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Chapter 30

Petroleum resources in Alaska

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INTRODUCTION

Alaska has the largest oil field in North America, and it has the nation's highest daily oil production of approximately 2 million barrels per day. This chapter summarizes the status of exploration and development for oil and gas resources of onshore Alaska and offshore state lands (Fig. 1). Emphasis is on geologic and geochemical evidence for the occurrence of oil and gas in three petroliferous areas and their evolution as studied by petroleum system models. Areas of primary interest are the North Slope, Cook Inlet, and Gulf of Alaska. The rest of Alaska has negligible petroleum potential and is discussed only briefly. For a more in-depth discussion of Alaskan geology, the reader is referred to other chapters on regional geology. Other chapters discuss onshore northern Alaska (Moore and others, this volume) and the offshore (Grantz and others, this volume), west-central Alaska (Patton and others, this volume), east-central Alaska (Dover, this volume; Foster and others, this volume), and south-central Alaska (Nokleberg and others, this volume, Chapter 10). The deformed flysch basins are discussed by Kirschner (this volume, Chapter 14), and the lithotectonic terranes are shown on Plate 3 (Silberling and others, this volume). The sedimentary basins and oil fields of Alaska are delineated on Plate 7 (Kirschner, this volume), and the petroleum potential of interior basins is discussed by Kirschner (this volume, Chapter 14). The petroleum potential of the Bering Sea shelf is considered by Marlow and others (this volume), and that of the southern Alaska shelves is in Plafker and others (this volume, Chapter 12), and Vallier and others (this volume). Miller and others (1959), Cram (1971), Miller and others (1975), Dolton and others (1981), and U.S. Geological Survey and Minerals Management Service (1988) are important earlier references that discuss the petroleum potential of the entire state.

Resources

The oil and gas resources of Alaska can be allocated to three categories: produced, discovered, and undiscovered (Table 1; U.S. Geological Survey and Minerals Management Service, 1988). As of December 31, 1987, 6.1 billion barrels of oil (bbo) and 3.8 trillion cubic feet of gas (tcfg) have been produced. In addition, a significant amount of gas has been reinjected back into the reservoirs to maintain pressure. Except for safety reasons, gas is seldom flared. Gas produced on the North Slope is consumed locally to run the facilities, the rest is reinjected into the Prudhoe Bay oil field. Cook Inlet gas is consumed locally, liquified and shipped overseas, or reinjected into other reservoirs. Reinjected gas is not included in the cumulative production.

Discovered hydrocarbons include measured reserves and inferred plus indicated reserves. Measured reserves is a known volume of petroleum remaining to be produced, whereas inferred plus indicated reserves is an expected volume of hydrocarbons from field extensions, infilling drilling, or enhanced recovery techniques.

Undiscovered recoverable resources, a quantity not yet found but based on geological information, is expected to exist; regardless of economics, it is technically and physically recoverable. For the undiscovered recoverable resources, two probability fractiles, F95 and F5, and the mean are shown for both oil and gas (Table 2). The F95, for example, indicates a 95-percent chance that at least 1.50 bbo is yet to be discovered under the Arctic Coastal Plain. If the numbers in Table 1 are correct, then Alaska could ultimately produce 32.6 bbo and 97.4 tcfg. Based on mean values for all of Alaska shown on Table 2, 95 percent (12.6 bbo) of the undiscovered oil and 93 percent (54.1 tcfg) of the undiscovered gas will be found on the North Slope. Areas of oil potential for the rest of Alaska, in descending order, are Cook Inlet, Gulf of Alaska, and Yukon-Kandik basin. Gas potential is highest for Cook Inlet, followed by the entire Alaska interior, Gulf of Alaska, and Bristol Basin.

Unconventional sources of hydrocarbons have been left out of all estimates. The West Sak and Ugnu sands of local usage above the Kuparuk River oil field on the North Slope contain billions of barrels of heavy oil (API oil gravity from 10 to 20°; Werner, 1987). On the North Slope, the volume of methane included in gas hydrate is estimated to be 8 to 10 tcfg (Collett and others, 1988).

Framework geology

The geology of Alaska is complex. Much of the state is made up of lithotectonic terranes that were assembled in their present

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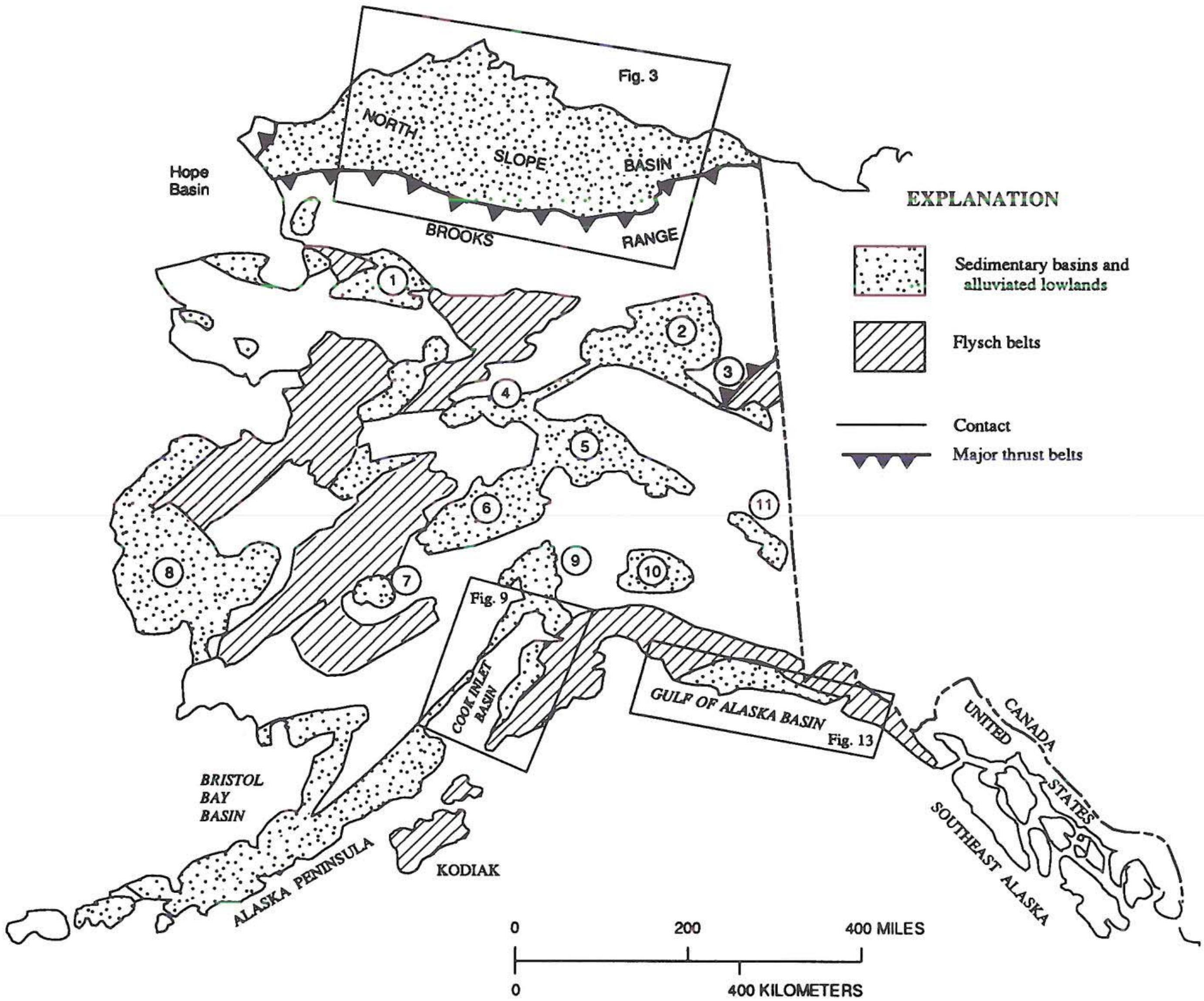

Figure 1. Index map of Alaska showing the three known onshore oil and gas provinces: North Slope basin, Cook Inlet basin, and Yakutat terrane in the Gulf of Alaska basin. The location of Figures 3, 9, and 13 are shown. Names of sedimentary basins are as follows: (1) Kobuk basin, (2) Yukon Flats basin, (3) Kandik basin, (4) Ruby-Rampart trough, (5) Nenana basin, (6) Minchumina basin, (7) Holitna basin, (8) Bethel basin, (9) Susitna basin, (10) Copper River basin, and (11) Northway lowlands. (Adapted from Kirschner, this volume, Chapter 14, Plate 7.)

positions relative to North America during the late Mesozoic and early Cenozoic (Silberling and others, this volume). These terranes contain myriad lithologies comprising sedimentary and igneous rocks, some of which were deformed and metamorphosed during accretion. South of the Brooks Range, deformed flysch deposits described by Kirschner (this volume, Chapter 14) have no petroleum potential and are considered economic basement. Throughout the Cenozoic within interior Alaska, significant thicknesses of nonmarine sedimentary rocks were deposited over these flysch basins (Kirschner, this volume, Plate 7 and Chapter 14). These sedimentary rocks contain coal, conglomerate, and sandstone where microbial gas might originate and accumulate.

The economic basement and geologic history of northern and southern Alaska differ from those of interior Alaska. Except for northeastern Alaska where pre-Mississippian rocks are petroleum reservoirs, basement rock is pre-Mississippian for the North Slope, pre-Middle Jurassic for Cook Inlet, and pre-Cenozoic for the Yakutat terrane. In northern Alaska, the hydrocarbon source-

TABLE 1. ULTIMATE OIL AND GAS RESOURCES FOR ONSHORE AND STATE OF ALASKA OFFSHORE WATERS*

	Produced Cumulative production	Discovered Measured reserves	Inf + ind reserves	Undiscovered Recoverable resources
Oil (bbo)	6.1	6.9	6.4	13.2
Gas (tcf)	3.8	32.7	3.0	57.9

*Inf + ind, inferred plus indicated; bbo, in billions of barrels of oil; tcf, in trillion cubic feet of gas. Undiscovered recoverable resources from U.S. Geological Survey and Minerals Management Service, 1988; cumulative production to 12/31/87; measured reserves, for 1/1/88 from Energy Information Administration, 1987, annual report; inferred + indicated, for 1/1/88 from D. H. Root (USGS), written communication.

rock interval ranges in age from Triassic through Cretaceous. The provenance for the primary quartz-rich reservoir rock is to the north and ranges in age from Mississippian through Early Creteceous, while the provenance for the secondary lithic-rich reservoir is to the south and ranges in age from Early Cretaceous through Tertiary. The north-to-south flip in provenance is marked by rifting in mid-Mesozoic time. In Cook Inlet, the Middle Jurassic marine-shale source rock was deposited in a back-arc basin, whereas the Cenozoic nonmarine conglomerate sandstone reservoirs were deposited in a fore-arc basin. A major unconformity separates the Mesozoic from the Cenozoic rocks. In the Gulf of Alaska, Paleogene marine source and reservoir rocks were deposited on the allochthonous Yakutat terrane in an unknown tectonic environment and were buried by thick glaciomarine sedimentary rocks deposited on the northward-moving Yakutat terrane. For these areas, each of these geologic events was important to the development of a petroleum system.

