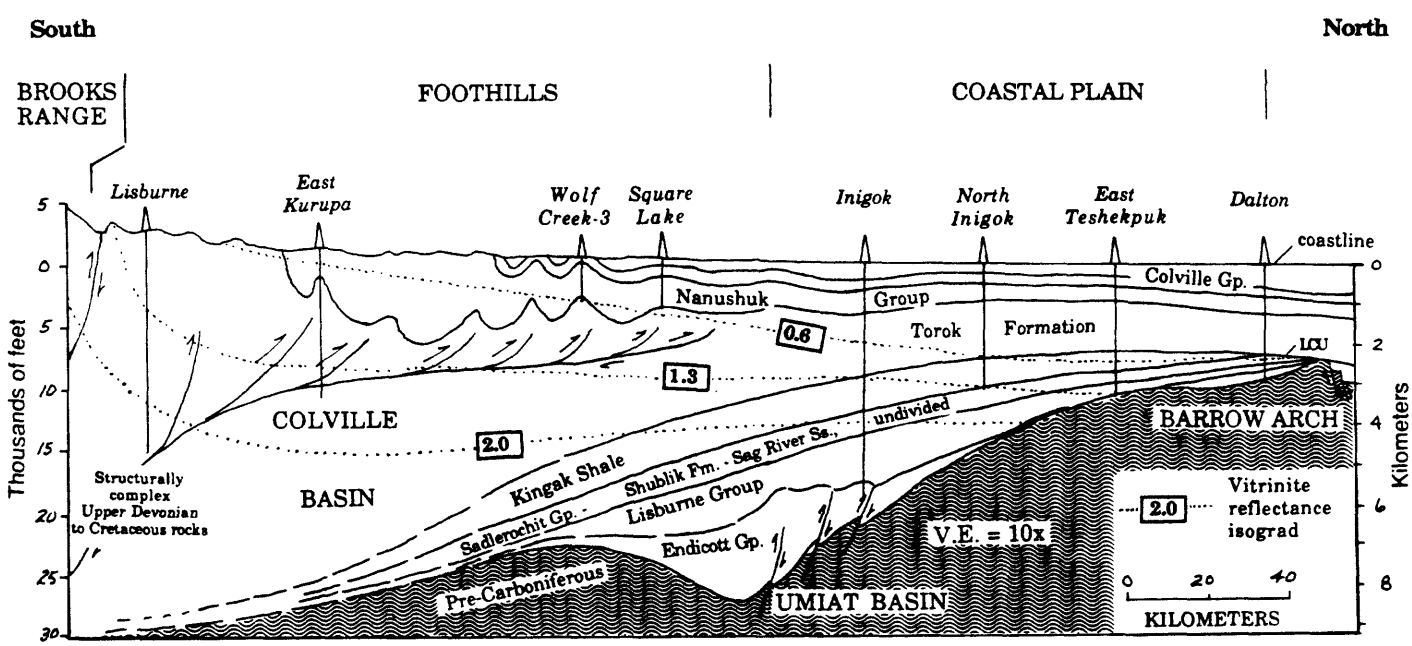

Figure 6. Cross section of the North Slope showing diagrammatic structure and generalized stratigraphy. Vitrinite isograds show disposition of oil window (0.6 to 1.3 Ro) and condensate window (1.3 to 2.0 Ro). See Figure 5 for location of section and wells.

The foothills structural province consists of deformed foredeep deposits and, along its southern margin, thrust blocks of older Brooks Range rocks (Fig. 6). This province is characterized by detachment folds. Thrust faults occur at many levels and generally cut stratigraphically upsection to the north. Fault displacements and fold amplitudes diminish northward; their northern extent generally coincides with the northern limit of the foothills province. Structures characteristic of this province extend offshore to the west beneath the southern part of the Chukchi Sea (north of the Herald arch) and to the northeast beneath the Beaufort shelf east of 146° W, offshore from the ANWR (Craig and others, 1985; Thurston and Theiss, 1987; Grantz and May, 1988; Grantz and others, 1988; Fig. 2).

North of the region affected by the Brooks Range orogeny, the North Slope petroleum province consists mostly of nearly flat-lying Mississippian and younger strata and east-trending extensional faults. Prominent structural features of this area are the (1) Arctic platform, (2) Barrow arch, and (3) Beaufort passive margin. An exception to the generalization above is the region of extensive north-trending wrench faults and associated structures in the western part of the United States Chukchi shelf, the Chukchi platform and Hanna trough (Figs. 2, 5).

The Arctic platform, that region beveled by pre-Carboniferous erosion and upon which the Ellesmerian and Brookian sequences were deposited, has remained fairly stable from Mississippian to Early Cretaceous time. Its northern margin was disrupted by rifting in Early Cretaceous time and its western edge is marked by the Hanna trough. Its gentle southward tilt during Ellesmerian deposition was accentuated by Brooks Range thrust loading and deposition of Brookian foredeep deposits beginning in Late Jurassic time. On the Arctic platform, several local basins developed in Mississippian time as sags or partially fault-bounded basins (half-grabens) that are inferred to be filled largely with nonmarine, coal-bearing clastic deposits. The combined Ikpikpuk and Umiat basins, with an areal extent of about 14,000 km^2 and more than 3 km of fill, are the largest of these basins (Figs. 5, 6). High-angle normal and reverse faults (with possible strike-slip motion) that cut Pennsylvanian to Jurassic rocks extend eastward across the central part of the NPRA, and probably beyond. The Inigok-1 well, located in the eastern NPRA (Figs. 5, 6), tested a prominent anticlinal fold related to this faulting.

In the Chukchi Sea, the north-trending Hanna trough (Central Chukchi basin of Thurston and Theiss, 1987) is a downbowed and downfaulted feature with a long and complex history of subsidence that separates the Arctic platform from the Chukchi platform (Figs. 2, 5). Ellesmerian and Brookian deposits in the Hanna trough are more than 12 km thick; these depostis accumulated in three areally coincident structural basins that formed at different times in highly contrasting settings, according to Thurston and Theiss (1987). These authors report numerous structural features commonly associated with wrench tectonics in a north-trending zone more than 160 km wide (the Hanna wrench-fault zone) that crosses the Hanna trough and Chukchi platform. Southward, the Hanna trough merges with the axis of the Colville basin.

The Chukchi platform is a long-standing positive feature beneath the western Chukchi shelf characterized by westward-shallowing basement, onlapping Ellesmerian rocks, and thin Brookian rocks. Lengthy, north-trending faults segment the Chukchi platform. From seismic stratigraphic evidence, these faults are Ellesmerian in age, and in the northern part of the platform, they were reactivated in Late Cretaceous(?) to early Tertiary time as wrench faults. Diapiric structures are also identified in the northern part of the platform (Thurston and Theiss, 1987; Grantz and May, 1988). The southern part of the Chukchi platform is bounded by the Herald arch, the offshore extension of the Brooks Range thrust belt. Northward across the Chukchi platform, Brookian deposits thicken toward the tectonic hinge that marks the southern boundary of the North Chukchi basin, a part of the passive margin sequence (Fig. 5).

The Barrow arch, a broad, east-trending, ridge-like feature, underlies the coast of northern Alaska and the northeastern Chukchi Sea and separates the Colville basin from the Beaufort passive margin and the Canada basin (Figs. 2, 5). Most North Slope oil and gas accumulations occur along or near this arch. Flank dips on the Barrow arch are generally less than 2° and its axis plunges eastward at about 0.5°. Defined as the line along which previously south-dipping beds (the Ellesmerian sequence) begin to dip northward as a result of sagging of the new (rifted) continental margin (Rickwood, 1970), the Barrow arch is not a simple, symmetrical anticlinal feature. Its eastward plunge results from uplift in the Point Barrow area, and subsidence to the east, probably related to tectonic and sedimentary loading by the northeast Brooks Range and adjacent foredeep deposits (Fig. 5). The concentration of oil and gas accumulations on the Barrow arch in the general area of Prudhoe Bay is explained by Hubbard and others (1987) as the result of four-way closure that developed in a favorable up-dip position that trapped migrating hydrocarbons generated in nearby Brookian depocenters. The four-way closure resulted from the intersection of the high-standing rift margin trend and lithospheric flexural bulges that developed in front of the Brooks Range thrust belt along the northern edge of the foreland basin.

The continental margin of northern Alaska is an Atlantic-type passive margin, called the Beaufort passive margin by Hubbard and others (1987). In this margin, Grantz and May (1988) and Grantz and others (1988) recognize three regions of contrasting structure and stratigraphy. Typically, the margin consists of an 8 to 10 km-thick prism of Cretaceous and Tertiary sediments (North Chukchi, Nuwok, and Kaktovik basins) overlying horst and graben structures developed during a 60-m.y.-long period (Middle Jurassic to Early Cretaceous) of rift-related faulting. Structures in the passive margin deposits trend subparallel to the coastline and consist of growth faults, related rollover anticlines, and diapiric ridges. The earlier episode of extensional tectonism produced sediment-filled grabens, a regional unconformity (the LCU), the Barrow arch, and the oceanic Canada basin.

STRATIGRAPHY

The stratigraphic record of the North Slope province probably spans a billion years of geologic time, but rocks with petroleum potential are mostly younger than Devonian (Figs. 7, 8). Traditionally, the petroleum-prospective rocks of the North Slope have been grouped into two sequences (Ellesmerian and Brookian) to emphasize source areas and genetic relations. Both sequences contain important petroleum source and reservoir rocks, although present oil extraction is entirely from Ellesmerian reservoirs. Pre-Carboniferous (basement) rocks, especially carbonate rocks, that have been buried and metamorphosed beyond the thermal stage for oil, may, in favorable circumstances, provide reservoirs for oil or gas.

Pre-Carboniferous rocks of the North Slope province consist of a complex assemblage of slightly to moderately metamorphosed Proterozoic to Devonian sedimentary and igneous rocks; Precambrian crystalline rocks typical of the Canadian Shield are not known to occur in this area. In the subsurface, pre-Carboniferous rocks (known mostly along the Barrow arch) consist of steeply dipping and slightly metamorphosed argillite of Ordovician and Silurian age (Carter and Laufeld, 1975). Their fine-grained character and apparent great thickness suggest a continental slope depositional environment. Near Point Barrow, these rocks have an organic carbon content of as much as 12 percent and may have generated oil or gas prior to Mississippian time (Magoon and Bird, 1988). Most primary porosity in pre-Carboniferous rocks was destroyed during their long history of deep burial, heating, and deformation. Secondary porosity, however, may occur as a result of tectonic fracturing or selective leaching of grains or cements. Oil and condensate have been recovered from fractured(?) pre-Carboniferous sandstone and carbonate rocks that lie unconformably beneath an Early Cretaceous sandstone in the Point Thomson field (no. 22 on Fig. 2; Bird and others, 1987).

The **Ellesmerian sequence** records a major northward advance of the sea following the Ellesmerian orogeny. The sequence consists of marine carbonate rocks, marine and nonmarine clastic rocks, and scarce igneous rocks representing about 220 m.y. (Mississippian to Early Cretaceous) of continental margin sedimentation (Fig. 7). Northward-directed stratigraphic features such as onlap, convergence, truncation, increasing grain size, and marine to nonmarine facies changes indicate that the ancient shoreline lay near the present coast and that the open ocean was to the south. Total Ellesmerian thickness is generally less than 2 km, but in local areas, such as the Umiat basin, may exceed 6 km (Fig. 6). Ellesmerian sandstones, typically composed of quartz and chert grains (van de Kamp, 1988), generally make better reservoirs than the relatively immature Brookian sandstones that contain more feldspar and rock fragments (Bartsch-Winkler and Huffman, 1988). Because the Ellesmerian sequence is generally less than 2 km thick (Figs. 6, 8), rocks rich in organic material deposited during this time were not capable of generating oil until buried by the much thicker Brookian deposits.

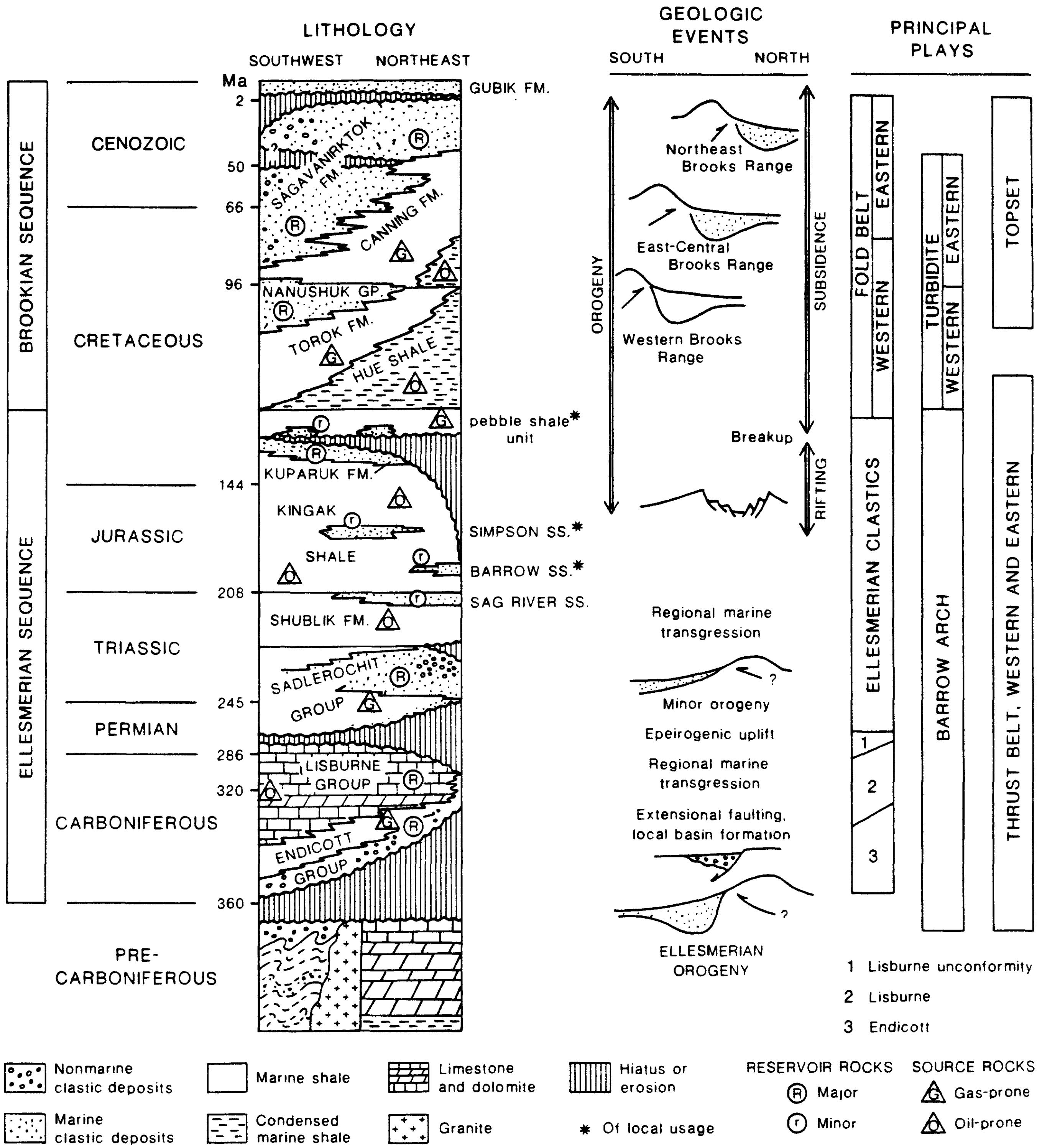

Figure 7. Generalized stratigraphic column for the North Slope showing petroleum source and reservoir rocks, major geologic events, and the stratigraphic intervals encompassed by principal petroleum plays. Time scaie from Palmer (1983).