Petroleum system

The petroleum system model (Magoon, 1988a, b) is used to explain the occurrence of oil and gas in Alaska. As used herein, a petroleum system encompasses a hydrocarbon source rock and all generated oil and gas accumulation, and includes all those geologic elements and processes that are essential for a hydrocarbon deposit to exist in nature: namely, a petroleum source rock, migration path, reservoir rock, seal, trap, and the geologic processes that create each of these basic elements. All these elements must be correctly placed in time and space so that organic matter included in a source rock can be converted into a petroleum deposit. Or more simply, the petroleum system emphasizes the genetic relation between a source rock and an accumulation. A petroleum system exists wherever all the basic elements are known to occur, or are suspected to occur.

TABLE 2. ESTIMATES OF UNDISCOVERED RECOVERABLE RESOURCES FOR ONSHORE AND STATE OF ALASKA OFFSHORE WATERS AS OF 12/31/86*

	Oil (Billion barrels)			Gas (Trillion cubic ft)		
Area	F95	F5	Mean	F95	F5	Mean
North Slope						
Arctic Coastal Plain	1.50	14.80	6.00	4.66	58.24	22.11
Northern Foothills	0.67	5.12	2.24	4.03	24.31	11.49
Southern Foothills	0.58	13.18	4.35	2.85	61.56	20.49
Central Alaska						
Yukon-Kandik	0.00	0.49	0.11	0.00	0.49	0.11
Alaska Interior†	0.00	0.00	0.00	0.45	2.85	1.33
Bristol basin	0.00	0.00	0.00	0.11	0.67	0.32
Hope basin	....	....	....	....	....	....
Cook Inlet	0.09	0.64	0.29	0.35	3.91	1.53
Gulf of Alaska	0.03	0.58	0.19	0.03	2.00	0.56
Kodiak	....	....	....	....	....	....
Southeast Alaska	....	....	....	....	....	....
Total	3.6§	31.3§	13.2	15.6§	138.6§	57.9

*From U.S. Geological Survey and Minerals Management Service, 1988, Table IV.C.1, p. 218; ...., no information.
†Includes Alaska Peninsula, Bethel basin, Copper River basin, Holitna basin, Kobuk basin, Minchumina basin, Ruby-Rampart basin, Susitna basin, Nenana basin, Northway lowlands, and Yukon Flats basin.
§Fractile values are not additive.

The stratigraphic, areal, and temporal extent of each petroleum system is specific. Stratigraphically, the system is limited to the following rock units: a petroleum source rock, rock overburden required for maturity (time and temperature), rocks through which migration has occurred, and strata that make up the trap. The areal extent of the petroleum system is defined by a line that circumscribes the mature source rock and all oil and gas deposits, conventional and unconventional, originating from that source. The temporal extent of a petroleum system includes the duration or life-cycle of the system, and the preservation time indicates how long the hydrocarbons have been preserved in the geologic record.

A petroleum deposit includes high concentrations of any of the following substances: thermal and microbial natural gas, condensate, crude oil (including heavy oil), and solid bitumen. In any volume of hydrocarbons, these substances may be found in conventional siliciclastic and carbonate reservoirs as well as in gas hydrates, low-permeability rocks, fractured rocks, and coal beds.

A petroleum system (Table 3) can be identified in terms of a geochemical correlation of petroleum and source rocks at three levels of certainty: known, hypothetical, and speculative. In a known petroleum system, in the case of oil, a good geochemical match must exist between the source rock and oil accumulations; or, in the case of natural gas, the gas is produced from a gas source rock. In a hypothetical petroleum system, geochemical information is sufficient to identify a source rock, but no geochemical match exists between the identified source rock and a known petroleum deposit. In a speculative petroleum system, of which none are present in Alaska, the existence of source rocks and petroleum accumulations is postulated entirely on the basis of geologic or geophysical evidence. At the end of the system's name on Table 3, the level of certainty is indicated by a (!) for known, or a (.) for hypothetical.

The name of the petroleum system includes the name of the source rock followed by the name of the major reservoir rock and symbol expressing the level of certainty. For example, the Torok-Nanushuk(.) is a hypothetical system on the North Slope and is composed of the Cretaceous Torok Formation as the source rock and the sandstone of the Nanushuk Group as the major reservoir.

Seven petroleum systems are discussed. Their level of certainty is shown only on Table 3. For the North Slope, presently a foreland basin, there are three petroleum systems: Ellesmerian, Torok-Nanushuk, and Hue-Sagavanirktok. In Cook Inlet, presently a fore-arc basin, there are two systems: Tuxedni-Hemlock and Beluga-Sterling. The Stillwater-Kulthieth and Poul Creek petroleum systems explain the occurrence of petroleum in the Yakutat terrane along the Gulf of Alaska.

TABLE 3. PETROLEUM SYSTEMS IN ALASKA

Region	System Name
North Slope	Ellesmerian(!) Torok–Nanushuk(.) Hue–Sagavanirktok(!)
Cook Inlet	Tuxedni–Hemlock(.) Beluga–Sterling(.)
Yakutat terrane Gulf of Alaska	Stillwater–Kulthieth(.) Poul Creek(.)

NORTH SLOPE

The history of drilling exploratory and production wells on the North Slope commenced in 1944 with three wildcat wells (Fig. 2; Petroleum Information, 1988). Through 1987, 1,973 wells have been drilled, of which 283 were exploratory and 1,690 were field development wells (Petroleum Information, 1988). The first exploratory program was carried out by the U.S. Navy from 1944 through 1952 and included 69 wells drilled on the western half of the North Slope (Bird, 1981). Several small oil and gas fields were discovered, which prompted the drilling of 11 development wells (Figs. 2 and 3; Tables 4 and 5). In 1964, industry exploration shifted to the east-central North Slope, where in 1967, the Prudhoe Bay oil field was discovered. The

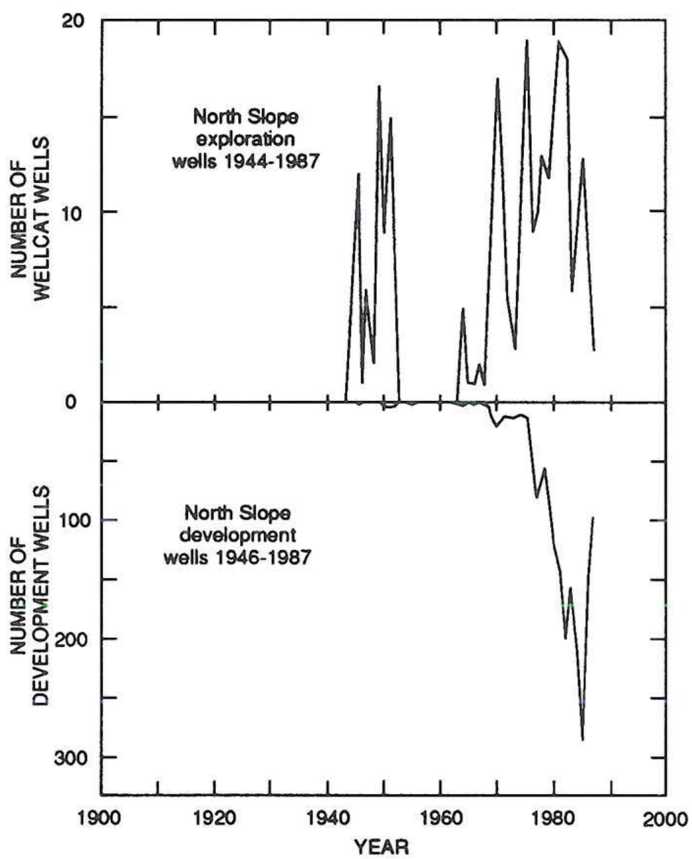

Figure 2. Exploration and development drilling history for the North Slope. Wells are plotted at year they reached total depth.

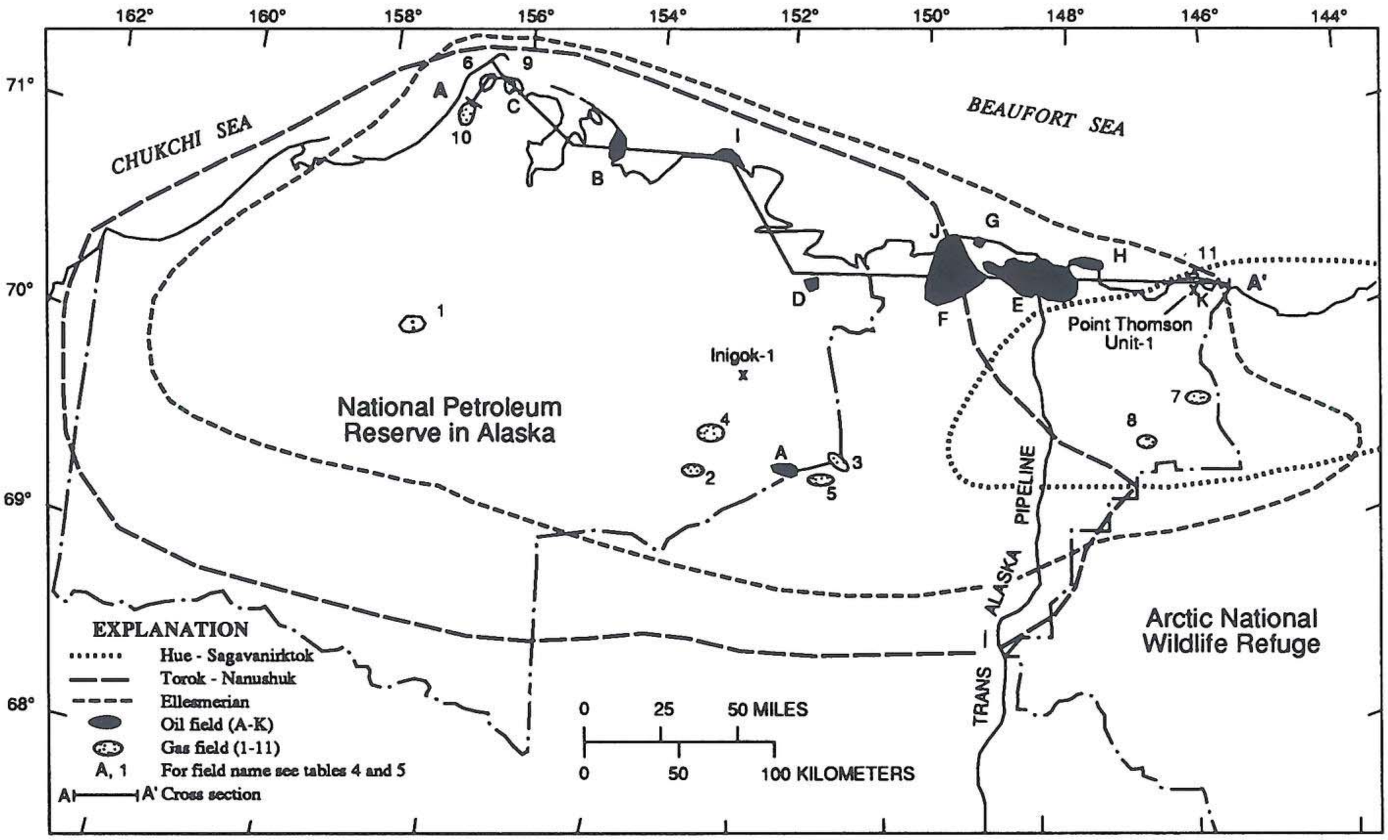

Figure 3. The North Slope showing oil and gas fields, National Petroleum Reserve in Alaska, Arctic National Wildlife Refuge, boundaries of petroleum systems, and location of cross section A–A′.

discovery of this supergiant oil field triggered a flurry of activity in exploratory drilling by industry and the federal government in the immediate area onshore and offshore as well as to the west, where there was hope of discovering another "Prudhoe" (Gryc, 1988). In addition, the trans-Alaska pipeline, completed in 1977, stimulated development drilling that peaked in 1985. Cumulative production (1988) on the North Slope is 5.9 bbo and 8.2 tcfg. This leaves 6.0 bbo and 25.4 tcfg left to be extracted (Tables 4 and 5). Much more gas is being produced than the cumulative production indicates because much of the gas is being reinjected into the Prudhoe Bay reservoirs to maintain pressure. Because there is no way to move the gas to market, gas consumption is restricted to production facilities on the North Slope. The exploration and petroleum geology of the North Slope are discussed by many workers (Miller and others, 1959; Collins and Robinson, 1967; Alaska Geological Society, 1972; Tailleur, 1973; Walker, 1973; Drummond, 1974; Bird, 1978, 1981, 1985, 1986a, b, 1988; Van Dyke, 1980; Sweeney, 1982; Huffman, 1985; McWhae, 1986; Molenaar and others, 1986; Bird and Magoon, 1987; Hubbard and others, 1987; Tailleur and Weimer, 1987; and Gyrc, 1988).

The productive stratigraphic section on the North Slope can be divided into two sequences: the Ellesmerian and the Brookian (Fig. 4). Rocks older than the Ellesmerian, except in northeastern Alaska, are considered economic basement. The Ellesmerian sequence ranges in age from Mississippian to Early Cretaceous and includes important petroleum source, reservoir, and seal rocks. Except for the carbonate and coal deposits, the provenance of the quartz-rich Ellesmerian sediment is to the north, or the site of the present-day Arctic Ocean. The Colville basin, the site of deposition during this time, received many thousands of meters of sediment deposited in environments that ranged from nonmarine to deep marine. In Jurassic and Early Cretaceous time, rifting in the Arctic Basin reoriented the depositional pattern such that the Brooks Range was the provenance for lithic-rich sediment that prograded from the southwest to the northeast from Early Cretaceous to Holocene time (Ahlbrandt, 1979; Molenaar, 1983). Depositional environments ranged from nonmarine to deep marine and also include important source, reservoir, and seal rocks. Three petroleum systems, the Ellesmerian, Torok-Nanushuk, and Hue-Sagavanirktok, are present on the North Slope.

Ellesmerian system

The Ellesmerian petroleum system includes (Fig. 3; Table 4) the largest oil field in North America, Prudhoe Bay. Rocks involved in this petroleum system include both the Ellesmerian and

TABLE 4. OIL ACCUMULATIONS IN THE TOROK–NANUSHUK AND ELLESMERIAN PETROLEUM SYSTEMS BY DISCOVERY DATE, INDICATING CUMULATIVE PRODUCTION AS OF DECEMBER 31, 1987, REMAINING RESERVES, RESERVOIR CHARACTERISTICS, AND OIL CHEMISTRY*

Map symbol	Accumulation name	Year dis	Prod unit	Pool	Res lith	Prod stat	Trap type	Cum prod oil ($x10^3$bbl)	Cum prod gas (bcd)	Reserves oil ($x10^6$bbl)	Reserves gas (bcf)	Prod depth (m)	Orig press (kPa)	Sat press (kPa)
							TOROK–NANUSHUK							
A	Umiat	1946	Nanushuk	–	ss	shut-in	FA	–	–	70	–	75	–	–
B	Simpson	1950	Nanushuk	–	ss	abd	L	–	–	7	–	90	–	–
C	East Barrow	1980	pebble shale unit	–	ss	shut-in	FA	–	–	–	–	475	–	–
							ELLESMERIAN							
D	Fish Creek	1949	Nanushuk	–	ss	abd	L	–	–	–	–	915	–	–
E	Prudhoe Bay	1967	Kuparuk River	PBKR	ss	shut-in	C	–	–	–	–	1,890	22,130	20,550
E	Prudhoe Bay	1967	Sag River	Prudhoe	ss	prod	C	–	–	–	–	–	–	–
E	Prudhoe Bay	1967	Shublik	Prudhoe	co	prod	C	–	–	–	–	–	–	–
E	Prudhoe Bay	1967	Sadlerochit	Prudhoe	ss	prod	C	5,506,886	7,652	4,219	23,441	2,680	30,270	30,270
E	Prudhoe Bay	1967	Lisburne	PBL	co	prod	S	21,919	76	189	406	2,715	30,960	–
F	Kuparuk River	1969	Kuparuk River	Kuparuk	ss	prod	C	397,913	470	1,105	634	1,890	23,170	–
F	Kuparuk River	1969	Sagavanirktok	W. Sak	ss	shut-in	L	3	5	–	–	–	–	–
G	Milne Point	1969	Kuparuk River	Kuparuk	ss	shut-in	S	5,453	2	95	–	–	–	–
C	East Barrow	1974	Sag River	–	ss	shut-in	FA	–	–	–	–	670	6,895	–
H	Endicott	1978	Endicott	Endicott	ss	prod	C	8,807	8	366	907	3,050	33,580	–
I	Dalton	1979	Sadlerochit	–	ss	abd	L	–	–	–	–	2,400	–	–
I	Dalton	1979	Lisburne	–	co	abd	L	–	–	–	–	2,530	–	–
J	Niakuk	1981	–	–	–	shut-in	S	–	–	58	–	–	–	–
K	Point Thomson	1975	Canning	–	ss	shut-in	C	–	–	–	–	3,825	67,915	–
K	Point Thomson	1975	Thomson sand†	–	cg	shut-in	S	–	–	–	–	3,950	70,050	–

TABLE 4. OIL ACCUMULATIONS IN THE TOROK–NANUSHUK AND ELLESMERIAN PETROLEUM SYSTEMS BY DISCOVERY DATE, INDICATING CUMULATIVE PRODUCTION AS OF DECEMBER 31, 1987, REMAINING RESERVES, RESERVOIR CHARACTERISTICS, AND OIL CHEMISTRY* (continued)

Res temp (°C)	Net pay (m)	Por (%)	Perm (md)	Orig GOR (SCF/STB)	Water sat, S_{wi} (%)	Dev acres (ha)	Oil grav (API)	Sulfur (%)	$\delta^{34}S$ (‰)	Pr/Ph I	Pr/nC_{17}	$\delta^{13}C$ sat (‰)	$\delta^{13}C$ arom (‰)	Map symbol
							TOROK–NANUSHUK							
–	–	12	1-200	<100	–	2,430	36	0.1	-3.5	1.9	0.7	-28.0	-28.6	A
–	–	–	–	–	–	–	24	0.2	-5.2	B	B	-28.5	-28.1	B
–	–	–	–	–	–	–	31	0.2	+7.7	1.3	0.6	-29.5	-28.9	C
							ELLESMERIAN							
–	–	–	–	–	–	–	15	1.8	-2.3	B	B	-29.9	-29.6	D
66	9-25	23	3-200	450	28-47	–	23	–	–	–	–	–	–	E
–	–	–	–	–	–	–	–	–	–	–	–	–	–	E
–	–	–	–	–	–	–	–	–	–	–	–	–	–	E
93	0-135	22	265	730	21	61,110	28	0.9	-2.6	1.4	–	-29.8	-29.3	E
84	–	11	0.1-2.0	830	30	–	27	1.0	-2.7	–	–	-29.9	29.4	E
66	–	21	–	228-413	35	5,180	23	1.4	-0.4	–	–	-30.1	-29.7	F
–	–	–	–	–	–	–	–	–	–	–	–	–	–	F
–	–	–	–	–	–	–	–	–	–	–	–	–	–	G
14	–	22	44	–	–	730	18	1.5	+0.5	B	B	-29.5	-29.4	C
99	–	20	–	750	–	–	23	1.0	-0.2	–	–	-29.0	-28.7	H
–	–	–	–	–	–	–	–	1.9	+3.7	B	B	-29.6	-29.5	I
–	–	–	–	–	–	–	10	2.5	+4.4	B	B	-29.9	-30.1	I
–	–	–	–	–	–	–	–	–	–	–	–	–	–	J
91	–	–	–	864-934	–	–	23	–	–	–	–	–	–	K
96	–	–	–	5,830	–	–	18§	1.2	–	1.4	0.7	–	–	K

*Map symbols correspond to locations shown on Figure 3. References to complete this table include: Alaska Oil and Gas Conservation Commission, 1985, 1988; Bird and Magoon, 1987; R. P. Crandall, written communication, 1988; Hughes and Holba, 1988; Molenaar, 1982; Oil and Gas Journal, 1988; Petroleum Information, 1988. –, no information available; 1 ft = 0.3048 m; 1 psi = 6.895 kPa (kiloPascals); 1 acre = 0.4047 ha (hectare); 1 barrel = 0.1590 kiloliter; 1 cubic ft = 0.0283 cubic m; abd, abandoned; API, American Petroleum Institute; arom, aromatic hydrocarbons; B, biodegraded; bbl, barrel; bcf, billion cubic feet; C, combination trap; cg, conglomeratic sandstone; co, carbonate reservoir, cum prod, cumulative production through 12/31/87; dev, developed; dis, discovery; FA, faulted anticlinal trap; GOR, gas-to-oil ratio, in SCF/STB, standard cubic feet of gas per stock tank barrel of oil; grav, gravity; L, stratigraphic trap; PBKR, Prudhoe Bay–Kuparuk River; PBL, Prudhoe Bay Lisburne; perm, permeability; ph, phytane; por, porosity; pr, pristane; press, pressure; prod, producing; reserves, remaining reserves; res, reservoir; res lith, reservoir lithology; S, structural trap; sat, saturated hydrocarbons; ss, sandstone reservoir; stat, status; temp, temperature; W., west.