The Mississippian to Early Permian part of the Ellesmerian constitutes a transgressive megacycle, as much as 4 km thick in some areas. It consists of nonmarine coal-bearing sandstone, shale, and conglomerate (Kekiktuk Conglomerate) that is succeeded by shallow marine black shale (Kayak Shale) or, along the northern basin margin, by red and green shale (Itkilyariak Formation). These shale units grade upward and laterally into an areally extensive carbonate platform sequence composed of limestone and dolomite (Lisburne Group). Epirogenic movements in Late Pennsylvanian(?) and Early Permian time caused a withdrawal of the sea and development of a regional unconformity at the top of the Lisburne. Significant oil accumulations occur in the Kekiktuk Conglomerate (Endicott field) and in limestone and dolomite of the Lisburne Group (Lisburne field)(Fig. 4).

Advance of the sea over the eroded Lisburne platform resulted in the deposition of the next megacycle, the clastic deposits (~300 m thick) of the Permian and Triassic Sadlerochit Group. The lower part of the Sadlerochit is a northward-thining, transgressive marine sandstone and siltstone unit (Echooka Formation). The Echooka is abruptly overlain by prodelta shale and siltstone (Kavik Member of the Ivishak Formation) that grades upward into a southward prograding clastic wedge of marine and nonmarine sandstone and conglomerate (Ledge Sandstone Member of the Ivishak Formation). The Ledge is the main reservoir of the Prudhoe Bay oil field; there it consists of alluvial fan and deltaic facies (Melvin and Knight, 1984). The uppermost part of the Sadlerochit Group consists of a transgressive upward-fining and northward-thinning marine siltstone and argillaceous sandstone (Fire Creek Siltstone Member of the Ivishak Formation).

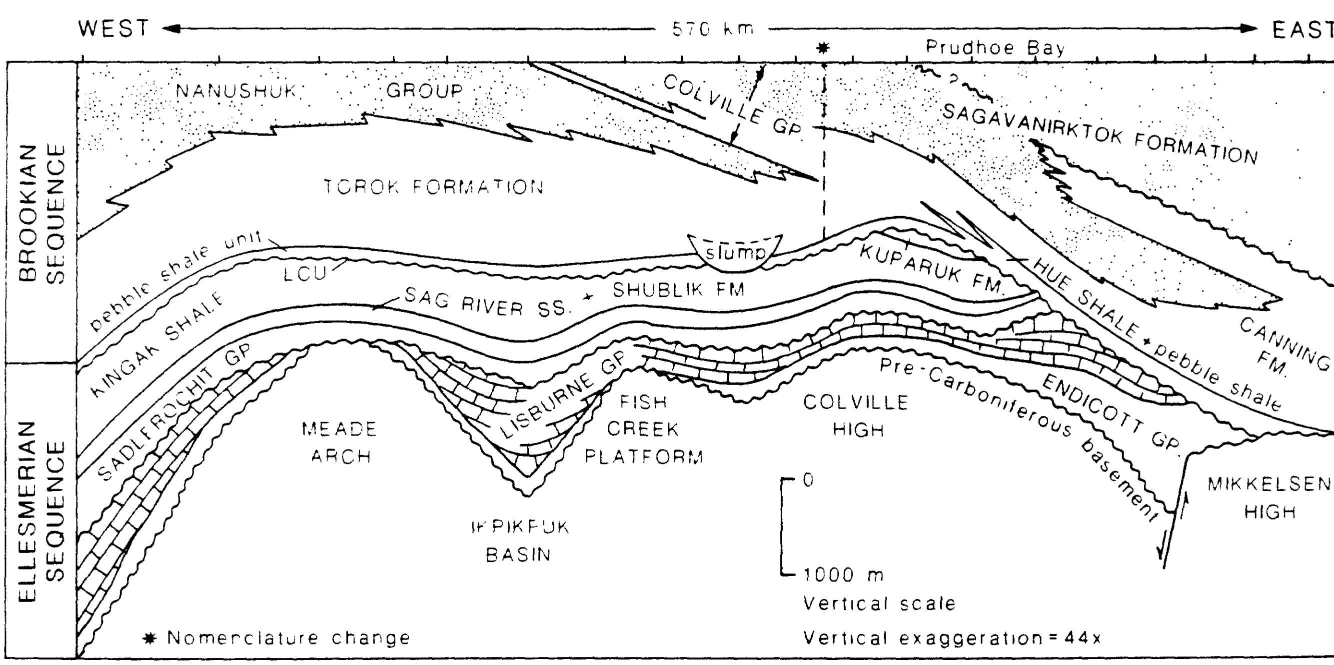

Figure 8. West-to-east cross section of the North Slope Coastal Plain province illustrating major structural and stratigraphic features of the Ellesmerian and Brookian sequences. Tick marks along top edge of figure are locations of wells providing subsurface control. Figure is generalized from Molenaar and others (1986). See Figure 5 for location. LCU, Lower Cretaceous unconformity.

The transgression that began with deposition of the Fire Creek continued in Middle and Late Triassic time with deposition of as much as 100 m of richly fossiliferous shale, siltstone, mudstone, and limestone (Shublik Formation). This unit, believed to represent deposition under oceanic, upwelling conditions (Parrish, 1987), is an important petroleum source rock. A thin (<30 m), regressive marine sandstone and siltstone (Sag River Sandstone, Karen Creek Sandstone) gradationally overlies the Shublik Formation along the northern basin margin and marks the end of the Shublik transgressive cycle.

Jurassic to Early Cretaceous (Neocomian) strata consist of as much as 1.5 km of marine shale and siltstone (Kingak Shale and pebble shale unit) with locally developed, predominantly marine sandstones (e.g., Kuparuk Formation). The Kingak Shale, an important petroleum source rock composed of a complex of southward prograding, offlapping and downlapping wedges of shale and siltstone, was deposited during an episode of crustal extension and represents the last complete megacycle of the Ellesmerian sequence. Normal faulting and development of sediment-filled grabens and half-grabens, some with as much as 3 km of fill (e.g., Dinkum graben, Fig. 5; Grantz and others, 1988), occurred mainly north of the present-day coastline; rock types of the graben-fill are unknown because of a lack of well penetrations.

Uplift along the rift margin in Early Cretaceous (Valanginian) time resulted in the formation of a northwesterly elongate land mass that, at its maximum, occupied the area beneath most of the present-day coastal plain and the inner continental shelf. Erosion of this landmass produced the regional Lower Cretaceous unconformity (LCU). Subsidence of the rift margin resulted in a marine transgression and deposition of local sandstones, such as the Kemik Sandstone. A blanket-like marine shale (pebble shale unit) that forms the final deposit of the Ellesmerian sequence constitutes an important petroleum source rock, and provides the seal for many of the petroleum accumulations in the Prudhoe Bay area (Fig. 4). The pebble shale unit is conformably overlain by distal, condensed marine shale deposits (Hue Shale) representing the basal unit of the Brookian sequence.

The **Brookian sequence** includes all of the sediments that were shed across northern Alaska from the Brooks Range orogenic belt. This sequence spans 180 to 150 m.y. (Middle or Late Jurassic to the present) and mostly represents foreland basin deposits developed ahead of northward advancing thrust sheets. The oldest Brookian strata (Jurassic and earliest Cretaceous), probably deposited several hundred kilometers to the south of the present Brooks Range, were tectonically transported in Early Cretaceous time with the Brooks Range allochthons, and are now discontinously preserved in the Brooks Range and adjacent foothills. The majority of Colville basin fill (>8 km thick) is Aptian(?) and younger in age. Filling of the basin occurred from southwest to northeast in a series of migrating depocenters. Because Brookian deposits provided the overburden necessary for petroleum source rocks to be heated to reach maturity, Brookian depocenters provided changing sites of maturity and changing directions of petroleum migration. Shifting depocenters may also reflect geographically and temporally distinct orogenic pulses. Brookian deposits thin northward over the Barrow arch and grade into the passive margin sequence, where they again thicken to as much as 8 km (Fig. 5).

The earliest preserved Brookian depocenter developed during Aptian(?) to Cenomanian time in the western and central part of the North Slope (beneath the Chukchi shelf and the NPRA). During Cenomanian to Eocene time, the depocenter shifted to the central part of the North Slope (approximately the area between the NPRA and the ANWR). From Eocene time to the present, the depocenter has been located in the northern ANWR and adjacent offshore (Moore and others, in press).

Seismic reflection profiles show that the Brookian sequence is characterized by well-developed sigmoidal reflectors. These reflectors, interpreted as time lines, record successive basin profiles (Molenaar, 1988). Well and outcrop studies show that (1) topset reflections represent deltaic coal-bearing sandstone, conglomerate, and shelf shale deposits, (2) foreset reflections depict slope shale and turbidite sandstone deposits, and (3) bottomset reflections include basin-plain shale and turbidite sandstone deposits and distal, condensed shale with interbedded volcanic ash (Molenaar and others, 1987; Molenaar, 1988). Brookian deltaic deposits include the Nanushuk Group and Sagavanirktok Formation; marine shelf, slope, and basin-plain shale and interbedded sandstone include the Torok and Canning Formations; and distal, condensed basin-plain shale and bentonites are represented by the Hue Shale (Figs. 7, 8).

THERMAL HISTORY

Compared to most basins, the broad outlines of the thermal history are reasonably well known for the onshore North Slope; for most parts offshore, there are no direct observations. Undoubtedly this region has been affected by regional thermal events related to rifting and thrusting, as well as localized events related to magma intrusion, contrasts in radioactive heat production, fluid flow, and thermal conductivity variations. However, the contribution and relative importance of these factors at any particular locality are poorly known. Our knowledge of North Slope thermal history is based on measurements of organic metamorphism for surface and well samples (mainly vitrinite reflectance, R_o), thermal alteration index, conodont alteration index, present-day thermal profiles, and most recently, apatite fission-track analysis. Trends of organic metamorphic thresholds for the onset of oil (R_o = 0.6 percent), condensate (R_o = 1.3 percent), and dry gas (R_o = 2.0 percent) generation are plotted on the north-south structure section (Fig. 6). These trends and other features are discussed below.

Organic metamorphic grade of rocks at the surface and at similar subsurface depths generally decreases northward across the North Slope; this is a reflection of uplift and erosion in the orogenic belt and subsidence and sedimentation in the adjacent foredeep basin and passive margin. Data from Brosge and others (1981), Harris and others (1987), and Magoon and Bird (1987, 1988) show that the 2-percent R_o value is generally found at the surface within the northern margin of the Brooks Range and at depths of 4 km or more beneath the Colville basin. The 0.6-percent R_o value intersects the surface in the foothills and plunges northward and eastward into the subsurface; along the coastline it occurs at a depth of about 600 m near Point Barrow and about 4,000 m at the western edge of the ANWR. The distance (vertical separation) between R_o values 0.6 and 2.0 percent tends to increase from about 1.5 km in the north to about 4.5 km in the south, apparently a reflection of higher thermal gradients to the north and lower gradients to the south.

The Lisburne-1 well, located near the northern edge of the Brooks Range (Fig. 5, well no. 8), shows a progressive vitrinite reflectance increase with depth through five thrust repetitions (Magoon and others, 1988, pl. 19.38). This relation appears to indicate that thermal maturity was achieved after thrusting and before uplift. At this site, more than 3 km of uplift and erosion are indicated.

For the offshore Beaufort passive margin, Grantz and others (1988) utilized heat flow measurements from the Canada basin, combined with a model of passive-margin thermal history, to estimate that the top of the oil-generating zone occurs about 3 km below the sea floor, and the top of the thermal gas generation zone occurs at about 6 km.

Thermal history relative to hydrocarbon maturation at the 6,127-m-deep Inigok well in the eastern part of the NPRA is illustrated in Figure 9. Burial history curves for this well show continuous subsidence and sedimentation from Mississippian to middle Tertiary time, followed by an estimated 300 m of uplift and erosion. Lopatin's method of integrating time and temperature (Waples, 1980) shows that thermal conditions favorable for oil generation (TTI value of 10) in the Endicott Group and lower part of the Lisburne Group occurred here as early as Triassic time. As subsidence and burial continued, the zone of oil generation (TTI 10 to 1,000) effectively moved upward through the stratigraphic section to its present position, encompassing rocks of Jurassic to mid-Cretaceous age between the depths of 1,980 to 3,690 m. The zone of oil generation is expected to have migrated northeastward across the North Slope in concert with the filling of the Colville basin.

The present-day North Slope thermal regime is characterized by thick permafrost and variable geothermal gradients (American Association of Petroleum Geologists and U.S. Geological Survey, 1976; Blanchard and Tailleur, 1982; Lachenbruch and others, 1988). The long-term mean surface temperature systematically varies from -12° C along the northern coast to -4° C inland near the Brooks Range. Depth to base of permafrost, the 0° C isotherm, generally ranges from 200 to 400 m, but in the area of the Prudhoe Bay oil field it reaches a depth of 630 m. Thermal gradients within the permafrost range from 15 to 50° C/km, while gradients below the permafrost range from 24 to 47° C/km. Although a simple pattern of gradient variation has yet to emerge from these data, higher gradients are generally found in coastal plain wells (area of Barrow arch and northern flank of Colville basin) and lower gradients in foothill wells (area of Colville basin and the fold and thrust belt). Anomalous thermal characteristics -- high geothermal gradients, thin permafrost, and a shallow occurrence of the oil window -- have been identified in the area of the South Meade well and in wells on the Fish Creek platform (Fig. 5). The origin of these anomalies is unknown.

The present-day North Slope thermal regime provides conditions suitable for the occurrence of natural gas hydrates (solids composed of light gases caged in an ice crystal lattice). Gas hydrates may occur offshore where water depths exceed about 400 m or onshore where permafrost thickness exceeds 240 m. Evidence for the presence of gas hydrate was found on about 75 percent of the seismic lines collected in areas along the continental slope north of Alaska where water depths exceed 400 m (Grantz and others, 1988). A comprehensive study of onshore North Slope hydrates (Collet and others, 1988) shows that multiple hydrate-bearing reservoirs underlie the western part of the Prudhoe Bay oil field and the eastern part of the Kuparuk River oil field (Fig. 4). The amount of gas contained in these hydrates is estimated at 10 to 12 x 10^{12} ft^3 (28 to 34 x 10^{10} m^3), or about half the volume of gas in the Prudhoe Bay oil field.

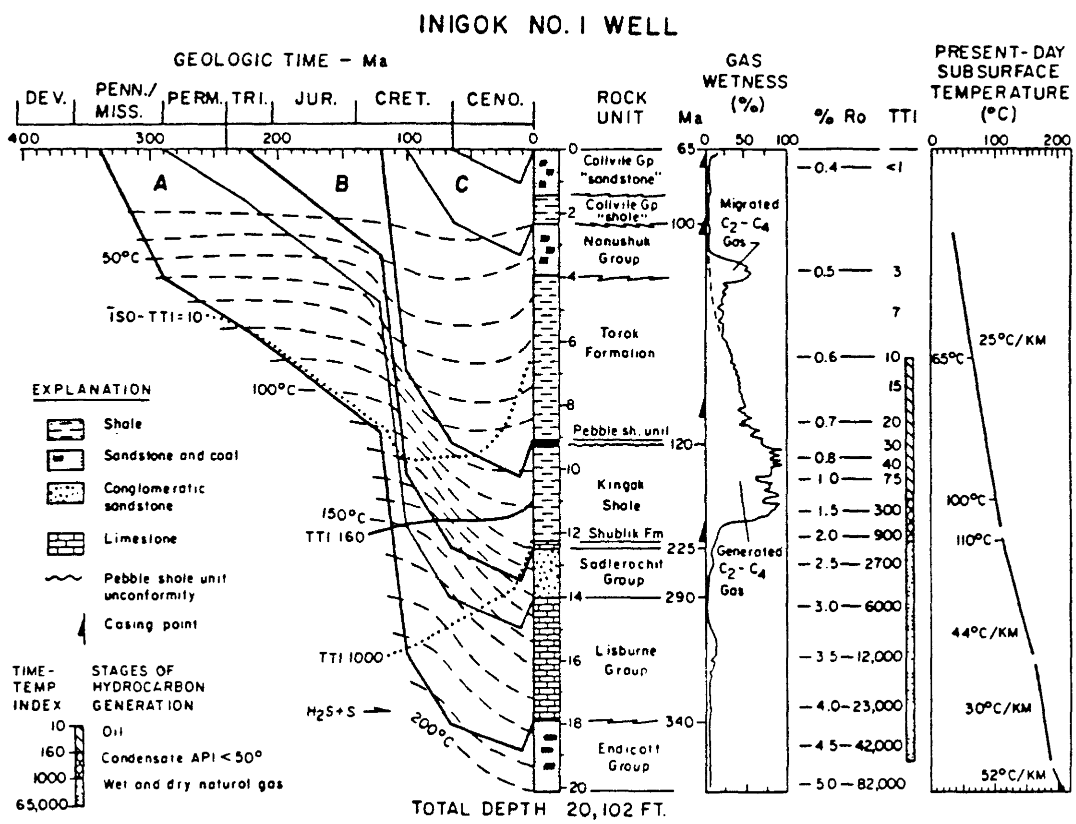

Figure 9. Burial and thermal history of the second deepest well in Alaska, Inigok-1, central North Slope (from Magoon and Claypool, 1983). Zone of oil (and condensate) generation, which corresponds to interval between time-temperature index (TTI) values of 10 and 1000, is confirmed by the gas wetness curve, based on analysis of drill cuttings. The Inigok well is located in Figure 5, well number 4.

OILS AND SOURCE ROCKS

Chemical analyses of North Slope oils and source rocks indicate that there are multiple oil types that have been generated by multiple source rocks. Prior to the discovery of the Prudhoe Bay field, investigations of North Slope oils from wells and seeps (McKinney and others, 1959) focused on the quality of products that could be derived from these oils rather than their relations to source rocks or to other oils. This emphasis changed, however, with the discovery of multiple oil-bearing reservoirs in the Prudhoe area (Fig. 4). Analysis indicated that oils from widely separated Prudhoe-area reservoirs --Sadlerochit, Kuparuk, and Sagavanirktok--were similar and thus, commonly sourced (Jones and Speers, 1976).

The most comprehensive study aimed at discovering related types of North Slope oils is that of Magoon and Claypool (1981). From their analyses of 40 samples collected from seeps and wells all across the North Slope, two groups of oil were identified: (1) the Barrow-Prudhoe (from the Barrow and Prudhoe Bay fields), and (2) the Simpson-Umiat (from the Simpson seeps and Umiat field). The Barrow-Prudhoe group, volumetrically the predominant North Slope oil, occurs in reservoirs of Mississippian to Tertiary age. It is characterized by high sulfur content, medium API gravity, light isotopic composition and a pristane-phytane ratio less than 1.5. The Simpson-Umiat group occurs in Cretaceous and Tertiary reservoirs and, surprisingly, is the only oil found in seeps. This group is characterized by low sulfur content, high API gravity, heavy isotopic composition, and a pristane-phytane ratio greater than 1.5.

Other studies of the same and newly discovered oils (e.g., Seifert and others, 1980; Magoon and Claypool, 1985, 1988; Curiale, 1987; Sedivy and others, 1987; Anders and others, 1987) reveal various oil types within the two groups. Many investigators now regard the Simpson and Umiat oils as being derived from different terrigenous source-rock facies. Additional oil types identified within the Simpson-Umiat group include the Manning (from the Manning Point seep), the Jago (from oil-stained rocks along the Jago River), and the Kavik (from oil-stained rocks near the Kavik field) in the ANWR area (Anders and others, 1987) and the pebble shale in the Barrow area (Magoon and Claypool, 1988). The Kingak oil in the Prudhoe area, a type within the Barrow-Prudhoe oil group, is locally derived from the marine Kingak Shale (Seifert and others, 1980).

The organic-carbon content of most North Slope rock-units exceeds the threshold value of 0.5 weight-percent of potential petroleum source rocks (Fig. 10); although their hydrogen content, an indicator of propensity to generate oil or gas, varies considerably. Generally, the deltaic and prodeltaic units (Endicott Group, Sadlerochit Group, Nanushuk Group, Torok Formation, Colville Group, Sagavanirktok Formation, and Canning Formation) that have relatively high organic-carbon content but low hydrogen content are considered gas-prone source rocks. Marine units such as the Shublik Formation, Kingak Shale, Hue Shale, and parts of the pebble shale unit, which have both high organic-carbon and hydrogen content, are considered oil-prone source rocks (Fig. 7). The inferred North Slope thermal history indicates that all but the youngest of these rock units are mature to overmature somewhere on the North Slope (Magoon and Bird, 1988).

Considerable effort has been devoted to matching North Slope oils with specific source rocks. The earliest efforts (Morgridge and Smith, 1972) identified Cretaceous shales above the LCU and the Kingak Shale (Fig. 4B) as the most probable source rocks for the Prudhoe Bay oils, based on geologic relations and bulk geochemical characteristics of the proposed source rocks. Later, comparison of biomarker compounds from rocks and oils (Seifert and others, 1980) suggested that these oils were sourced from an assemblage of rocks including the Shublik Formation, Kingak Shale, and deeply buried HRZ shale (Hue Shale). Isotopic correlations of Sedivy and others (1987, Fig. 10) complement the biomarker results by showing an excellent correlation between source rocks (Shublik Formation and Kingak

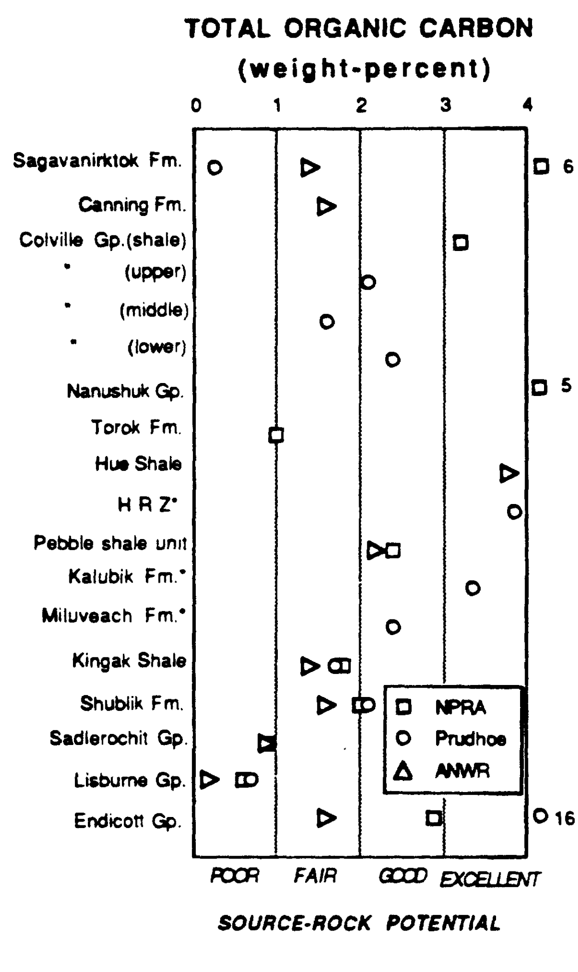

Figure 10. Average organic-carbon content of North Slope rock units. NPRA area values modified from Magoon and Bird (1988); Prudhoe Bay area values from Sedivy and others (1987); ANWR areas values from Magoon and others (1987). Rock units with values greater than 4-percent are coal bearing.

Shale) and the Prudhoe oils. The landmark USGS-sponsored oil-rock correlation study (Magoon and Claypool, 1985) was a multilaboratory effort that focused on a common set of oil and candidate source-rock samples, mostly from outside of the Prudhoe Bay area. The majority (17 of 30 laboratories) agreed that the Shublik Formation and, to a lesser extent (eight laboratories), the Kingak Shale are source rocks for the Prudhoe oils. There was also general agreement (14 laboratories) that the pebble shale unit and, to a lesser extent (seven laboratories), the Torok Formation are source rocks for the Umiat oil type (Claypool and Magoon, 1985).

Geologic relations, source-rock geochemistry, and oil analyses indicate that the most important petroleum source rocks for the North Slope are marine shales of Mesozoic age. These rocks began to generate oil as early as mid-Cretaceous time, and some may continue to generate oil today. Magoon (1989) recognizes three separate North Slope petroleum systems--a petroleum system is that set of geologic elements (such as source rocks and reservoir rocks) and processes (such as petroleum generation, migration, and entrapment) necessary to form oil and gas deposits. The Ellesmerian petroleum system is responsible for most North Slope oil (Barrow-Prudhoe group). Most of this oil originated from Triassic and Jurassic source rocks and accumulated in early-formed traps on the Barrow arch in the Prudhoe Bay area during Late Cretaceous and early Tertiary time. Eastward regional tilting in middle to late Tertiary time redistributed this oil, changed the size and shape of accumulations, and even created new accumulations (Jones and Speers, 1976; Carman and Hardwick, 1983; Bird, 1985; Werner, 1987). The Simpson-Umiat oil group originated from two petroleum systems. Those oils of this group from west of the Prudhoe Bay area are of the Torok-Nanushuk petroleum system, while those oils east of Prudhoe Bay are of the Hue-Sagavanirktok petroleum system (Magoon, 1989; in press).

PRINCIPAL PETROLEUM PLAYS

In petroleum exploration and assessment, a play represents an area and stratigraphic interval characterized by geologically similar petroleum prospects. The recently completed assessment of United States undiscovered conventional oil and gas resources utilized a play analysis method (Mast and others, 1989). The twelve plays identified and assessed for the North Slope are described below in approximate geographic and stratigraphic order from north to south and youngest to oldest. These plays are newly defined or modifications of the 17 plays previously defined in the NPRA (Bird, 1988) and the seven plays defined in the ANWR (Dolton and others, 1987). The stratigraphic interval encompassed by each play is shown in Figure 7, the areal distribution of each play is shown in Figures 11 to 18, and the area covered by each play is tabulated in Table 3.

Table 3. Areas of North Slope petroleum plays relative to selected physical and cultural features. Percentages are of total play area. Province boundaries are those followed in the national assessment and illustrated in Varnes and others (1981). Areas were determined by planimetering 1:1,000,000-scale map. NPRA, National Petroleum Reserve in Alaska; ANWR, Arctic National Wildlife Refuge. See play maps (Figures 11 to 18) for play outlines.

PLAY	AREA: TOTAL ($mi.^2$)	AREA: STATE OFFSHORE	AREA: ONSHORE	AREA: NPRA	AREA: ANWR	PROVINCE: Coastal Plain	PROVINCE: Northern Foothills	PROVINCE: So. Foothills-Brooks Range
Topset	23,765	3,231 (14%)	20,534 (86%)	14,811 (62%)	371 (2%)	86%	--	--
Turbidite, West	18,193	2,187 (12%)	16,006 (88%)	14,811 (81%)	-- --	88%	--	--
Turbidite, East	7,860	1,349 (17%)	6,511 (83%)	1,037 (13%)	371 (5%)	83%	--	--
Barrow Arch	5,749	2,276 (40%)	3,473 (60%)	1,034 (18%)	185 (3%)	60%	--	--
Ellesmerian Clastics	33,559	1,035 (3%)	32,524 (97%)	23,347 (70%)	144 (<1%)	58%	39%	--
Lisburne	14,718	478 (3%)	14,240 (97%)	11,098 (75%)	163 (1%)	97%	--	--
Lisburne Unconformity	18,521	1,527 (8%)	16,994 (92%)	11,804 (64%)	89 (<1%)	92%	--	--
Endicott	15,491	497 (3%)	14,994 (97%)	11,826 (76%)	163 (1%)	97%	--	--
Fold Belt, West	31,098	588 (2%)	30,510 (98%)	16,452 (53%)	-- --	--	93%	5%
Fold Belt, East	6,352	503 (8%)	5,849 (92%)	-- --	4,366 (69%)	27%	43%	22%
Thrust Belt, West	20,759	579 (3%)	20,179 (97%)	4,844 (23%)	318 (2%)	--	--	97%
Thrust Belt, East	9,723	487 (5%)	9,136 (95%)	-- --	8,308 (85%)	15%	24%	56%

Topset Play

The Topset play consists of stratigraphic traps in sandstone reservoirs of Cretaceous and Tertiary age and includes those rocks represented on seismic records in the topset position of a clinoform sequence. These rocks, the Nanushuk Group and Sagavanirktok Formation, consist of marine and nonmarine deltaic sandstone, siltstone, shale, conglomerate, and coal (Fig. 7). These are the youngest petroleum prospective rocks in the province. Their total thickness, about 3,000 m, is also the maximum drilling depth in the play area. The play is limited to the area of relatively flat-lying strata north of the fold and thrust belt (Fig. 11).