†Of local usage; includes oil and gas in pre-Mississippian reservoir rock

§Oil gravity ranges from 18°–45° API

the Brookian sequences. However, the source rocks and the major reservoir rocks are restricted to the Ellesmerian sequence (Fig. 4). Numerous authors have described the petroleum geology of the Ellesmerian sequence (Morgridge and Smith, 1972; Van Poollen and others, 1974; Jones and Speers, 1976; Bird and Jordan, 1977; Jamison and others, 1980; Seifert and others, 1980; Molenaar, 1981; Magoon and Claypool, 1981b, 1983, 1984, 1985, 1988; Carman and Hardwick, 1983; Alaska Oil and Gas Commission, 1984, 1985, 1988; Melvin and Knight, 1984; Oil and Gas Journal, 1984; Claypool and Magoon, 1985, 1988; Magoon and Bird, 1985, 1988; Magoon and Claypool, 1985; Specht and others, 1986; Whelan and others, 1986; Curiale, 1987; Sedivy and others, 1987; Werner, 1987; Farrington and others, 1988; and Hughes and Holba, 1988).

Both the Ellesmerian and Brookian sequences are required to complete this petroleum system. First, the Ellesmerian sequence includes three source rocks with mostly type II organic matter—the Shublik Formation, Kingak Shale, and to a lesser extent the pebble shale unit (Seifert and others, 1980; Magoon and Bird, 1985)—and three siliciclastic reservoir rocks—the Endicott Group, Sadlerochit Group (Ivishak Formation), and Kuparuk River Formation of Jamison and others (1980); it also includes a carbonate reservoir, the Lisburne Group (Bird, 1981, 1985; Figs. 4 and 5). The most important reservoir rock, in terms of volume of recoverable oil, is the Sadlerochit Group, a quartz-rich conglomeratic sandstone (Table 4). Other hydrocarbon accumulations in this system include both siliciclastic and carbonate reservoirs (Tables 4 and 5; Bird, 1981; Bird and Magoon, 1987). The Brookian, a northeasterly prograding deltaic and prodeltaic deposit, is the other sequence that provides the necessary overburden to mature the organic matter within the Ellesmerian source rocks. The areal distribution of the Ellesmerian system is controlled by the axis of the Colville trough and the present-day distribution of accumulations (Fig. 3).

Of the producing oil pools, the typical accumulation is situated in a combination structural-unconformity trap at a drill depth of 2,585 m (1,890 to 3,050 m) and covers 22,340 hectares (730 to 61,100 ha). The net pay ranges up to 135 m thick with an average porosity of 19 percent (11 to 22 percent) and permeabilities up to 265 millidarcies. The original pressure of the fluid in the reservoir is 29,500 kiloPascals (23,170 to 33,580 kPa); water saturation is 29 percent (21 to 35 percent), and temperature is 86 °C (66 to 99 °C). The API gravity of the oil is 25 degrees (23 to 28), and the oil has a gas-to-oil ratio of 635 (228 to 830) and a sulfur content of 1.1 percent (0.9 to 1.4 percent). When the oil is not biodegraded, the pristine/phytane ratio is 1.4, the carbon isotope value for the saturated hydrocarbons is –29.7 permil (–30.1 –29.0 permil), and for the aromatic hydrocarbons is –29.3 permil (–29.7 to –28.7 permil). Using carbon isotope and biological marker compounds, a source-rock-to-oil comparison is possible (Seifert and others, 1980; Sedivy and others, 1987). Therefore, the level of certainty for the Ellesmerian petroleum system is known.

The duration of the Ellesmerian petroleum system was 300

TABLE 5. GAS ACCUMULATIONS IN THE TOROK–NANUSHUK AND ELLESMERIAN PETROLEUM SYSTEMS BY DISCOVERY DATE, INDICATING ESTIMATED RESERVES, RESERVOIR CHARACTERISTICS, AND GAS CHEMISTRY*

Map No.	Accumulation name	Year dis	Prod unit	Pool	Res lith	Prod stat	Trap type	Cum prod oil ($x10^3$bbl)	Cum prod gas (bcf)	Reserves gas bcf	Prod depth (m)	Orig press (kPa)	Gas spec grav
	Torok–Nanushuk												
1	Meade	1950	Nanushuk	–	ss	abd	A	–	–	10-20	1,280	–	–
2	Wolf Creek	1951	Nanushuk	–	ss	abd	A	–	–	–	460	–	–
3	Gubik	1951	Colville	–	ss	abd	A	–	–	22-295	440	–	–
4	Square Lake	1952	Colville	–	ss	abd	A	–	–	–	500	–	–
5	East Umiat	1963	Nanushuk	–	ss	abd	A	–	–	–	550	5,170	0.600
	Ellesmerian												
6	South Barrow	1949	Kingak	Barrow ss†	ss	prod	FA	–	18	7	685	335	0.560
7	Kavik	1969	Sag River	–	ss	abd	FA	–	–	–	1,065	730	0.587
7	Kavik	1969	Sadlerochit	–	ss	abd	FA	–	–	–	–	730	0.588
8	Kemik	1972	Shublik	–	ss	abd	FA	–	–	–	2,620	815	0.600
9	East Barrow	1974	Kingak	Barrow ss†	ss	prod	FA	–	4	8	580	305	0.570
10	Walakpa	1980	pebble shale unit	–	ss	shut-in	L	–	–	–	635	315	–
11	Point Thomson	1975	Thomson sand†	–	cg	shut-in	C	–	–	–	3,930	3,050	–

TABLE 5. GAS ACCUMULATIONS IN THE TOROK–NANUSHUK AND ELLESMERIAN PETROLEUM SYSTEMS BY DISCOVERY DATE, INDICATING ESTIMATED RESERVES, RESERVOIR CHARACTERISTICS, AND GAS CHEMISTRY* (continued)

Res temp (°C)	Net pay (m)	Por (%)	Perm (md)	Water sat, S_{wi} (%)	Dev acres (ha)	Btu (Btu/ft^3)	$\delta^{13}C$ methane (‰)	C_1/C_{1-5}	Map No.
					Torok–Nanushuk				
–	–	–	–	–	–	–	–	–	1
–	–	–	–	–	–	–	–	–	2
–	–	–	–	–	–	–	–	–	3
–	–	–	–	–	–	–	–	–	4
10	20	15.4	15	32	–	–	–	–	5
					Ellesmerian				
17	8	20	30	52	1,415	–	-40.8	0.984	6
46	12	5	2	50	518	–	–	–	7
53	85	13	200	50	518	–	–	–	7
51	–	–	–	–	260	–	–	–	8
14	5	22	44	55	728	–	–	–	9
–	5	20	28	40	–	–	-37.8	0.997	10
96	–	–	–	–	–	–	–	–	11

*Map numbers correspond to locations shown on Figure 3. References to complete this table include: Alaska Oil and Gas Conservation Commission, 1985, 1988; Bird, 1981; R. P. Crandall, written communication, 1988; –, no information available; 1 ft = 0.3048 m; 1 psi = 6.897 kPa (kilo Pascals); 1 acre = 0.4047 ha (hectare); A, anticlinal trap; abd, abandoned; bbl, barrels; bcf, billion cubic feet; Btu, British thermal unit; cg, conglomeratic sandstone; cum prod, cumulative production through 12/31/87; dev, developed; dis, discovery; FA, faulted anticlinal trap; L, stratigraphic trap; orig press, original pressure; perm, permeability; por, porosity; prod, producing; res lith, reservoir lithology; res temp, reservoir temperature; sat, saturation; spec grav, specific gravity; ss, sandstone; stat, status.

†Of local usage.

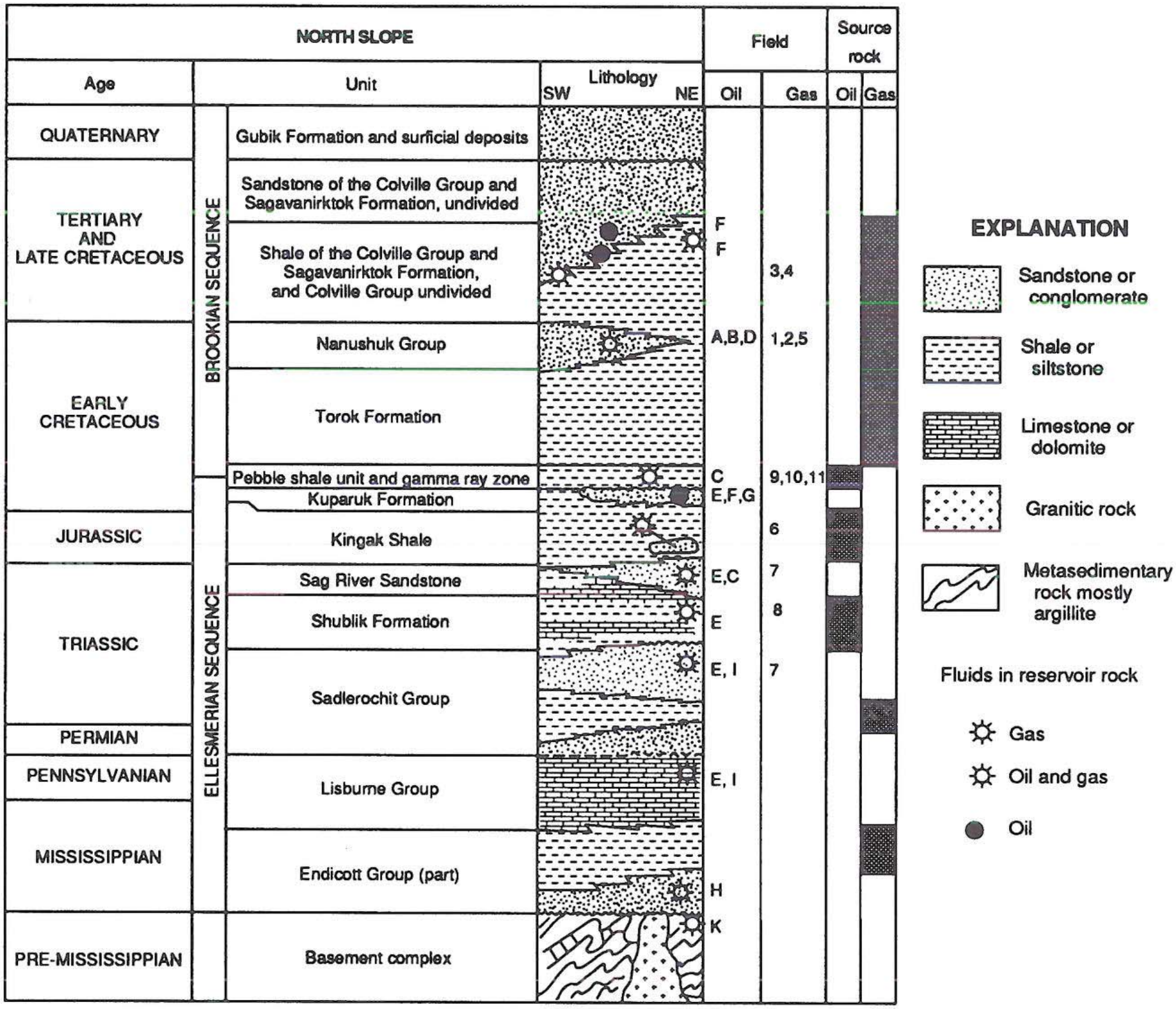

Figure 4. A generalized stratigraphic column for the North Slope (modified from Bird, 1985) showing petroleum in reservoir rocks and source rock intervals. See Tables 4 and 5 for oil and gas field names.