Reservoir rocks in this play consist of sandstone and conglomerate and may comprise as much as half of the total thickness of the play interval, even though individual beds seldom exceed 15 m. Fair to good reservoir continuity is expected parallel to depositional strike (northwesterly) but marked changes may occur over short distances perpendicular to strike. Porosity is expected to improve eastward, from 10 to 20 percent in the western part of the play to better than 20 percent in the eastern part.

Potential source rocks within the play are interbedded deltaic shales and mudstones which are immature and probably gas-prone. Beneath the play interval are marine foreset and bottomset shales and the informally designated pebble shale unit; these rocks are fair to good oil source rocks and are immature to marginally mature in the play area. Oil shows are reported in several wells just west of the ANWR from the lower part of the Sagavanirktok Formation. The multi-billion barrel West Sak and Ugnu heavy oil and tar accumulations just west of the Prudhoe Bay field are within this play as are the smaller oil accumulations, Fish Creek and Simpson, located in the northeastern part of the NPRA (Fig. 11).

Postulated traps in this play are mostly stratigraphic and are related to facies changes, cut and fill structures, or traps formed against small-displacement normal faults. Faults and interbedded shales are expected to provide only fair to poor seals. Because of the poor sealing characteristics in this play, hydrocarbon accumulations are expected to consist of oil rather than gas. Although thousands of wells (exploratory and development) have penetrated the rocks of this play, relatively few have been drilled for prospects within this play.

Western Turbidite Play

The Western Turbidite Play consists of stratigraphically trapped deep-marine sandstone reservoirs of Cretaceous age, and includes those rocks represented by the foreset and bottomset seismic reflectors in the clinoform sequence beneath the western part of the coastal plain, north of the fold and thrust belt. The play is limited to the Torok Formation (Fig. 7), the eastern limit of which lies at about longitude150° 30' W, where the Torok thins by downlap to less than 100 m and grades laterally into the Hue Shale

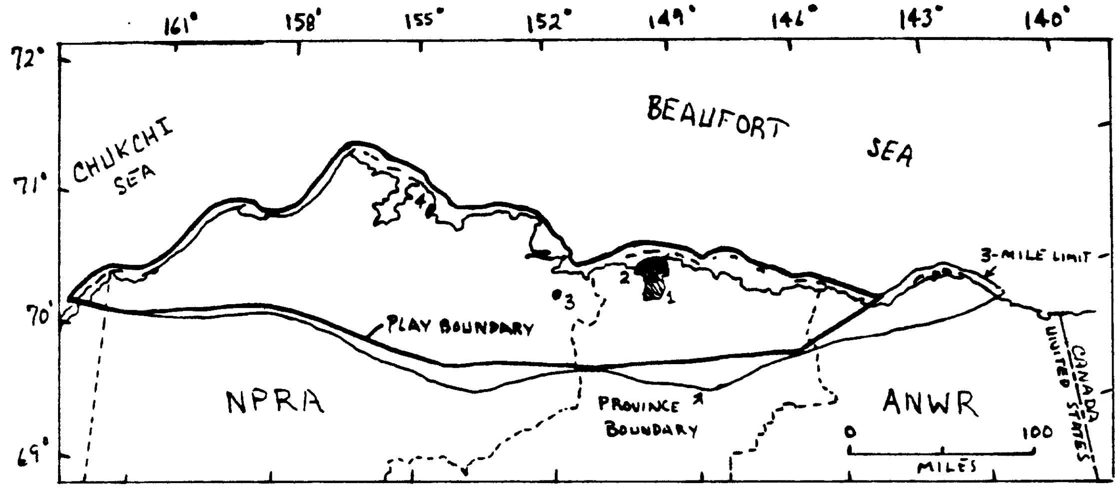

Figure 11. Areal distribution of the Topset play and oil accumulations in the play: (1) West Sak, (2) Ugnu, (3) Fish Creek, and (4) Simpson. NPRA, National Petroleum Reserve in Alaska. ANWR, Arctic National Wildlife Refuge.

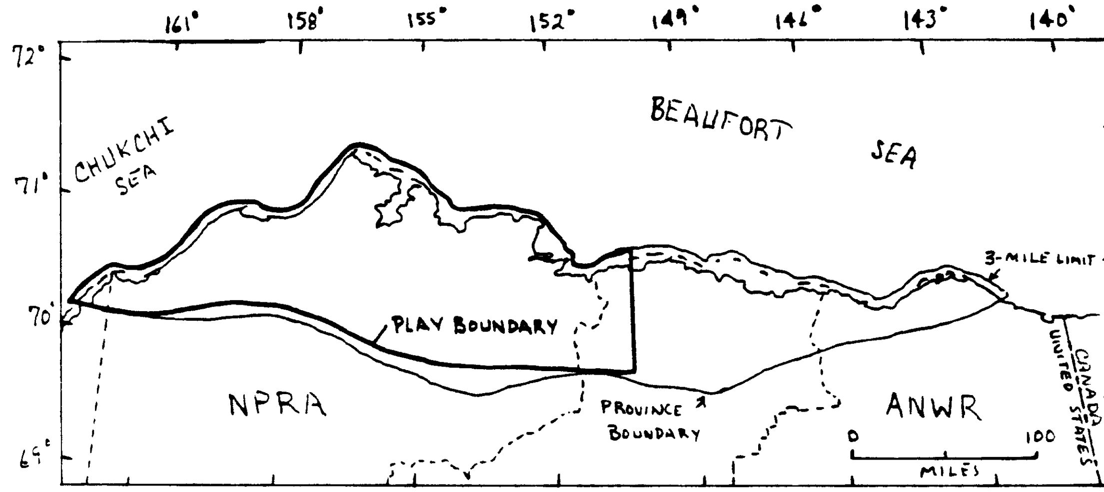

Figure 12 Areal distribution of the Western Turbidite play. NPRA, National Petroleum Reserve in Alaska. ANWR, Arctic National Wildlife Refuge.

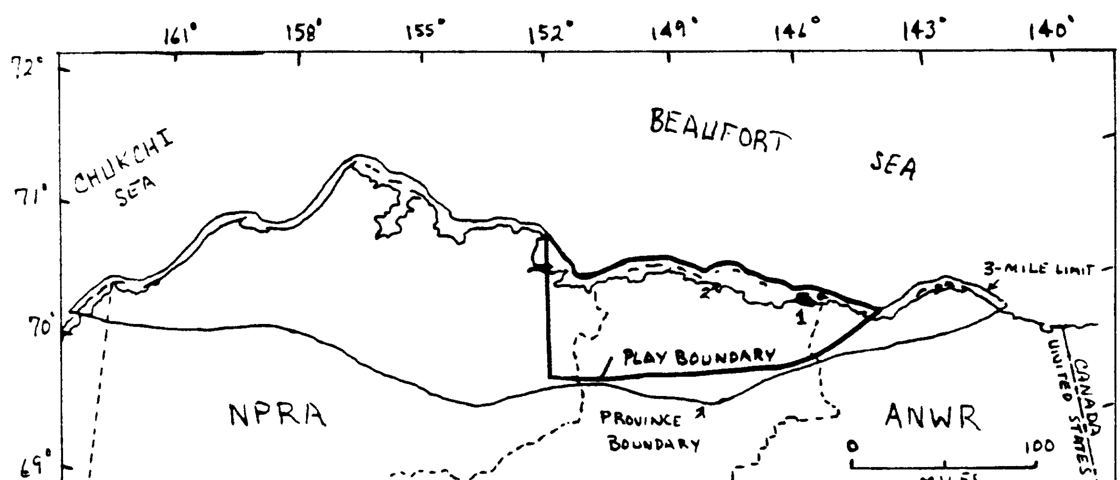

Figure 13. Areal distribution of the Eastern Turbidite play and areas where oil and gas have been found: (1) Point Thomson-Flaxman Island, (2) Point McIntyre. NPRA, National Petroleum Reserve in Alaska. ANWR, Arctic National Wildlife Refuge.

(Fig. 12). Rock types in this play are predominantly marine shale and siltstone with minor amounts of sandstone. The maximum play interval thickness is about 1,800 m, and drilling depths range from near the surface in the Barrow area to a maximum depth of about 3,000 m.

Reservoir rocks may occur anywhere within the play interval, but they are most frequently encountered in the lower half of the play interval as toe-of-slope or basin-plain turbidites. Individual sandstone bodies are expected to be thin, laterally discontinuous, and to have an aggregate thicknesses of several tens of meters. Porosity in Torok sandstone is expected to be in the 5 to 15 percent range.

Source rocks include the marine shale of the Torok, which is expected to be relatively gas-prone, and the underlying Hue Shale, pebble shale unit, Kingak Shale, and Shublik Formation, all of which are relatively more oil-prone shales. All of these shales are marginally mature to mature in the play area. Although oil and gas indications have been found in numerous wells, no accumulations are known in this play.

Postulated traps in this play are stratigraphic and are related to facies changes or traps formed against small-displacement normal faults. Faults and the surrounding thick marine shales are expected to provide fair to good seals. Prospects are difficult to map in this play. Of the several dozen exploratory wells that have penetrated this play, few, if any, are believed to have been drilled for prospects.

Eastern Turbidite Play

The Eastern Turbidite Play consists of stratigraphically trapped deep-marine sandstone reservoirs of Late Cretaceous and Tertiary age, and includes those rocks represented by the foreset and bottomset seismic reflectors in the clinoform sequence beneath the eastern part of the coastal plain, north of the fold and thrust belt (Fig. 13). The Eastern Turbidite play is composed primarily of the Canning Formation (Fig. 7). West of longitude 150° 30' W, this play includes a marine shale tongue, a part of the Colville Group which overlies rocks of the Western Turbidite play and part of the Nanushuk Group. Rock types in this play are predominantly marine shale and siltstone with minor amounts of sandstone. The maximum play interval thickness is about 1,800 m, and drilling depths range from near the surface in the westernmost part of the play to a maximum depth of about 4,600 m.

Reservoir rocks may occur anywhere within the play interval, but they are most frequently encountered in the lower half of the play interval as toe-of-slope or basin-plain turbidites. Individual sandstone bodies are expected to be thin, laterally discontinuous, and to have an aggregate thickness of several tens of meters. Porosity in Canning Formation sandstone is expected to be in the 10 to 30 percent range. Abnormally high fluid pressures are present in the easternmost part of this play, and as a result, porosities should be better than normally expected for rocks at these depths.

Source rocks include the marine shale of the Canning, which is expected to be relatively gas-prone, and the underlying Hue Shale, pebble shale unit, Kingak Shale, and Shublik Formation which are relatively more oil-prone shales. All of these shales are marginally mature to mature in the play area. Oil and gas have been recovered from turbidite reservoirs in several wells in the Point Thomson and Flaxman Island area adjacent to the ANWR (Fig. 13). The upper of two oil-bearing reservoirs in the recently discovered Point McIntyre field, located in State waters in Prudhoe Bay, may be in this play.

Postulated traps in this play are stratigraphic and are related to facies changes or traps formed against small-displacement normal faults. Faults and the surrounding thick marine shales are expected to provide fair to good seals. Prospects are difficult to map in this play. Of the several 100 or more exploratory wells that have penetrated this play, few, if any, are believed to have been drilled for prospects.

Barrow Arch Play

The Barrow Arch play consists of broad, anticlinal structures involving Mississippian to Early Cretaceous rocks that are found in a relatively narrow strip along the northern coast of Alaska (Fig. 14). Traps in this play often have an important component of faulting and erosional truncation (Fig. 4B). The northern limit of the play is approximately the outer limit of State offshore waters. The southern limit is arbitrarily selected as the downdip limit (on the south flank of the Barrow arch) of the characteristic structural-stratigraphic trapping mechanism described above.

Potential reservoir rocks include both sandstone and carbonate rocks (Fig. 7). Sandstone reservoirs (Kekiktuk Conglomerate, Sadlerochit Group, Sag River Sandstone, unnamed Jurassic sandstones, Kuparuk River Formation, and Put River Sandstone and its equivalents) predominate over carbonate reservoirs (Lisburne Group). The most important reservoir is expected to be the nonmarine to shallow-marine Sadlerochit reservoir. Porosity in sandstone reservoirs is expected to average better than 20 percent; limestone porosity is expected to be less than 5 percent, with that in the dolomite variable, but potentially as high as 20 percent or more. All potential reservoirs in this play have oil shows or are oil productive. Drilling depths range from 500 m to 4,500 m.

Potential source rocks include marine shale of Triassic to Early Cretaceous age including the Kavik Member of the Ivishak Formation, Shublik Formation, Kingak Shale, pebble shale unit, and Hue Shale. Lacustrine shale, mudstone, and coal of Mississippian age may also be source rocks in this play. All potential source rocks are marginally mature within the play are, but are mature to overmature south of the play area, and where present, are also overmature to the north.

Traps in this play are generally combinations of structure and stratigraphy. Closure is generally achieved by faulting and partial truncation of the reservoir in broad, gentle anticlines. Truncation is

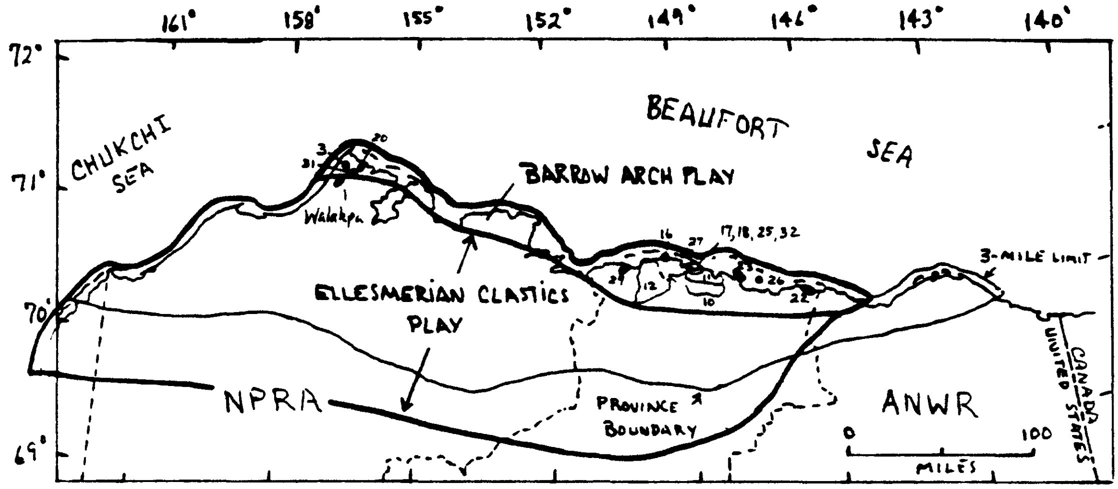

Figure 14. Areal distribution of the Barrow Arch play and the Ellesmerian Clastics play. Oil and gas accumulations in each play are keyed to numbers in Table 1. See also Figure 4 for detailed map of oil and gas fields. NPRA, National Petroleum Reserve in Alaska. ANWR, Arctic National Wildlife Refuge.

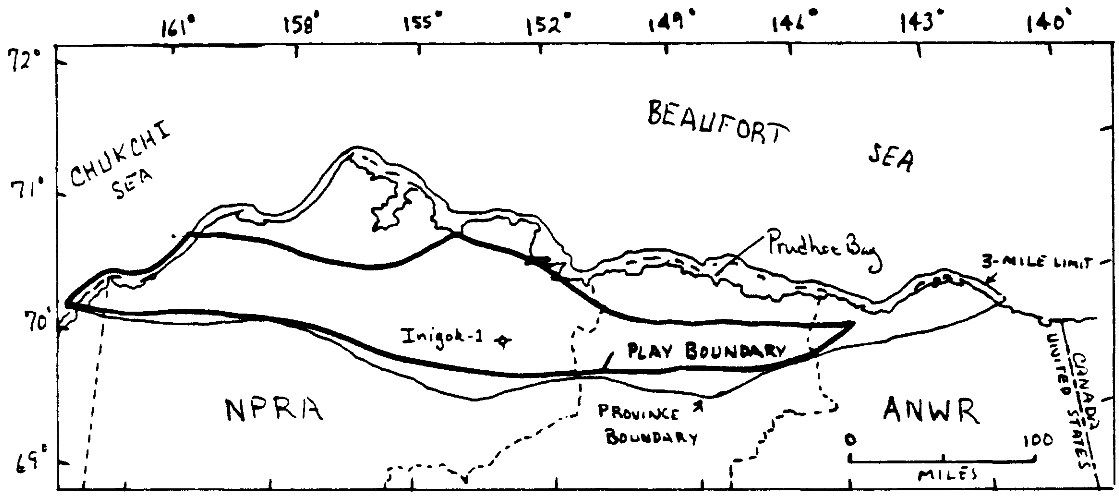

Figure 15. Areal distribution of the Lisburne play. NPRA, National Petroleum Reserve in Alaska. ANWR, Arctic National Wildlife Refuge.

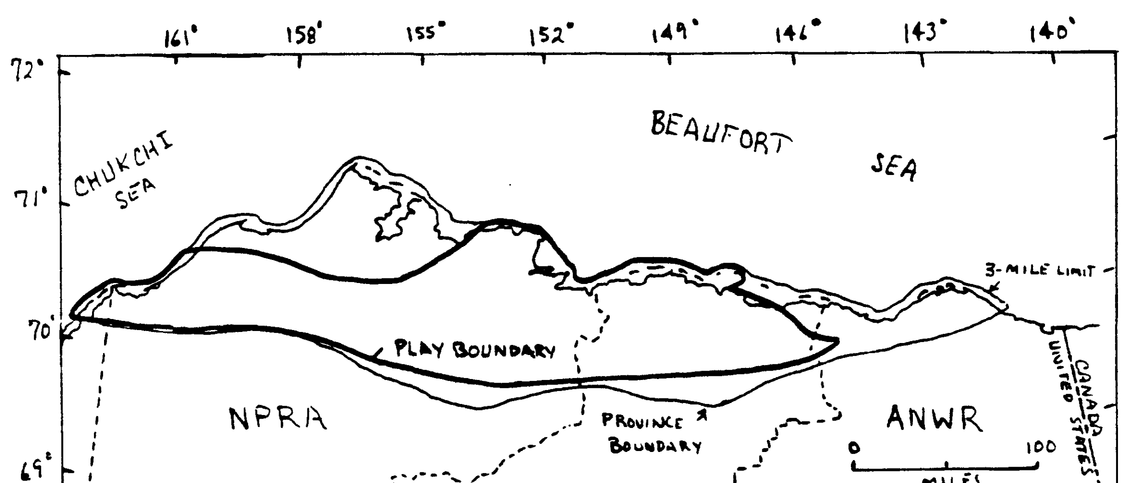

Figure 16. Areal distribution of the Lisburne Unconformity play. NPRA, National Petroleum Reserve in Alaska. ANWR, Arctic National Wildlife Refuge.

usually the result of a regionally prevalent Lower Cretaceous unconformity, and sealing is accomplished by the overlying pebble shale unit and younger marine shales. All currently productive North Slope fields are in this play (Endicott, Kuparuk River, Lisburne, Milne Point, Prudhoe Bay oil fields and the South and East Barrow gas fields), as well as numerous subeconomic accumulations (Gwydyr Bay, North Prudhoe Bay, Seal Island, Tern Island, Point Thomson, Colville Delta, Niakuk, and Point McIntyre). This is the most intensly explored play on the North Slope with about 200 exploratory wells, some of which date from the beginning of North Slope drilling in 1946.

Ellesmerian Clastics Play

The Ellesmerian Clastics play consists of stratigraphic, structural, and combination traps of sandstone reservoirs in the gently south-dipping Permian to Early Cretaceous part of the Ellesmerian sequence (above the Lisburne Group)(Fig. 7). The play interval consists mostly of siltstone and shale with as much as 10-percent sandstone. The northern boundary of the play is the southern boundary of the Barrow Arch play, where the play interval may be as thin as 120 m. The southern play boundary lies beneath the northern part of the Northern Foothills province, where the play interval, which may be as thick as 1,800 m, occurs at depths greater than 4,500 m, yielding vitrinite reflectance values greater than 2 percent (Fig. 14).

Reservoir rocks in this play consist of sandstone deposited primarily in shallow-marine environments. Also present are minor amounts of fluvial sandstone in the northernmost areas of the play and turbidite sandstone of northern derivation in the southernmost areas of the play. Potential reservoirs include the Echooka Formation, Ivishak Formation, Sag River Sandstone, several unnamed sandstone units in the Kingak Shale, Kuparuk Formation, and stratigraphic equivalents of the Kemik Sandstone. Porosities may reach 25 percent in the northern parts of the play area, but are anticipated to decrease to less than 10 percent in the southern parts of the play area. Drilling depths range from 600 m in the north to 6,100 m at the southern play boundary. Most reservoirs, particularly those with the best porosity, are expected to occur beneath the coastal plain province, where drilling depths are generally less than 3,600 m.

The play interval contains many of the richest source rocks on the North Slope, including the Kavik Shale, Shublik Formation, Kingak Shale, pebble shale unit, and Hue Shale. These shales are mature throughout most of the play, but range from marginally mature in the northernmost parts of the play to overmature in the southern parts of the play. Oil and gas shows are reported in several wells in this play, and a gas accumulation of undetermined size is present just south of Barrow (Walakpa).

Because of the homoclinal south dip of strata comprising this play and the rarity of structural reversals, oil and gas accumulations in this play are expected to be trapped in stratigraphic or combination structural and stratigraphic traps. Shales within the play interval are expected to provide adequate seals. A few dozen exploratory wells have penetrated this play, only a few of which were drilled for prospects in the play interval. Estimated conventional oil and gas resources in this play have been apportioned to the Coastal Plain province (80%) and to the Northern Foothills province (20%).

Lisburne Play

The Lisburne play consists of structurally and stratigraphically trapped carbonate or clastic reservoirs of the Lisburne Group (Fig. 7). The northern play boundary in the north-central part of the NPRA is the Lisburne onlap limit; east of longitude154° W, it is the southern boundary of the Barrow Arch play. The southern boundary of the play is approximately the south boundary of the coastal plain province, where the Lisburne is buried to depths greater than 4,500 m, and vitrinite reflectance values are greater than 2 percent (Fig. 15). The Lisburne Group is composed of shallow-marine limestone and dolomite with minor amounts of interbedded shale and sandstone. Lisburne thickness varies and may be as much as 1,200 m.

Potential reservoir rocks include dolomite, limestone, and sandstone. Dolomite, the most important reservoir with porosity occassionally as high as 25 percent, is expected to occur most abundantly in the late Mississippian part of the Lisburne as in the Prudhoe Bay area. Dolomite of this age is not expected in the northernmost or western part of the NPRA because Lisburne of this age is missing by onlap. Limestone porosity in the Lisburne is expected to average less than 5 percent, thus constituting a poor potential reservoir. Sandstone, which may be common along the northern onlap edge in the NPRA, may be partially to completely cemented with calcite and, thus, a marginal reservoir. Depth to the top of the Lisburne in this play ranges from 2,750 m to 6,100 m.

Potential source rocks include marine shale in the overlying Sadlerochit Group, marine shale and limestone within the Lisburne, and marine to lacustrine shale and coal in the underlying Endicott Group. Where truncated by the regional Lower Cretaceous unconformity, such as the western edge of the ANWR, the pebble shale unit and the Hue Shale overlying the unconformity may be important source rocks for the Lisburne. Limited geochemical data suggest that all except the pebble shale unit and Hue Shale are fair to poor, gas-prone source rocks that are mature in the northern part of the play and overmature in the southern part. Oil residue is often encountered in porous dolomite in the Lisburne, and hydrogen sulfide gas was encountered in interbedded limestone and shale near the Lisburne-Endicott boundary at a depth of about 5,330 m in Inigok-1 well, near the southern play boundary in the eastern NPRA (Fig. 15).

Stratigraphic traps related to the Lisburne onlap edge and to facies changes are expected in the northern part of the play area. Structural traps are relatively rare, although in the NPRA folding and faulting during Carboniferous and Permian(?) time produced some structures, such as that drilled by the Inigok well. Seismic reflection records in the northwestern part of the NPRA suggest that carbonate buildups may be present. Interbedded shale and impermeable limestone are expected to provide adequate seals. Only a few exploratory wells have been drilled for prospects in this play, and no hydrocarbon accumulations are known.

Lisburne Unconformity Play

The Lisburne Unconformity play consists of stratigraphic traps developed as a result of differential erosion on the regional Permian unconformity that lies at the top of the Lisburne Group (Fig. 7). Postulated traps are envisioned to consist of erosional scarps and remnants of porous Lisburne Group carbonates sealed by the overlying Sadlerochit Group. These postulated traps are analogous to those which trap most Mississippian oil and gas accumulations beneath the plains of Alberta (Procter and Macauley, 1968). This play is considered speculative because the amount of differential erosion on the Permian unconformity is largely unknown. Evidence for relief on this unconformity is known from outcrops in the eastern Shublik Mountains of the ANWR where conglomerate-filled channels cut into the uppermost part of the Lisburne Group (Reiser and others, 1971; see also Crowder, 1990).

The play encompasses the entire area of Lisburne Group beneath the Permian unconformity, including that area overlying the Barrow arch (Fig. 16). The Barrow arch area is included in this play because the size distribution of oil and gas accumulations in this play is likely to be significantly different from that in the Barrow arch play. The southern limit of this play coincides with the southern limit of the Lisburne play.

Reservoir rocks and source rocks for this play are expected to be the same as for the Lisburne play. Depth to the Lisburne unconformity in the play area ranges from about 2,450 m to 6,100 m. As many as 50 exploratory wells may have penetrated this play, but few, if any, were drilled for prospects in this play.

Endicott Play

The Endicott play consists of structural, stratigraphic, and combination traps in sandstone reservoirs in the Kekiktuk Conglomerate and sandstone or dolomite reservoirs in the overlying Kayak Shale, both formations belonging to the Endicott Group (Fig. 7). The northern boundary of the play in the north-central part of the NPRA is the onlap edge of the Endicott Group; east of longitude 155° W, it is the southern boundary of the Barrow Arch play. The southern boundary of the play is the southern boundary of the coastal plain province where these rocks are buried to depths of more than 6,100 m and have vitrinite reflectance values greater than 2 percent (Fig. 17). Thickness of the Endicott Group is generally 30 to 300 m, but locally may be as much as 3,000 m.

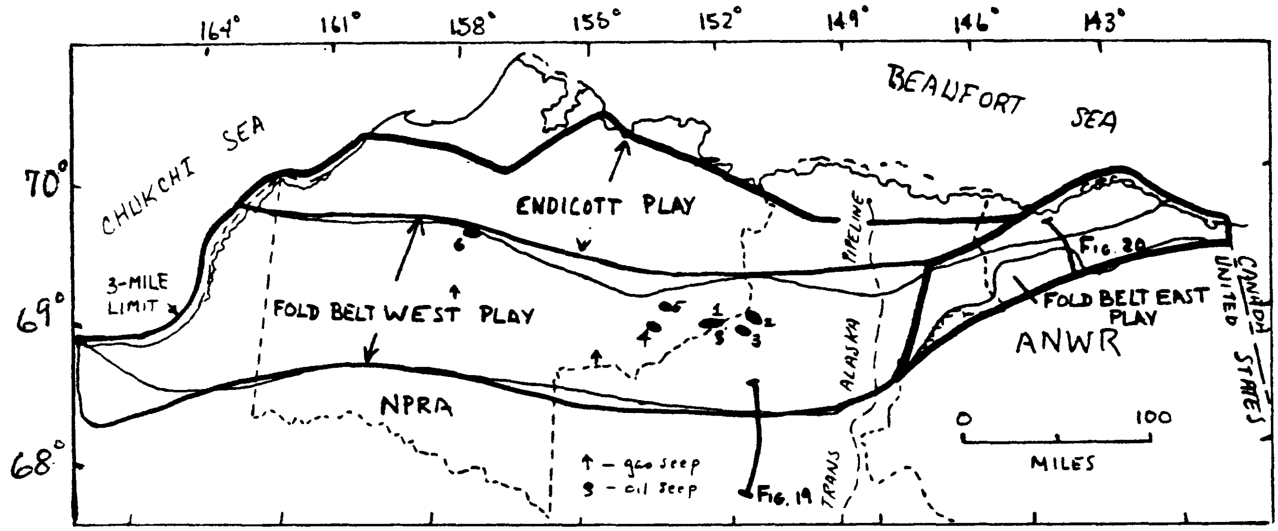

Figure 17. Areal distribution of the Endicott, Fold Belt West, and Fold Belt East plays. Numbers and symbols refer to oil and gas fields (Table 1) and oil and gas seeps (Figure 2). NPRA, National Petroleum Reserve in Alaska. ANWR, Arctic National Wildlife Refuge.