m.y.—from the Mississippian (360 Ma) to early Tertiary time (60 Ma; Fig. 6). Based on a Lopatin diagram for the Inigok No. 1 well in the eastern part of NPRA, the Shublik Formation and the Kingak Shale were well into the gas-generation phase (>160 TTI) by the end of the Cretaceous (Fig. 7). Extrapolating this model to the same rock units to the east in the Colville trough suggests that most oil near Prudhoe Bay migrated into the area by early Tertiary time. During the Tertiary some of the hydrocarbon generated was gas, but for the most part, already accumulated oil remigrated from the Prudhoe Bay pool into shallower reservoirs; the preservation time for this system is 60 m.y.

Torok-Nanushuk system

On the western part of the North Slope of Alaska, noncommercial quantities of hydrocarbons are associated with the Torok-Nanushuk petroleum system (Figs. 3, 4, and 5; Tables 4 and 5). Stratigraphic intervals involved include the Brookian se-

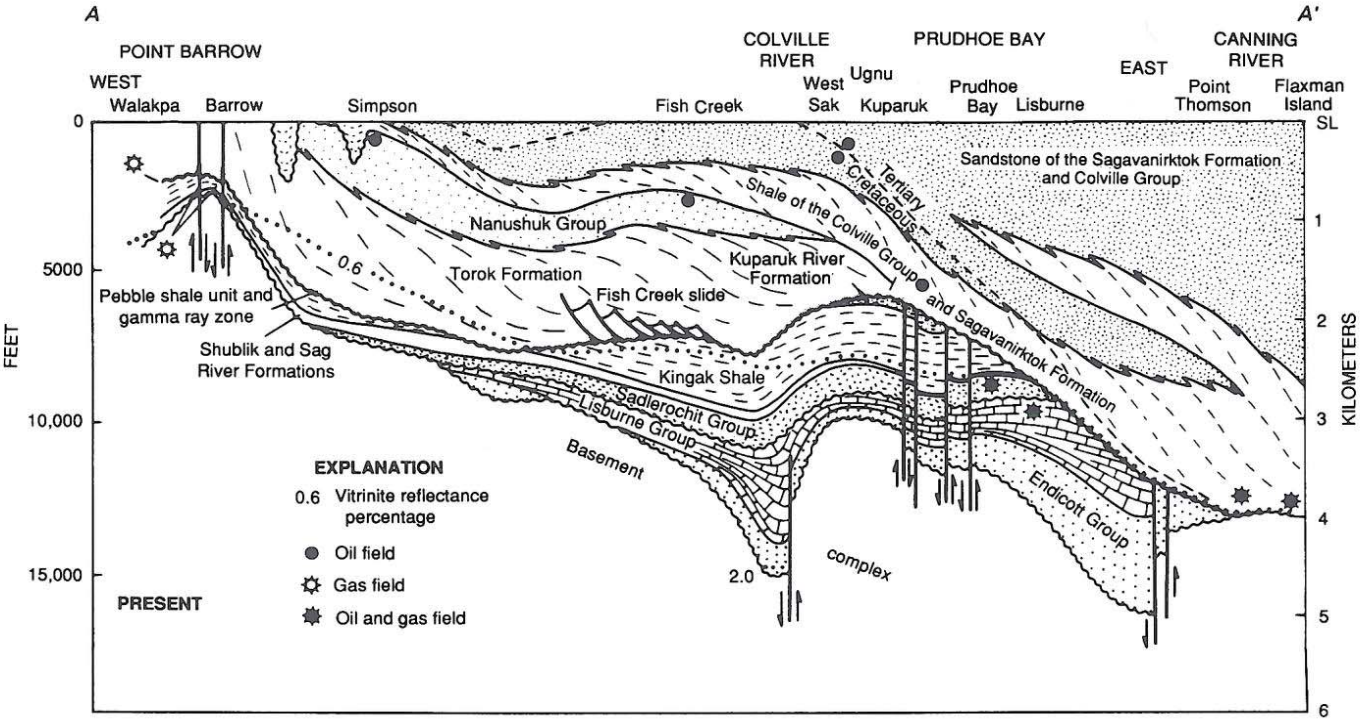

Figure 5. Cross section A-A′ showing present stratigraphic relations, petroleum-bearing units, and depth to the onset of petroleum generation (vitrinite reflectance = 0.6 percent; figure slightly modified from Bird, 1985). See Figure 3 for location of section. Rock symbols explained in Figure 4.

quence and the pebble shale unit; all are from the base of the unconformity below the pebble shale unit to the surface. References that describe the petroleum geology of this system are as follows: Ahlbrandt (1979); Magoon and Claypool (1981b, 1983, 1985, 1988); Molenaar (1981, 1982, 1988); Huffman (1985); and Magoon and Bird (1985, 1988).

The source rock for this system contains a type III kerogen and is most likely found in the lower part of the Torok Formation, and possibly in the underlying pebble shale unit (Magoon and Claypool, 1985). There are considerable geochemical data available on both the oils and source rocks, but a convincing geochemical correlation has not been demonstrated (Magoon and Bird, 1985; Magoon and Claypool, 1985). Therefore, the Torok-Nanushuk petroleum system is hypothetical. The geochemistry of these high-gravity, low-sulfur oils in this system separates them from the moderate-gravity, high-sulfur oils of the Ellesmerian system (Magoon and Claypool, 1981b, 1988). The composition of the Umiat and similar oils is consistent with their origin from the type III kerogen of the Torok Formation and pebble shale unit.

Sandstone of the Nanushuk Group of Early and Late Cretaceous age is the major reservoir rock (Bird, 1988). The reservoir rock is lithic-rich sandstone derived from the Brooks Range orogen (Ahlbrandt, 1979; Molenaar, 1981; Huffman, 1985). The undeveloped oil and gas accumulations are located in structural and stratigraphic traps (Collins and Robinson, 1967; Bird, 1985; Tables 4 and 5). The largest oil field is the Umiat, with 70 million barrels of recoverable oil in the Nanushuk Group (Molenaar, 1982; Table 4). It is unknown whether the gas in the Meade and Gubik fields is thermal or microbial. Since the oil and gas fields are, in many cases, relatively old, and have never been developed, comparatively little information is available for them.

The geologic setting, a foreland basin, remained the same during deposition of all the essential elements. The essential elements include the Torok Formation, and possibly the pebble shale unit, as the source rock; the Nanushuk Group as the reservoir rock; shale within the Nanushuk Group and shale of the Colville Group (Bird, 1988) as the regional seals; and the Brookian sequence, which includes the shale of the Colville Group and the Sagavanirktok Formation as the overburden necessary to mature the source rock. Although some hydrocarbons have been generated during Tertiary time, most of the oil has been preserved in the reservoir since early Tertiary time. Therefore, the duration of this petroleum system is estimated to be 105 m.y. and ranges from the Early Cretaceous (130 Ma) to the Paleogene (25 Ma); the preservation time is 25 m.y. The geographic distribution of