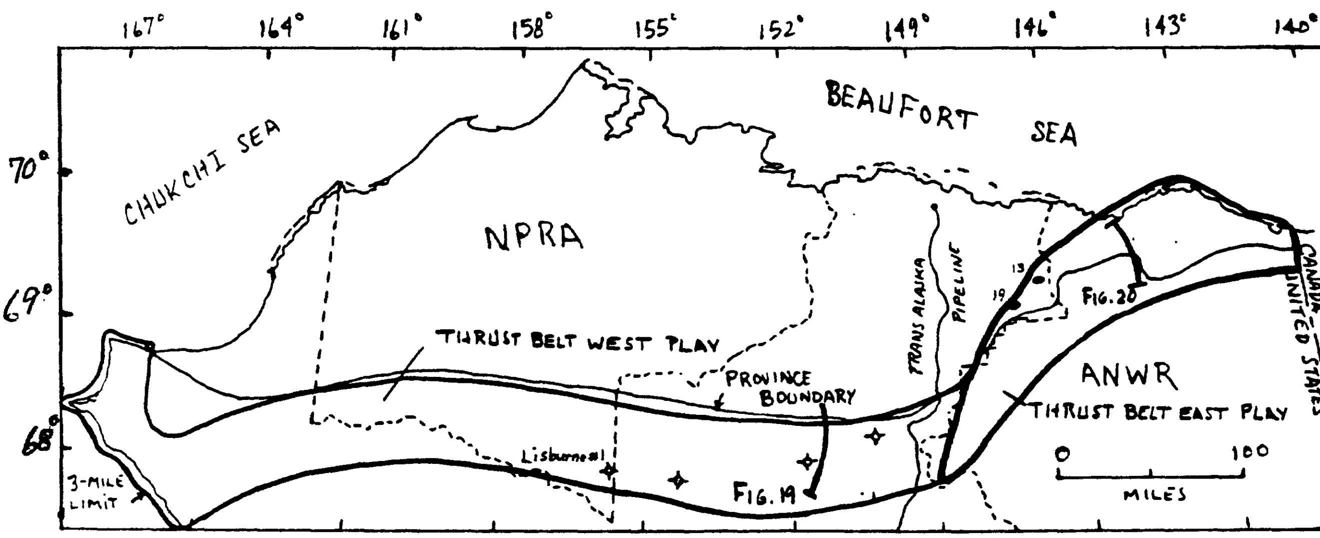

Figure 18. Areal distribution of the Thrust Belt West and Thrust Belt East plays. Numbers refer to gas fields (Table 1). NPRA, National Petroleum Reserve in Alaska. ANWR, Arctic National Wildlife Refuge.

Reservoir rocks in this play consist primarily of fluvial to shallow-marine(?) quartzose sandstone and conglomerate within the Kekiktuk Conglomerate. Minor amounts of shallow-marine dolomite and sandstone are present in the overlying Kayak Shale. Porosity is generally expected to be less than 10 percent because of burial depths ranging from 2,100 to greater than 6,100 m. Better porosity in the Kekiktuk may be present beneath the Early Cretaceous unconformity, along the western edge of the ANWR.

Source rocks include coal and lacustrine shale in the Kekiktuk, marine shale in the Kayak, and, where truncation is present, the pebble shale unit and Hue Shale. Throughout most of the play area these rocks are overmature. Accordingly, few oil and gas shows are known from this play. However, hydrogen sulfide gas was encountered in the uppermost part of the Kayak Shale at a depth of about 5,330 m in the Inigok well, located near the southern play boundary in the eastern part of the NPRA.

Traps are expected to be mostly combination traps related to faulting. Locally, folds and faults were developed during the formation of Endicott basins in Carboniferous and Permian(?) time. The Kayak Shale is expected to provide adequate seals for any reservoirs which may occur in this play. Less than a dozen exploratory wells have penetrated this play.

Fold Belt West Play

The Fold Belt West play consists primarily of anticlinal traps in Cretaceous and Tertiary sandstone reservoirs in the northern part of the Brooks Range fold and thrust belt (Fig. 17). The Fold Belt West play is situated north of the Thrust Belt West play and south of undisturbed Brookian deposits of the coastal plain province (the Topset and Turbidite plays); its western border is the State 3-mile limit in the Chukchi Sea; its eastern border lies a short distance east of the Trans Alaska Pipeline, where the structural style changes (Figs. 19, 20). The Fold Belt West play encompasses the Nanushuk Group, Torok Formation, Hue Shale, pebble shale unit, and Kemik-equivalent sandstones; in the eastern quarter of the play, parts of the Sagavanirktok and Canning Formations are also included (Fig. 7).

Potential reservoirs are sandstones, representing deltaic, shallow-marine, and turbidite environments. Sandstone porosity is expected to range from 5 to 20 percent and to improve eastward across the play. Drilling depths range from the near-surface to greater than 6 km.

Potential source rocks include generally gas-prone shales of the Nanushuk Group and the Sagavanirktok, Torok and Canning Formations and the underlying more oil-prone shales of the Shublik Formation, Kingak Shale, pebble shale unit and Hue Shale. Gas-prone source rocks within this play range from immature to mature, while most oil-prone source rocks range from mature to overmature. Both oil and gas seeps are known in the play and six subeconomic accumulations have been discovered: the

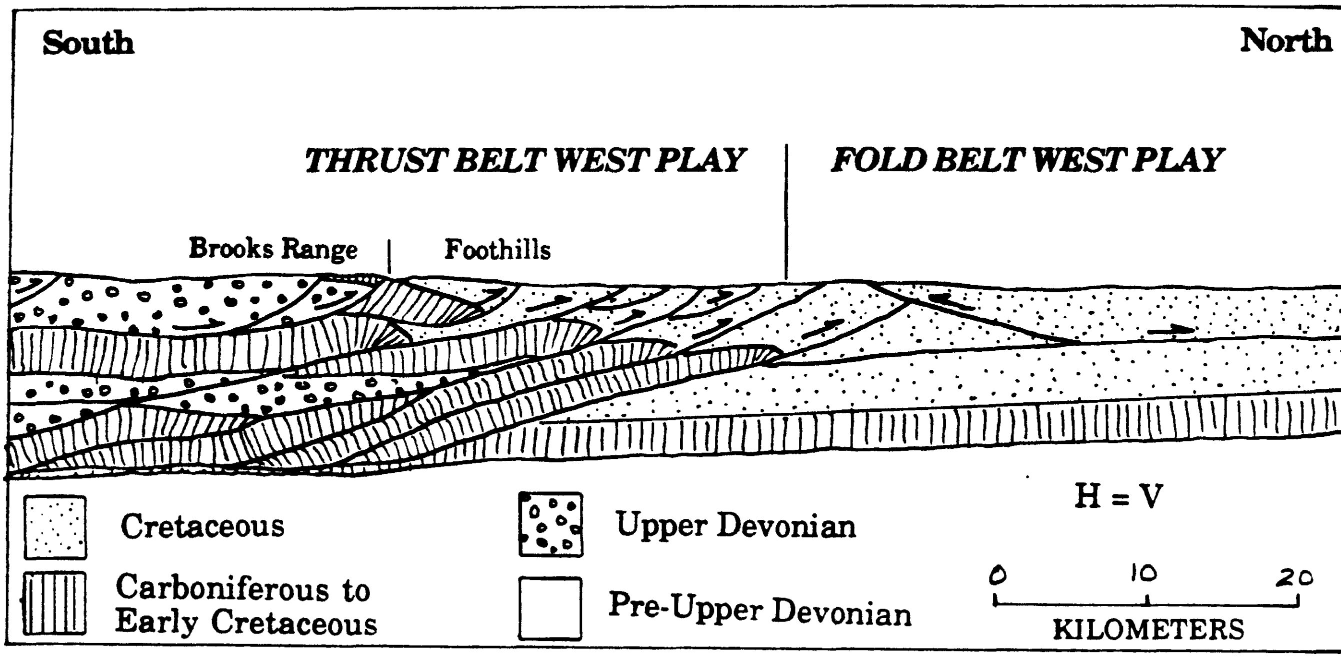

Figure 19. Cross section illustrating the relationship of the Thrust Belt West Play and the Fold Belt West Play. Section adapted from Oldow and others (1987). See Figure 17 for location of section.

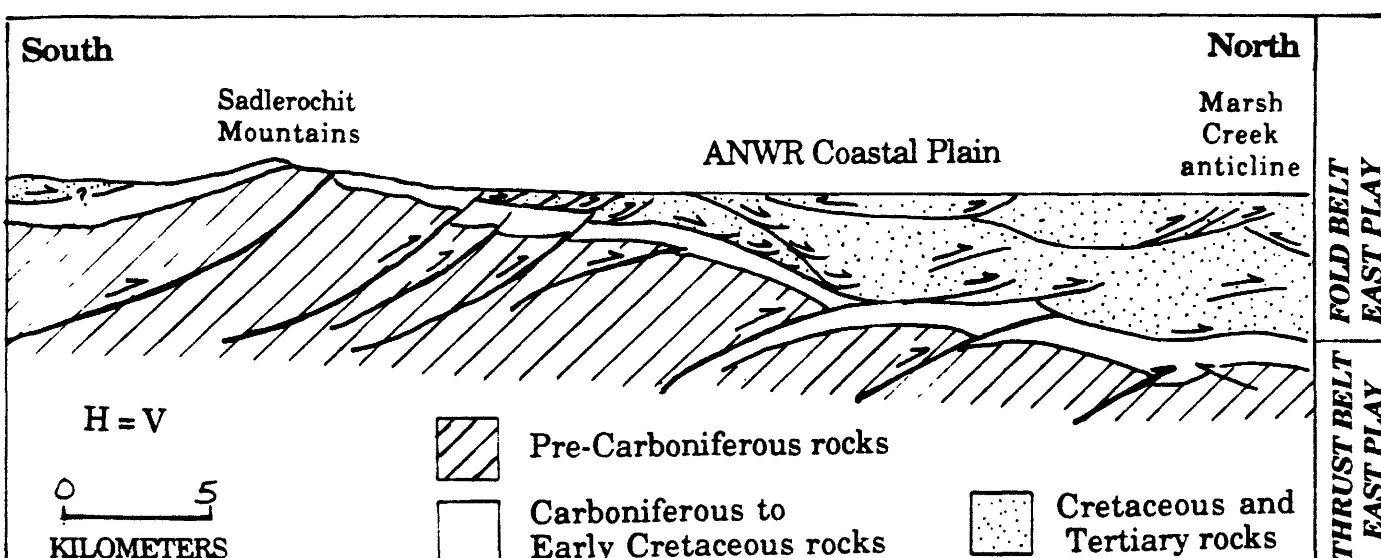

Figure 20. Cross section illustrating the relationship of the Thrust Belt East Play and the Fold Belt East Play. Section adapted from Kelley and Foland (1987, plate 5). See Figure 17 for location of section.

Umiat oil field, the Gubik, East Umiat, Wolf Creek, Square Lake, and Meade gas fields (Fig. 17).

Traps are fault-cored anticlines related to Brooks Range thrusting. Stratigraphic traps, such as updip pinchouts on the flanks of anticlines, may also be present. Shales within the plays are expected to provide fair to good seals, although their effectiveness may be reduced by faulting and related fracturing. Approximately 40 exploratory and delineation wells have tested 30 structures in this play. The number of untested structures may be more than a hundred. Estimated conventional oil and gas resources in this play have been apportioned to the Northern Foothills province (98%) and the Southern Foothills-Brooks Range province (2%).

Fold Belt East Play

The Fold Belt East play consists primarily of anticlinal traps in Cretaceous and Tertiary sandstone reservoirs in the northern part of the Brooks Range fold and thrust belt (Fig. 17). The play is situated southeast of the the undisturbed Brookian deposits of the coastal plain province (the Topset and Turbidite plays) and largely overlies the Thrust Belt East play (Fig. 20). The eastern half of the play extends offshore to the State 3-mile limit in the Beaufort Sea. Its western border lies a short distance east of the Trans Alaska Pipeline, where the structural style changes. The Fold Belt East play includes the Sagavanirktok and Canning Formations, the Hue Shale, pebble shale unit, and Kemik Sandstone (Fig. 7).

Potential reservoir rocks are sandstones, representing deltaic, shallow-marine, and turbidite environments. Porosity is expected to improve eastward across the play (10 to 30 percent or more) because of lesser burial and shorter duration of burial in that direction. Drilling depths range from the near-surface to greater than 6 km.

Potential source rocks include gas-prone shale in the Sagavanirktok and Canning Formations and oil-prone shale in the Hue Shale, pebble shale unit, Kingak, Shale and Shublik Formation. This play is considered more oil prospective than the Fold Belt West play because of the presence of a thicker section of the oil-prone Hue Shale. The gas-prone source rocks are immature to mature, while the oil-prone source rocks are immature to overmature. Oil seeps and oil-stained sandstones are known in the play, but no oil or gas accumulations have been discovered.

Traps are fault-cored anticlines related to Brooks Range thrusting. Stratigraphic traps, such as updip pinchouts on the flanks of anticlines, may also be present. Shales within the play are expected to provide fair to good seals, although their effectiveness may be reduced by faulting and related fracturing. About 10 exploratory wells have penetrated rocks assigned to this play; most wells are believed to have been drilled for objectives assigned to the underlying Thrust Belt East play. Untested structures may number more than a hundred. Estimated conventional oil and gas resources in this play have been apportioned to the Coastal Plain province (73%), the Northern Foothills province (25%), and the Southern Foothills-Brooks Range province (2%).