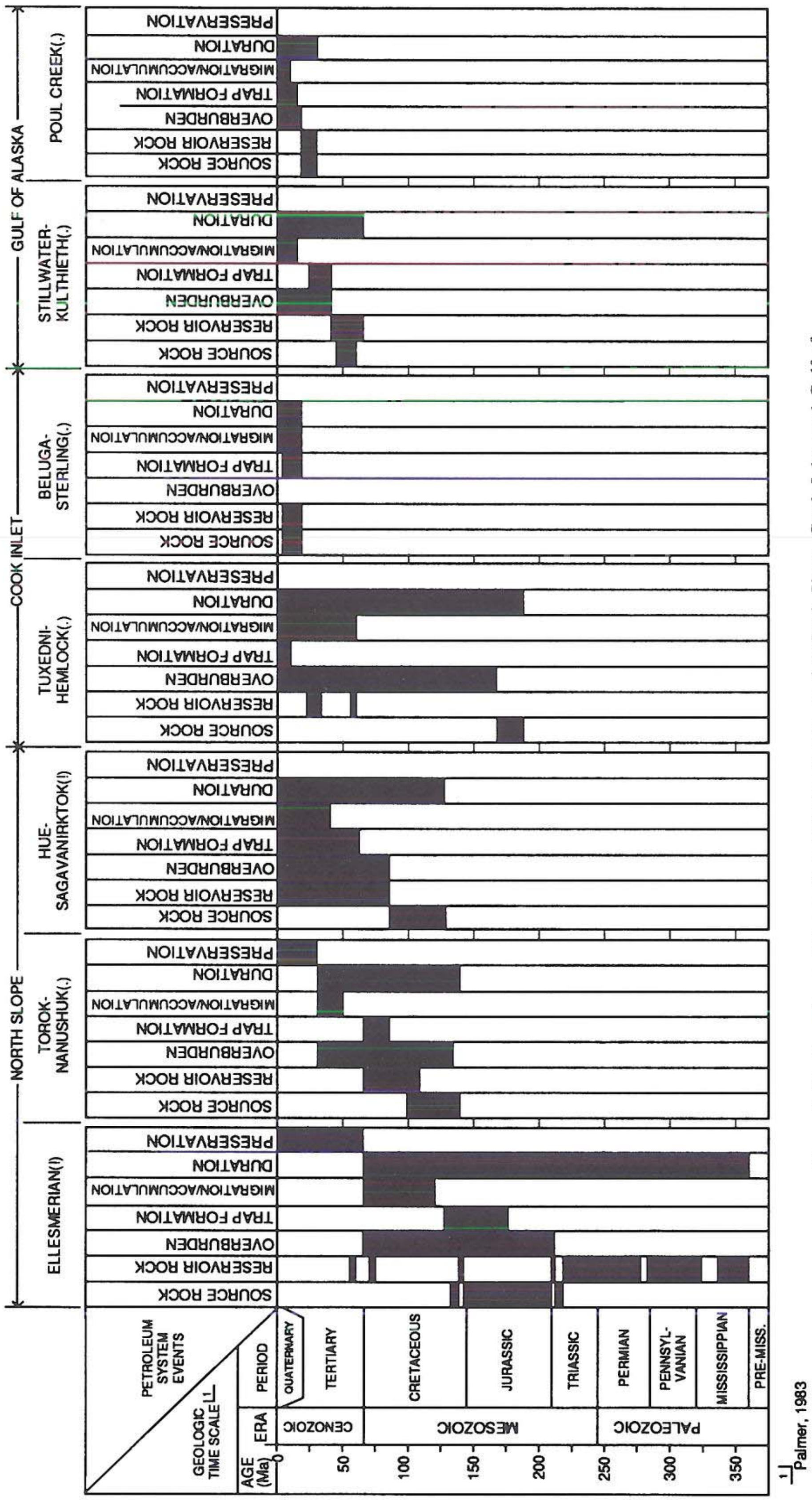

Figure 6. Timing of events for each petroleum system on the North Slope, Cook Inlet, and Gulf of Alaska.

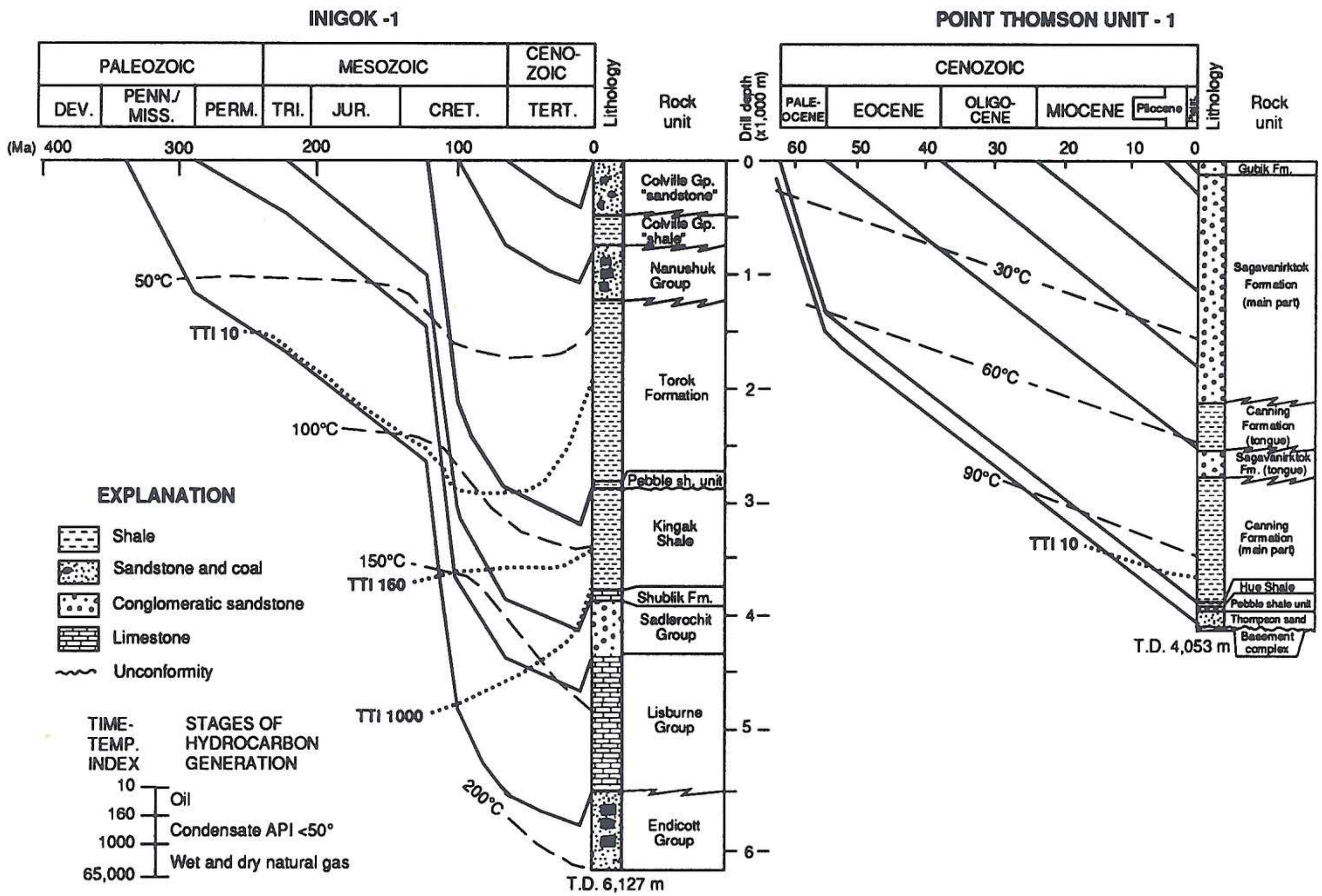

Figure 7. Lopatin diagrams indicating the time of oil and gas generation for the rocks penetrated in the Inigok No. 1 well and the Point Thompson unit No. 1 (from Magoon and Claypool, 1983; Magoon and others, 1987). Location shown on Figure 3.

the Torok-Nanushuk system is controlled on the east by the geographic extent of the Torok Formation and on the west by the known accumulations (Figs. 3 and 5).

Hue-Sagavanirktok system

On the eastern part of the North Slope in northeastern Alaska, an unknown quantity of hydrocarbons is associated with the Hue-Sagavanirktok petroleum system (Fig. 3). From the Point Thomson area east to the Canadian border, stratigraphic intervals involved in this system are the Hue Shale and Canning and Sagavanirktok Formations (Bird and Magoon, 1987). Additional references that relate to the petroleum geology of this system are relatively few because only recently has much subsurface information become available (Detterman and others, 1975; Wood and Armstrong, 1975; Mull and Kososki, 1977; Molenaar, 1983; Bader and Bird, 1986; Anders and others, 1987; Bird and Magoon, 1987; Magoon and others, 1987; and Molenaar and others, 1987).

The Hue Shale is the oil-source rock for this system. Other shale units (Shublik Formation, Kingak Shale, or pebble shale unit) that are oil prone west of the Canning River are either overmature or gas prone (type III kerogen) in northeastern Alaska. The Canning Formation and shale within the Sagavanirktok Formation are either immature or gas-prone source rocks. However, the Hue Shale contains large amounts of type II kerogen whose bitumen extract compares well with certain compounds and properties of the seep oil and oil that stains outcropping sandstones east of the Canning River. The major reservoir rock for this petroleum system probably is the Sagavanirktok Formation or turbidites in the Canning Formation because the oil seeps and stains commonly occur in these units. Because the Hue Shale unconformably overlies many of the Ellesmerian sequence and older units, future drilling may encounter oil pools that originated from this source rock in older reservoir rocks. The reservoir properties for most potential reservoirs in northeastern Alaska are discussed in Bird and Magoon (1987).

The Hue-Sagavanirktok petroleum system took approximately 95 m.y. to develop, from Late Cretaceous to Holocene time. Based on the Lopatin diagram in the Kavik area (field no. 7 in Fig. 3), the Hue Shale began generating oil 45 m.y. ago (Magoon and others, 1987), and in the Point Thompson No. 1 well (field K in Fig. 3), the Hue Shale began generating oil in Miocene time (10 Ma; Fig. 7). Trap formation occurred before, during, and after oil generation and migration. Since oil generation continues today, this petroleum system is incomplete, and the duration time is a minimum.

COOK INLET

Almost 60 years of exploration preceded the discovery of the first commercial oil field in the Cook Inlet area (Fig. 8). Exploration started on the Iniskin Peninsula in 1902, where seven wells were drilled. Between 1921 and 1957, only nine exploratory wells were drilled before the Swanson River oil field was discovered (Parkinson, 1962). Over the next 15 years, seven oil and 23 gas accumulations were discovered. Except for one oil pool (Redoubt Shoal), and 14 gas accumulations, all are still producing (Tables 6 and 7). By the end of 1987, almost 1.1 billion barrels of oil and 5.3 trillion cubic feet of gas had been produced, leaving 90 million barrels of oil and 3.3 tcf of gas yet to be extracted. The history of exploration and the framework and petroleum geology in this area are discussed by many workers (Kelly, 1963, 1968; Detterman and Hartsock, 1966; Crick, 1971; Blasko and others, 1972; Kirschner and Lyon, 1973; MacKevett and Plafker, 1974; Blasko, 1974, 1976a; Boss and others, 1976; Hite, 1976; Magoon and others, 1976; Fisher and Magoon, 1978; Claypool and others, 1980; Magoon and others, 1980; Magoon and Claypool, 1981a; Reed and others, 1983; Magoon, 1986; and Magoon and Egbert, 1986).

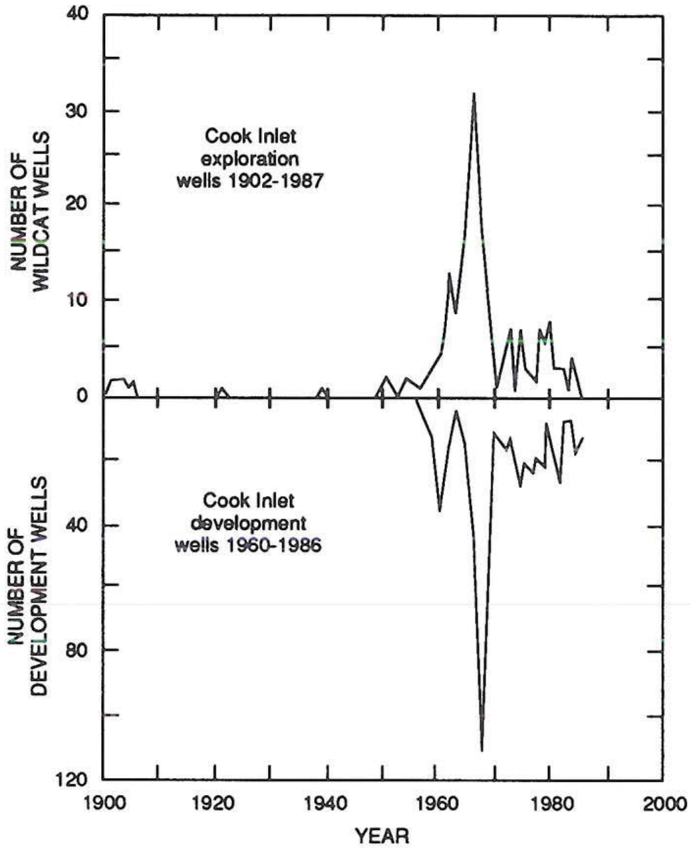

Figure 8. Exploration and development drilling history for Cook Inlet. Wells are plotted at year they reached total depth.

The tectonic evolution of the Cook Inlet area is complex because it is part of the northern Pacific margin, which has been the site of continuous convergence throughout the Mesozoic and Cenozoic (Coney and Jones, 1985). The Cook Inlet area is bounded on the northwest by the Alaska-Aleutian Range and the Talkeetna Mountains and on the southeast by the Kenai Mountains. The Jurassic and Lower Cretaceous rocks are included in the Peninsular terrane (Silberling and others, this volume); the Upper Cretaceous and Cenozoic rocks compose a post-amalgamation overlap sequence. Because all the commercial accumulations are associated with the Cenozoic rocks in the Cook Inlet area, the petroleum discussion is restricted to this area (Fig. 9).

In the Cook Inlet area, the pre–Late Cretaceous sequence and correlative plutonic rocks of the Alaska-Aleutian Range batholith constitute the Peninsular terrane (Silberling and others, this volume). The Border Ranges fault separates this terrane from the accreted Chugach terrane on the southeast. The Lower Jurassic Talkeetna Formation, a volcaniclastic sequence, and the Alaska-Aleutian batholith are economic basement for this petroleum province (Fig. 10). The Tuxedni Group of Middle Jurassic age is important because it contains rich source rocks and is the most likely source for all the oil and some gas in the area. The Upper Jurassic Naknek Formation contains a high percentage of feldspathic sandstone and conglomerate, but because of laumontite cementation, it is a poor reservoir (Franks and Hite, 1980; Bolm and McCulloh, 1986). The Cretaceous Matanuska Formation contains little organic matter, but does contain potential sandstone reservoirs. All these units in the Peninsular terrane were deposited in a coastal to deep marine environment and unconformably underlie the petroleum-bearing Cenozoic rocks.

The Cenozoic rocks in the Cook Inlet area overlap the Alaska-Aleutian batholith on the northwest and the Border Ranges fault on the southeast. Calderwood and Fackler (1972) defined and named the critical Cenozoic stratigraphic units—West Foreland Formation, Hemlock Conglomerate, Tyonek Formation, Beluga Formation, and Sterling Formation—that are regionally correlated (Alaska Geological Society, 1969a–d, 1970a, b) and mapped (Hartman and others, 1972). These rock units were all deposited in a nonmarine fore-arc basin setting. The provenance for the conglomerate, sandstone, siltstone, shale, and volcaniclastic debris was local highs flanking the basin and interior Alaska. Each of these rock units is a reservoir for oil or gas somewhere in the basin. Throughout the section, numerous large coal deposits formed and were preserved (Wahrhaftig and others, this volume; Barnes and Payne, 1956; Barnes and Cobb, 1959).

Tuxedni-Hemlock system

In the Cook Inlet area, all the large oil fields occur in reservoirs of early Tertiary age (Fig. 10; Table 6). Rock units that range in age from Middle Jurassic to Holocene are involved in the Tuxedni-Hemlock petroleum system.

Two different depositional settings, separated by a period of nondeposition and deformation, were required to complete this petroleum system. The first setting, a marine environment from Middle Jurassic to Late Cretaceous, accumulated sedimentary rocks deposited in both a fore-arc and back-arc basin associated with volcanic and plutonic rocks. The Middle Jurassic (187 to 163 Ma) Tuxedni Group, which contains a type III kerogen, is considered to be the source rock for the oil. The second setting, a fluvial environment, produced siliciclastic rocks deposited in a narrow fore-arc basin. Approximately 80 percent of the oil is contained in the Hemlock Conglomerate, a conglomeratic sandstone of Oligocene age (37 to 24 Ma; Magoon and others, 1976; Wolfe, 1981). The McArthur River field is the largest, with original reserves of almost 570 million barrels of oil, of which almost 500 million barrels are from the Hemlock Conglomerate (Table 6). The level of certainty for the Tuxedni-Hemlock petroleum system is hypothetical because geochemical information on the oils and rocks are insufficient to demonstrate a correlation (Magoon and Claypool, 1981a).

A typical oil pool in this petroleum system is located in a faulted anticline at a drill depth of 2,560 m (765 to 4,500 m). The pool covers 1,000 hectares (ranges from 195 to 5,000 ha), and has a net pay of 90 m (21 to 300 m). The reservoir rock is a conglomeratic sandstone with an average porosity of 17 percent (12 to 22 percent), an average permeability of 80 millidarcies (10 to 360 md), a reservoir pressure of 29,650 kiloPascals (14,045 to 52,071 kPa), and a temperature of 72 °C (44 to 102 °C). The typical oil in this reservoir has an API oil gravity of 34 ± 6°, a gas-oil ratio of 600 (175 to 3,850), a sulfur content of 0.1 percent, a pristine/phytane ratio of 2.7 (1.6 to 3.4), and carbon isotope values for saturated hydrocarbons of −30 permil (−30.4 to −29.6) and for aromatic hydrocarbons of −28 permil (−29.1 to −27.8). This information and biological marker data indicate that the oil originates from a marine-shale source rock (Peters and others, 1986).

Tertiary rocks include not only the reservoir rock but the overburden necessary to mature the Middle Jurassic marine source rock. Because the source rock is at maximum burial depth, the duration time for this petroleum system is 187 m.y., with no preservation time (Fig. 6). No Lopatin diagram is available for Cook Inlet; late Cenozoic oil generation is indicated by the thick Cenozoic sedimentary section east of the Middle Ground Shoal field (Figs. 10 and 11). Oil generation probably started within the last 5 m.y. and continues today; the petroleum system thus is still active, and the duration is lengthening. The geographic boundary for the Tuxedni-Hemlock petroleum system is restricted by known accumulations because the mature source rock is covered between the Swanson River and Middle Ground Shoal fields (Fig. 11).

Beluga-Sterling system

In Cook Inlet, a cumulative production of more than 6.1 tcf of dry gas is attributed to upper Tertiary rocks, which were deposited in a fore-arc basin (Magoon and Egbert, 1986; Fig. 5; Table 7). Three stratigraphic units are involved in the Beluga-Sterling petroleum system: the Tyonek, Beluga, and Sterling Formations (Fig. 10).

The siliciclastic Sterling Formation of late Miocene and Pliocene age is the major reservoir rock. Most of the microbial gas is in the Sterling Formation reservoirs, a medium-grained, well- to fairly well-sorted, and slightly conglomeratic sandstone (Crick,

TABLE 6. TUXEDNI–HEMLOCK OIL ACCUMULATIONS BY DISCOVERY DATE, INDICATING CUMULATIVE PRODUCTION AS OF DECEMBER 31, 1987, REMAINING RESERVES, RESERVOIR CHARACTERISTICS, AND OIL CHEMISTRY*

Map symbol	Accumulation name	Year dis	Prod unit	Pool	Res lith	Prod stat	Trap type	Cum prod oil ($x10^3$bbl)	Cum prod gas (bcf)	Reserves oil ($x10^6$bbl)	Reserves gas (bcf)	Prod depth (m)	Orig press (kPa)	Sat press (kPa)
A	Swanson River	–	Hemlock	34-10	cg	prod	A	–	–	–	–	3,285	39,300	7,240
A	Swanson River	–	Hemlock	Center	cg	prod	A	–	–	–	–	3,220	39,300	7,860
A	Swanson River	–	Hemlock	SCU	cg	prod	A	–	–	–	–	3,140	38,265	9,310
A	Swanson River	1957	**Field total**					208,469	1,752	10	250			
B	Mid Grd Shl	–	Tyonek	A	ss	prod	FA	2,000	4	–	–	765	–	–
B	Mid Grd Shl	–	Tyonek	B,C,D	ss	prod	FA	10,420	7	–	–	1,830	19,085	13,100
B	Mid Grd Shl	–	Ty-Hem	E,F,G	ss-cg	prod	FA	140,683	65	–	–	2,590	29,095	10,345
B	Mid Grd Shl	1962	**Field total**					153,103	77	11	7			
C	Granite Point	–	Tyonek	MGS	ss	prod	A	106,838	92	–	–	2,675	29,310	16,550
C	Granite Point	–	Hemlock	–	cg	prod	A	3	–	–	–	–	–	–
C	Granite Point	1965	**Field total**					106,841	92	19	15			
D	Trading Bay	–	Tyonek	C	ss	prod	FA	–	–	–	–	1,340	14,045	–
D	Trading Bay	–	Tyonek	D	ss	prod	FA	–	–	–	–	1,715	18,180	13,245
D	Trading Bay	–	Ty-Hem	–	ss-cg	prod	A	–	–	–	–	2,990	30,820	12,275
D	Trading Bay	–	Hemlock	–	cg	prod	FA	–	–	–	–	1,860	19,320	11,185
D	Trading Bay	1965	**Field total**					89,424	61	2	2			
E	McArthur River	–	Tyonek	MGS	ss	prod	A	36,769	18	–	–	2,695	27,640	12,590
E	McArthur River	–	Hemlock	–	cg	prod	A	474,421	171	–	–	2,820	29,305	12,320
E	McArthur River	–	W Foreland	–	ss	prod	A	19,317	6	–	–	2,940	30,730	8,170
E	McArthur River	1965	**Field total**					530,507	194	47	25			
F	Redoubt Shoal	1968	Hemlock	–	cg	abd	–	2	–	–	–	–	–	–
G	Beaver Creek	1972	Tyonek	MGS	ss	prod	–	3,521	1	1	1	4,510	52,070	–

TABLE 6. TUXEDNI–HEMLOCK OIL ACCUMULATIONS BY DISCOVERY DATE, INDICATING CUMULATIVE PRODUCTION AS OF DECEMBER 31, 1987, REMAINING RESERVES, RESERVOIR CHARACTERISTICS, AND OIL CHEMISTRY* (continued)