Thrust Belt West Play

The Thrust Belt West play consists primarily of structural traps in Mississippian carbonate reservoirs in the Brooks Range thrust belt. The northern boundary of the play, guided by seismic reflection data within the NPRA, is drawn far enough north to encompass all of the estimated occurrences of thrust sheets of Lisburne Group carbonates (Figs. 18, 19). The southern boundary is arbitrarily placed about 50 km into the Brooks Range. The area farther south is expected to have negligible petroleum potential based on the observed southward increase in the level of thermal maturity. The western play boundary is the State 3-mile limit in the Chukchi Sea. The eastern boundary is a short distance east of the Trans Alaska Pipeline where the structural style changes. Greatest potential for petroleum in the Thrust Belt West play is expected to be along the immediate range front and the foothills to the north. The thickness of rocks in this play may exceed 6 km.

Lisburne Group carbonates are the primary reservoir rock in this play. Other potential reservoir rocks include graywacke sandstone of Jurassic and Cretaceous age and fractured chert and siliceous shale of Mississippian to Jurassic age (Fig. 7). The structural style of potential prospects and physical nature of potential reservoir rocks is exemplified by the Lisburne-1 well, which encountered five thrust repetitions of the Lisburne Group (Magoon and others, 1988, pl. 19.38). Each repetition is about 400-m thick and each has some intervals with indicated porosity in the 10-15 percent range.

Potential source rocks in this play include marine shales of Mississippian to Cretaceous age. Oil shales of Mississippian, Triassic, and Jurassic age are known to occur in this play, but they are considered representative of local occurrences and not characteristic of the entire play. Preliminary data from the Lisburne-1 well indicate that Jurassic-Triassic rocks are fair to good source rocks. Most source rocks in this play are expected to be mature to overmature, although the data are sparse and the geologic relationships complex. Pyrobitumen (dead oil) was encountered in the Lisburne well along with minor indications of gas. Veins of bitumen are known from outcrop localities.

Traps in the Thrust Belt West play are large anticlinal structures composed of multiple thrust sheets of carbonate rocks. Shales within the play are expected to provide fair to good seals, although their effectiveness may be reduced by faulting and related fracturing. Only four exploratory wells have been drilled in this play (Fig. 18). Information on three of the four remains confidential. Large, untested structures remaining in the play may number in the dozens.

Thrust Belt East Play

The Thrust Belt East play consists primarily of structural traps in carbonate and clastic reservoirs of Ellesmerian and pre-Mississippian sequences in the Brooks Range thrust belt. The northern boundary of the play, guided by seismic reflection data within the ANWR, is drawn far enough north to encompass all of the estimated occurrences of thrust blocks of Ellesmerian and older rocks (Figs. 18, 20). The southern boundary is arbitrarily placed about 50 km into the Brooks Range. The area farther south is expected to have negligible petroleum potential based on the observed southward increase in the level of thermal maturity. The eastern third of the play extends offshore to the State 3-mile limit in the Beaufort Sea. The western boundary lies a short distance east of the Trans Alaska Pipeline where the structural style changes. Greatest potential for petroleum in the Thrust Belt East play is expected to be north of the range front, beneath the foothills and coastal plain of the ANWR.

The most important reservoir rock is expected to be Lisburne Group carbonates, although other Ellesmerian reservoir rocks such as the Sadlerochit Group, may be of nearly equal importance in the northern parts of the play. Some or all of the Ellesmerian sequence may be missing from structures in the northernmost part of the play because of erosional truncation by the regional Lower Cretaceous unconformity. Pre-Mississippian carbonate rocks are also considered potential reservoirs in this play (Fig. 7). Depth to these reservoir rocks ranges from near the surface to greater than 6 km.

Potential source rocks include a continuous section of organic, carbon-rich marine shale that ranges in age from Middle Triassic to Late Cretaceous (Shublik Formation, Kingak Shale, pebble shale unit, and Hue Shale). Thermal maturity decreases northeastward across the play, ranging from mature and overmature in the southwest to mature and submature in the northeast. Minor oil staining in sandstones and carbonates is known from wells and outcrop in this play, and two subeconomic gas accumulations, Kemik and Kavik, have been discovered (Fig. 18).

Traps in this play are broad, thrust-faulted anticlinal structures that involve Ellesmerian and pre-Mississippian basement rocks, and typically produce only a single repetition of the stratigraphic section. Stratigraphic traps, such as updip pinchouts on the flanks of anticlines, may also be present. Shales within the play as well as shale in the basal Brookian sequence are expected to provide fair to good seals, although their effectiveness may be reduced by faulting and related fracturing. Ten exploratory wells have tested eight structures in this play; at least several dozen structures remain to be tested. Estimated conventional oil and gas resources in this play have been apportioned to the Coastal Plain province (66%), the Northern Foothills province (30%), and the Southern Foothills-Brooks Range province (4%).

NORTHERN ALASKA GEOLOGIC ASSESSMENT

Procedures

The assessment of undiscovered northern Alaska oil and gas, like that for the rest of the Nation, was a team effort and was accomplished in stages. The assessment team was composed of five USGS professionals who had participated in most previous North Slope assessments since 1975. An important difference from the lower-48 assessment was the extensive use in this effort of previously completed play-analysis assessments in the National Petroleum Reserve in Alaska (NPRA) and the Arctic National Wildlife Refuge (ANWR). Unlike assessments in most other onshore regions, the NPRA and ANWR assessments included a network of reflection seismic records in the available geologic data set.

The initial stage of the North Slope assessment was the review of the geologic and geophysical data and identification of the plays by the province geologist. A total of 12 plays were identified and are described in the preceding section.

An intermediate stage was assessment of the geologic input parameters and computer generation of initial oil and gas resource estimates. Judgements were elicited by consensus and entered on appraisal data forms. These judgements included assignment of risk to the geologic attributes in each play and estimation of probability distributions using seven fractiles for hydrocarbon accumulation size, reservoir depth, and number of accumulations. Small fields (<1 MMBO or <6 BCFG) were assessed for each province as a whole using an alternative, statistically-based approach (Root and Attanasi, 1988; Mast and others, 1989).

The final stage of the assessment was a process of review. This included review of initial play estimates to insure validity of geologic input and to analyse the plays to make sure they properly represent the geologic understanding of the area being assessed, including the relative value or ranking of plays as well as their absolute values. Completed data forms for each play may be found in Powers (in press).

The amount of undiscovered oil and gas for most of the U.S. was assessed by directly estimating field-size distributions, rather than estimating the underlying parameters that control field size, such as area of closure, reservoir thickness, porosity, etc. In addition, the distribution of the number of accumulations was estimated directly rather than estimating the number of prospects and prospect risk. The approach to estimating field sizes was made possible by the compilation of information by NRG Associates (1986) on discovered fields larger than 1 MMBO and 6 BCFG. This data set allowed analysis of discovery records for accumulations in the geologically defined plays. An important part of this analysis included the construction of distributions by field sizes and by one-third segments of history. These distributions were fitted to truncated shifted Pareto distributions (Houghton and others, 1988; Mast and others, 1989). Analysis of these distributions served as a guide along with other data in estimating the number and sizes of undiscovered oil and gas fields in each play.

On the North Slope, the number of discovered oil and gas fields (total of 32) is insufficient to establish meaningful field-size distributions by geological play using the above approach. For these plays we utilized the conditional numbers of undiscovered fields and their sizes estimated in the NPRA and the ANWR assessments. The underlying input to these estimates included numbers and sizes of prospects based on structure-contour maps derived from seismic data and other geologic parameters such as reservoir thickness, porosity, trap-fill, and hydrocarbon saturation. The number of prospects distribution for each play in the NPRA and the ANWR assessment was modified using the assessed prospect risk to determine the distribution for the number of accumulations. The NPRA and ANWR field-size distributions were modified by applying a recovery factor and truncating them at 1 MMBO and 6 BCFG. These estimates were then subjectively modified for this assessment to account for differences in play and parameter definitions, altered play areas, and new information acquired since the NPRA and ANWR assessments. New information included newly released well data, new field discoveries at Barrow and Prudhoe Bay, and new geological reports, such as those included in Tailleur and Weimer (1987) and Thurston and Thiess (1987).

The risking procedure at the play level in the northern Alaska assessment was the same as that employed in the lower-48. This procedure consists of evaluating the favorability of the play attributes. Play attributes are the geologic conditions or regional characteristics that apply to the play as a whole. They include (1) hydrocarbon source, (2) timing, (3) migration, and (4) potential reservoir-rock facies adequate to allow accumulations of oil and gas to occur. Jointly, they determine favorability in the play for the occurrence of oil or gas. They are taken to be independent and are assessed as to probability of occurrence (between 0 and 1). Their product is the marginal play probability. The marginal play probability is set to 1.0 when an oil or gas accumulation (even subeconomic) occurs in the play and/or a significant seepage or other important hydrocarbon indication is present. Conditional on the play being favorable, the probability was also assessed that at least one undiscovered accumulation exceeding the specified minimum amounts of oil and gas would occur in the play. Most lower-48 mature plays have little or no risk for the occurrence of additional hydrocarbon accumulations unless they are approaching exhaustion.

In the northern Alaska assessment, only three of the twelve plays were assigned any risk. The Thrust Belt West play was risked at the play level, while the Lisburne Unconformity play and the Endicott play were risked for the occurrence of accumulations greater than the minimum size. For the remaining nine plays, hydrocarbon accumulations or surface seepages were sufficient to remove the marginal play probability risk, and the chance of finding one or more hydrocarbon accumulations greater than the minimum size.

Data used in the Assessment

The North Slope assessment utilized only non-proprietary data. Available information included wells, seismic reflection profiles, structure cross sections, stratigraphic correlation sections, maps summarizing source-rock richness, maturity level, porosity, reservoir thickness, exploration drilling density, structure contours, lithofacies, and aeromagnetic and gravity contours. Available information is largely summarized for the NPRA in Gryc (1988), for the ANWR in Bird and Magoon (1987), and for the area between the NPRA and the ANWR in U.S. Geological Survey (1978). Also utilized were the numerous publications describing the oil and gas fields of the Prudhoe Bay region. Much of this information is cited and summarized herein.

Basin or play analogs from outside of northern Alaska were not directly used in this assessment. Analog information on percentage of trap-fill from Canadian oil and gas fields was employed in the NPRA and the ANWR assessments, and a list of field analogs of North Slope reservoirs was compiled for the NPRA assessment (Bird, 1988, table 4.1).

Since the assessment, no new data from the North Slope have become available that would modify the results of that effort. One small gas field, Sikulik, and one oil field, Point McIntyre, were discovered (numbers 31, 32 on Table 1). The Point McIntyre accumulation, which lies just offshore in State waters north of the Prudhoe Bay oil field within our Barrow Arch play (Fig. 4B), is reported to contain about 300 MMBO of recoverable oil (Williams, 1989). All commercial North Slope oil comes from the Barrow Arch play, and we judge it to be one of the most prospective of the North Slope plays. The size of this discovery seems to be well within the limits of our estimates, as described in the following section.

Geologic Assessment Results

The estimates of undiscovered conventional oil and gas resources for the onshore and State offshore waters of northern Alaska are summarized in Tables 4, 5, and 6. Table 4 provides estimates of both recoverable and economically recoverable categories of resources for each of the three North Slope provinces. Tables 5 and 6 summarize the results of the assessment by individual play.

In previous national oil and gas assessments (Miller and others, 1975; Dolton and others, 1981), a Delphi type of assessment method was employed and each of the three North Slope provinces was assessed as a separate entity. In the current assessment, individual plays were assessed without regard to province boundaries. Because the province is the basic unit of reporting, it became necessary to aggregate the play estimates for each province. An error was made in the aggregation process and the North Slope province totals reported in Mast and others (1989, tables A1 and A3) are incorrect. For those aggregations, each North Slope play was assigned to just one province. In fact, four plays cross province boundaries (the Ellesmerian Clastics, Fold Belt West, Fold Belt East, and Thrust Belt

East plays). In this report and in Attanasi and others (in press), the previously reported aggregation errors are corrected by allocating the estimated resources of those plays to the appropriate provinces. These corrections have no effect on the estimated resources for each play, for the North Slope, or for any other higher-level aggregation. But they do affect the individual North Slope province totals (Table 4); they reduce the amount of oil and gas resources estimated to lie within the Southern Foothills-Brooks Range province and increase the amount of resources in the Northern Foothills and Coastal Plain provinces. The provinces ranked in terms of decreasing amounts of undiscovered oil and gas resources are the Coastal Plain province, the Northern Foothills province, and the Southern Foothills-Brooks Range province.

The summary of estimated undiscovered conventionally recoverable oil and gas resources (Table 5) shows that 10 of 12 plays are expected to have recoverable oil and that all 12 plays are expected to have recoverable gas. Economically recoverable resources (Table 6), which consist only of oil and natural gas liquids at the present time on the North Slope, are estimated to occur in only 7 of the 12 plays. Plays with the largest volumes of economically recoverable oil (mean value) are, in order of decreasing amounts, the Thrust Belt East play, the Topset play, the Barrow Arch play, and the Eastern Turbidite play. The procedures followed in determining economically recoverable oil resources for northern Alaska are presented in Attanasi and others (in press).

Table 4. Summary of estimated undiscovered petroleum resources for the onshore and State offshore North Slope. Oil, gas, and natural gas liquid resources for each province include revised and rounded totals (from Tables 5 and 6 of this report) and, in parens, totals originally reported in Mast and others (1989, Tables A1 and A3). The all-provinces totals are aggregations, courtesy of R.A. Crovelli. See text for explanation of revisions.

PROVINCE	CRUDE OIL (Millions of barrels)			TOTAL GAS (Billions of Cubic Feet)			NATURAL GAS LIQUIDS (Millions of barrels)		
	F_{95}	F_{05}	Mean	F_{95}	F_{05}	Mean	F_{95}	F_{05}	Mean
Undiscovered Recoverable Resources									
Arctic Coastal Plain	1,962 (1,500)	25,939 (14,800)	9,707 (6,000)	5,846 (4,660)	97,024 (58,240)	34,291 (22,110)	149 (130)	2,060 (1,410)	762 (560)
Northern Foothills	270 (670)	7,711 (5,120)	2425 (2,240)	2,557 (4,030)	46,400 (24,310)	16,057 (11,490)	40 (70)	723 (440)	250 (210)
Southern Foothills-Brooks Range	9 (580)	1,758 (13,180)	455 (4,350)	151 (2,850)	13,973 (61,560)	3,744 (20,490)	2 (40)	162 (870)	43 (290)
Total of all provinces	2,502	33,838	12,587	10,545	146,400	54,091	224	2,769	1,055
Undiscovered Economically Recoverable Resources									
Arctic Coastal Plain	0.0 (0.0)	20,115 (10,930)	5,956 (3,360)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	315 (0.0)	93 (0.0)
Northern Foothills	0.0 (0.0)	5,416 (2,640)	1,416 (720)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	88 (0.0)	23 (0.0)
Southern Foothills-Brooks Range	0.0 (0.0)	1,185 (12,640)	299 (3,590)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	15 (0.0)	4 (0.0)
Total of all provinces	0.0	25,604	7,671	0.0	0.0	0.0	0.0	401	120

Table 5. Estimated undiscovered recoverable conventional oil, gas, and natural gas liquid resources for the onshore and State offshore North Slope reported by individual play and province. Although total North Slope estimate is unchanged (Table 4), individual province totals differ from Mast and others (1989), as explained in text. See Table 6 for estimates of economically recoverable resources. MMB, millions of barrels; BCF, billions of cubic feet.

PLAYS	CRUDE OIL (Millions of Barrels)			TOTAL GAS (Billions of Cubic Feet)			NATURAL GAS LIQUIDS (Millions of Barrels)		
	F_{95}	F_5	Mean	F_{95}	F_5	Mean	F_{95}	F_5	Mean
Arctic Coastal Plain Province (058)									
Topset	452.9	6,172.3	2,287.9	35.5	2,074.5	582.8	0.0	0.0	0.0
Topset*	9.1	963.3	254.2	0.5	244.7	64.8	0.0	0.0	0.0
Western Turbidite	16.8	222.0	85.8	603.7	3,594.4	1,706.4	12.1	71.9	34.1
Western Turbidite*	0.1	17.4	4.5	6.3	312.6	89.8	0.1	6.3	1.8
Eastern Turbidite	336.5	2,512.7	1,107.3	1,131.8	8,834.4	3,843.1	45.3	353.4	153.7
Eastern Turbidite*	10.7	414.0	123.0	33.0	1,463.2	427.0	1.3	58.5	17.1
Barrow Arch	207.9	2,622.5	992.0	290.1	5,972.0	2,008.5	11.6	238.9	80.3
Barrow Arch*	207.9	2,622.5	992.0	290.1	5,972.0	2,008.5	11.1	238.9	80.3
Ellesmerian Clastics[a]	9.5	247.6	81.4	1,190.7	14,162.0	5,450.7	17.9	212.4	81.8
Ellesmerian Clastics[a]*	Negl	6.1	1.7	0.9	420.2	111.2	Negl.	6.3	1.7
Lisburne	0.0	0.0	0.0	589.6	10,640.0	3,686.8	8.8	159.6	55.3
Lisburne*	0.0	0.0	0.0	0.1	127.2	37.2	Negl.	1.9	0.6
Lisburne Unconformity	0.0	124.7	27.1	0.0	5,166.0	1,426.6	0.0	129.2	35.7
Lisburne Unconformity*	0.0	12.4	3.0	0.0	710.1	158.5	0.0	7.8	4.0
Endicott	0.0	0.0	0.0	0.0	609.2	214.4	0.0	9.1	3.2
Endicott*	0.0	0.0	0.0	0.0	8.0	2.2	0.0	0.1	Negl.
Oil <1 MMB	14.6	56.0	31.0	7.3	28.0	15.5	0.1	0.6	0.3
Oil <1 MMB*	2.8	24.7	10.3	1.4	12.3	5.2	Negl.	0.2	0.1
Gas <6 BCF	0.0	0.0	0.0	135.4	401.3	246.2	2.7	8.0	4.9
Gas <6 BCF*	0.0	0.0	0.0	15.0	44.6	27.4	0.3	0.9	0.5
Onshore Total**	1,466.8	22,595.0	8,132.4	4,882.4	88,813.0	30,716.8	114.5	1,801.6	645.0
Offshore Total**	123.3	5,383.4	1,574.4	154.5	13,248.0	3,573.2	8.5	404.5	116.9
Province Total**	1,962.4	25,939.0	9,706.7	5,845.7	97,024.0	34,291.0	149.0	2,060.1	761.9
Northern Foothills Province (059)									
Fold Belt - West[b]	203.4	2,003.3	813.4	3,268.5	18,400.0	8,902.0	49.0	276.0	133.5
Fold Belt - West[b]*	0.2	64.6	16.6	7.3	678.2	181.7	0.1	10.2	2.7
Fold Belt - East[c]*	4.3	242.3	68.2	4.0	404.8	107.7	0.1	12.1	3.2
Fold Belt - East[c]	417.1	2,861.0	1,295.4	558.0	4,865.1	2,046.1	16.7	146.0	61.4
Oil <1 MMB[d]	20.2	83.4	45.1	20.2	83.4	45.1	0.4	1.7	0.9
Oil <1 MMB[d]*	0.1	6.9	1.9	0.1	6.9	1.9	Negl.	0.1	Negl.
Gas <6 BCF[d]	0.0	0.0	0.0	91.1	364.6	199.2	1.8	7.3	4.0
Gas <6 BCF[d]*	0.0	0.0	0.0	2.8	11.3	6.2	0.1	0.2	0.1
Onshore Total**	253.3	7,449.0	2,329.3	2,443.4	45,146.0	15,558.0	37.9	702.7	242.0
Offshore Total**	0.6	356.7	96.1	3.8	1,874.5	498.7	0.1	29.8	7.9
Province Total**	270.4	7,711.4	2,425.4	2,556.9	46,400.0	16,056.7	39.7	722.5	249.9
Southern Foothills Province (060)									
Thrust Belt - West	0.0	1,022.1	233.5	0.0	10,391.0	2,690.6	0.0	103.9	26.9
Thrust Belt - West*	0.0	22.5	7.2	0.0	303.6	83.2	0.0	3.0	0.8
Thrust Belt - East[e]	546.6	11,382.0	3,820.2	2,512.2	48,674.0	16,592.8	37.7	730.1	248.9
Thrust Belt - East[e]*	2.5	780.7	201.1	11.4	3,367.2	873.3	0.2	50.5	13.1
Oil <1 MMB[d]	32.6	153.2	79.0	32.6	153.2	79.0	0.5	2.3	1.2
Oil <1 MMB[d]*	0.2	15.2	4.2	0.2	15.2	4.2	Negl.	0.2	0.1
Gas <6 BCF[d]	0.0	0.0	0.0	69.0	294.1	157.0	1.0	4.4	2.4
Gas <6 BCF[d]*	0.0	0.0	0.0	0.5	29.8	8.3	Negl.	0.4	0.1
Onshore Total**	8.1	1,691.3	437.3	142.1	13,530.0	3,617.4	1.4	157.0	41.4
Offshore Total**	0.0	50.7	17.4	0.2	405.6	126.2	0.0	4.7	1.5
Province Total**	8.7	1,758.2	454.7	150.6	13,973.0	3,743.6	1.5	162.4	43.0

* Indicates State offshore. ** Province Total equals aggregation of play resources as allocated (per footnotes). Therefore, individual play estimates as listed do not sum to Province Total. a. Play estimate shown has been apportioned to the Coastal Plain province (80%) and the Northern Foothills province (20%). b. Play estimate shown has been apportioned to the Northern Foothills province (98%) and the Southern Foothills and Brooks Range provinces (2%). c. Play estimate shown has been apportioned to the Coastal Plain province (73%), the Northern Foothills province (25%), and the Southern Foothills-Brooks Range province (2%). d. Estimates shown have been apportioned to the Coastal Plain, Northern Foothills, and Southern Foothills-Brooks Range provinces. e. Play estimate shown has been apportioned to the Coastal Plain province (66%), the Northern Foothills province (30%), and the Southern Foothills-Brooks Range province (4%).

Table 6. Estimated undiscovered economically recoverable conventional oil, gas, and natural gas liquid (NGL) resources for the onshore and State offshore North Slope reported by individual play and province. Although total North Slope estimate (Table 4) is unchanged, individual province totals differ from Mast and others (1989), as explained in text. MMB, millions of barrels; BCF, billions of cubic feet.

PLAYS	CRUDE OIL (Millions of Barrels)			TOTAL GAS (Billions of Cubic Feet)			TOTAL NGL+ (Millions of Barrels)		
	F_{95}	F_{05}	Mean	F_{95}	F_{05}	Mean	F_{95}	F_{05}	Mean
Arctic Coastal Plain Province (058)									
Topset	0.0	5165.7	1482.5	0.0	0.0	0.0	0.0	0.0	0.0
Topset*	0.0	814.0	208.8	0.0	0.0	0.0	0.0	0.0	0.0
Western Turbidite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eastern Turbidite	0.0	1,446.0	429.4	0.0	0.0	0.0	0.0	57.9	17.2
Eastern Turbidite*	0.0	207.1	54.8	0.0	0.0	0.0	0.0	8.3	2.2
Barrow Arch	0.0	1,664.5	475.7	0.0	0.0	0.0	0.0	50.0	14.3
Barrow Arch*	0.0	2,063.8	708.7	0.0	0.0	0.0	0.0	61.7	21.2
Ellesmerian Clastics	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lisburne	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lisburne Unconformity*	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	Negl.
Endicott	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oil <1 MMB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gas <6 BCF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Onshore Total	0.0	16,335.0	4,847.2	0.0	0.0	0.0	0.0	228.1	67.7
Offshore Total	0.0	4,032.5	1,108.6	0.0	0.0	0.0	0.0	92.8	25.5
Province Total	0.0	20,115.0	5,955.8	0.0	0.0	0.0	0.0	314.8	93.2
Northern Foothills Province (059)									
Fold Belt - West[a]	0.0	1,214.8	273.5	0.0	0.0	0.0	0.0	27.5	6.2
Fold Belt - West*[a]	0.0	27.0	4.9	0.0	0.0	0.0	0.0	0.6	0.1
Fold Belt - East[b]	0.0	1,416.7	420.0	0.0	0.0	0.0	0.0	25.3	7.5
Fold Belt - East*[b]	0.0	101.7	25.7	0.0	0.0	0.0	0.0	2.0	0.5
Oil 1 MMB[c]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gas <6 BCF[c]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Onshore Total**	0.0	5,080.9	1,351.7	0.0	0.0	0.0	0.0	82.3	21.9
Offshore Total**	0.0	242.1	64.2	0.0	0.0	0.0	0.0	3.8	1.0
Province Total**	0.0	5,416.1	1,415.9	0.0	0.0	0.0	0.0	87.6	22.9
Southern Foothills Province (060)									
Thrust Belt - West	0.0	1,022.1	142.9	0.0	0.0	0.0	0.0	14.2	1.5
Thrust Belt - West*	0.0	7.6	4.4	0.0	0.0	0.0	0.0	Negl.	Negl.
Thrust Belt - East[d]	0.0	10,701.0	3,262.2	0.0	0.0	0.0	0.0	153.2	46.7
Thrust Belt - East*[d]	0.0	707.8	176.4	0.0	0.0	0.0	0.0	10.0	2.5
Oil <1 MMB[c]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gas <6 BCF[c]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Onshore Total**	0.0	1,158.3	287.3	0.0	0.0	0.0	0.0	14.9	3.7
Offshore Total**	0.0	35.9	12.1	0.0	0.0	0.0	0.0	0.3	0.1
Province Total**	0.0	1,185.3	299.3	0.0	0.0	0.0	0.0	15.0	3.8

+ NGL from gas associated with economic crude oil resources. * Indicates State offshore. ** Province Total equals aggregation of play resources as allocated (per footnotes). Therefore, individual play estimates as listed to not sum to Province Total. **a.** Play estimate shown has been apportioned to the Northern Foothills province (98%) and the Southern Foothills and Brooks Range provinces (2%). **b.** Play estimate shown has been apportioned to the Coastal Plain province (73%), the Northern Foothills province (25%), and the Southern Foothills-Brooks Range province (2%). **c.** Estimates shown have been apportioned to the Coastal Plain, Northern Foothills, and Southern Foothills-Brooks Range province. **d.** Play estimate shown has been apportioned to the Coastal Plain province (66%), the Northern Foothills province (30%), and the Southern Foothills-Brooks Range province (4%).

FUTURE POTENTIAL OF THE PROVINCE

The future petroleum potential of the North Slope province is considerable as indicated by the results of the latest assessment of undiscovered oil and gas resources (described above). These results show that the range of uncertainty (F_{05} and F_{95} values) is broad, and the mean values indicate about the same amounts of oil and gas remain to be found in the onshore as have already been found. State offshore potential is also estimated to be significant.

Onshore, the area comprising the foothills and coastal plain of the ANWR, which is presently closed to exploration, is considered the most promising region for future petroleum discoveries (Bird and Magoon, 1987). Greatest potential in this area is believed to occur in the thrust belt play. West of the ANWR, the coastal plain is considered highly prospective for oil and gas in combination structural-stratigraphic traps similar to known accumulations in the Prudhoe Bay field and nearby areas. Although nearly 40 separate structures have been tested in the foothills province, resulting in the discovery of one oil and six gas accumulations, several times as many structures remain to be tested.

SUMMARY

The North Slope petroleum province, one of North America's most prolific petroleum producing areas, currently provides 25 percent of total U.S. oil production; it is also the site of large but presently uneconomic gas reserves. This is a large, geologically complex province composed of a composite basin of late Paleozoic to Cenozoic age flanked on its north by a Cretaceous to Tertiary passive margin. The composite basin consists of a relatively thin sequence of northern-sourced continental margin deposits of late Paleozoic to Early Cretaceous age overlain by very thick, southern-sourced Cretaceous and Tertiary foredeep deposits. The majority of oil and gas accumulations, and all commercial oil deposits, lie along a major subsurface positive trend, the Barrow arch, that separates the foredeep basin deposits from the passive margin deposits. Geochemical signatures identify Triassic and Jurassic marine shales as the primary source rocks for North Slope oils, although other potential source rocks are also present in the region. Major oil accumulations occur in nonmarine to shallow-marine sandstone reservoirs of Mississippian, Triassic, Cretaceous, and early Tertiary age. Oil generation, migration, and entrapment dates from mid-Cretaceous and Tertiary time. Recent estimates show that considerable oil and gas remain to be discovered in both the onshore and offshore parts of this province.

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