Res temp (°C)	Net pay (m)	Por (%)	Perm (md)	Orig GOR (SCF/STB)	Water sat, S_{wi} (%)	Dev acres (ha)	Oil grav (API)	Sulfur (%)	$\delta^{34}S$ (‰)	Pr/Ph I	Pr/nC_{17}	$\delta^{13}C$ sat (‰)	$\delta^{13}C$ arom (‰)	Map symbol
82	23	21	55	175	40	193	30	–	–	–	–	–	–	A
82	21	20	75	175	40	–	30	0.1	-1.9	1.6	0.8	-30.0	-29.4	A
82	67	22	360	350	40	1,077	37	–	–	–	–	–	–	A
														A
53	58	16	15	3,850	–	300	42	–	–	–	–	–	–	B
54	102	16	15	650	–	300	36	<0.1	+2.7	3.4	0.6	-30.0	-27.8	B
68	152	11	10	381	–	1,620	35	0.1	+1.9	2.1	0.4	-30.0	-28.2	B
														B
66	183	14	10	1,110	–	1,295	42	–	–	–	–	–	–	C
–	–	–	–	–	–	–	–	–	–	–	–	–	–	C
							41	0.1	0.0	2.6	0.5	-29.7	-28.0	C
–	–	–	–	–	–	–	28	0.1	-0.6	B	B	-29.6	-28.4	D
44	305	24	250	268	–	567	28	0.1	+1.7	2.7	2.2	-30.0	-28.1	D
82	66	12	12	275	36	202	36	0.1	+0.3	2.9	0.9	-30.2	-28.5	D
58	91	15	10	318	–	486	31	0.1	+2.5	3.1	3.6	-30.0	-28.7	D
														D
73	30	18	65	297	35	1,008	36	0.1	+0.4	2.4	0.9	-30.1	-28.7	E
82	88	11	53	404	35	5,018	35	0.1	+2.5	2.9	0.7	-30.1	-28.8	E
85	30	16	102	271	–	613	33	0.1	+2.4	2.7	0.7	-30.4	-29.1	E
														E
–	–	–	–	286	–	65	28	–	–	–	–	–	–	F
102	30	–	–	280	–	334	35	<0.1	+0.9	2.7	0.9	-30.1	-28.7	G

*Map symbols correspond to locations shown on Figure 9. References to complete this table include: Alaska Oil and Gas Conservation Commission, 1985, 1988; R. P. Crandall, written communication, 1988; Oil and Gas Journal, 1988. –, no information available; 1 ft + 0.3048 m; 1 psi = 6.895 kPa (kiloPascal); 1 acre = 0.4047 ha (hectare); 1 barrel = 0.1590 kiloliter; A, anticlinal trap; abd, abandoned; API, American Petroleum Institute; arom, aromatic hydrocarbons; B, biodegraded; bbl, barrel; bcf, billion cubic feet; cg, conglomeratic sandstone; cum prod, cumulative production through 12/31/87; dev, developed; dis, discovery; FA, faulted anticlinal trap; GOR, gas-to-oil ratio, in SCF/STB, standard cubic feet of gas per stock tank barrel of oil; grav, gravity; lith, lithology; MGS, Middle Ground Shoal Member of Debelius (1974); Mid Grd Shl, Middle Ground Shoal; perm, permeability; ph, phytane; pool A to G, industry pool designation; por, porosity; pr, pristane; press, pressure; prod, producing; res, reservoir, sat, saturated hydrocarbons; SCU, Soldatna Creek unit; ss, sandstone; stat, status; temp, temperature; Ty-Hem, Tyonek Formation and Hemlock Conglomerate, undivided; W, West; water sat, water saturation.

†Of Debelius (1974).

TABLE 7. BELUGA–STERLING GAS ACCUMULATIONS BY DISCOVERY DATE, INDICATING CUMULATIVE PRODUCTION AS OF DECEMBER 21, 1987, REMAINING RESERVES, RESERVOIR CHARACTERISTICS, AND GAS CHEMISTRY*

Map No.	Accumulation name	Year dis	Prod unit	Mbr or pool	Res lith	Prod stat	Trap type	Cum prod oil ($x10^3$bbl)	Cum prod gas (bcf)	Reserves gas (bcf)	Prod depth (m)	Orig press (kPa)	Gas spec grav
1	Kenai	1959	Sterling	3	ss	prod	D	–	263	–	1,130	12,840	0.577
1	Kenai	1959	Sterling	4	ss	prod	D	–	367	–	1,205	13,230	0.577
1	Kenai	1959	Sterling	5.1	ss	prod	D	–	429	–	1,225	13,225	0.577
1	Kenai	1959	Sterling	5.2	ss	shut-in	D	–	44	–	1,255	14,330	0.577
1	Kenai	1959	Sterling	6	ss	prod	D	–	397	–	1,390	12,270	0.557
1	Kenai	1959	Beluga	–	ss	prod	D	–	120	–	1,520	17,640	0.555
1	Kenai	1959	Tyonek	MGS	ss	prod	D	12	210	–	2,745	30,450	0.560
1	Kenai	1959	Field total					12	1,831	463			
2	Swanson River	1960	Sterling	B,D,E	ss	prod	A	–	13	–	875	9,205–31,030	0.600
3	West Fork	1960	Sterling	–	ss	shut-in	FA	–	2	6	1,520	14,045	0.560
4	Falls Creek	1961	Tyonek	MGS	ss	shut-in	–	–	–	13	2,145	23,470	0.600
5	Sterling	1961	Sterling	–	ss	shut-in	D	–	2	23	1,535	15,170	0.569
6	West Foreland	1962	Tyonek	MGS	ss	shut-in	–	–	–	20	–	29,410	0.600
7	North Cook Inlet	1962	Sterling	–	ss	prod	D	–	–	–	1,280	14,065	0.566
7	North Cook Inlet	1962	Beluga	–	ss	prod	D	–	–	–	1,555	17,085	0.566
7	North Cook Inlet	1962	Field total						820	680			
8	Beluga River	1962	Sterling	–	ss	prod	A	–	–	–	1,005	11,275	0.556
8	Beluga River	1962	Beluga	–	ss	prod	A	–	–	–	1,370	15,270	0.556
8	Beluga River	1962	Field total						253	604			
9	No Mid Grd Shl	1964	–	MGS	ss	shut-in	–	–	–	–	2,775	28,890	–
10	Birch Hill	1965	Tyonek	MGS	ss	shut-in	–	–	–	11	2,345	26,475	0.561
11	Moquawkie	1965	Tyonek	–	ss	shut-in	–	–	1	–	–	8,690–15,895	0.600
12	North Fork	1965	Tyonek	MGS	ss	shut-in	–	–	–	12	2,195	23,510	0.562
13	Nicolai Creek	1966	Ster-Bel	–	ss	shut-in	–	–	1	3	660	7,320–11,640	0.575
14	Ivan River	1966	Tyonek	Chuit	ss	shut-in	D	–	–	26	2,375	28,475	0.560
15	Beaver Creek	1967	Sterling	–	ss	prod	D	–	–	–	1,524	15,170	0.560
15	Beaver Creek	1967	Beluga	–	ss	prod	D	–	–	–	2,470	26,200	–
15	Beaver Creek	1967	Field total						63	177			
16	Albert Kaloa	1968	Tyonek	–	ss	shut-in	–	–	–	–	980	–	–

Map No.	Accumulation name	Year dis	Prod unit	Mbr or pool	Res lith	Prod stat	Trap type	Cum prod oil ($x10^3$bbl)	Cum prod gas (bcf)	Reserves gas (bcf)	Prod depth (m)	Orig press (kPa)	Gas spec grav
17	McArthur River	1968	Tyonek	MGS	ss	prod	A	–	97	–	–	11,955	0.564
17	McArthur River	1968	Tyonek	Chuit	ss	prod	A	–	36	–	–	–	–
17	McArthur River	1968	Field total						133	600			
18	Lewis River	1975	Beluga	–	ss	prod	–	–	4	18	1,435	19,030	–
19	Pretty Creek	1975	Beluga	–	ss	prod	–	–	1	25	1,830	–	–
20	Stump Lake	1978	Beluga	–	ss	shut-in	–	–	–	–	2,040	22,685–23,855	0.565
21	Theodore River	1979	Beluga	–	ss	shut-in	–	–	–	–	1,130	11,590–13,120	–
22	Cannery Loop	1979	Bel-Ty	–	ss	shut-in	–	–	–	300	–	27,580	0.560
23	Trading Bay	1979	Tyonek	MGS	ss	prod	FA	–	3	29	2,745	26,960	0.582
24	Mid Grd Shl	1982	Tyonek	MGS	ss	prod	FA	–	2	–	1,080	9,845	0.564

1971; Boss and others, 1976; Hayes and others, 1976; Claypool and others, 1980). When the microbial gas ($\delta^{13}C$ –57.6 permil) that was produced through 1987 is added to the remaining reserves, the Sterling Formation reservoirs account for 3 tcf, the Beluga Formation for 0.5 tcf, and the Tyonek Formation, after removal of the thermal gas ($\delta^{13}C$ –43.7 permil) from the McArthur River field, for 0.3 tcf. In the McArthur River field, the thermal gas in the Tyonek Formation is interpreted to have migrated from the underlying oil reservoirs in the Hemlock Conglomerate. In the Kenai field, the sandstones of the Sterling Formation contain almost 1.9 tcf or 82 percent of the gas. The siliciclastic Sterling Formation is the most important reservoir rock in the Beluga-Sterling petroleum system.

An average gas pool in this petroleum system has the following characteristics (Table 7). The pool is located in a domal structure that covers 1,050 hectares (20 to 3,360 ha) and has a net pay of 22 m (6 to 65 m). The sandstone reservoir has a water saturation of 40 percent (35 to 50 percent), a reservoir porosity of 27 percent (10 to 37 percent), and permeability of 1,100 millidarcies (3.5 to 4,400 md). The drill depth is 1,615 m (980 to 2,775 m) to a reservoir under 19,300 kiloPascals (7,320 to 31,000 kPa) at 50 °C (35 to 100 °C). The natural gas produced is 99 percent methane, with a specific gravity of 0.571 (0.555 to 0.600) and a heating value of 251 kilogram calories (250 to 256 kc).

The source for the gas is unclear, but the Beluga Formation and, to a lesser extent, the Sterling Formation have considerable coal and type III kerogen (Claypool and others, 1980). Most of the coal and type III kerogen are below the Sterling Formation, so this source is in a good position to charge overlying reservoirs with microbial gas (Claypool and others, 1980). Because this system requires no overburden to mature the source rocks, the duration time is short—from the late Miocene to Holocene, or about 12 m.y. (Palmer, 1983; Magoon and Egbert, 1986). The geographic boundary for the Beluga-Sterling petroleum system is presently restricted by known accumulations (Fig. 9).

GULF OF ALASKA

Oil and gas seeps in the northern Gulf of Alaska in the Katalla, Yakataga, and Samovar Hills areas (Fig. 13) indicate the possibility of commercial accumulations (Miller and others, 1959; Blasko, 1976b). From 1901 to 1932, 25 exploratory and 18 development wells were drilled (Fig. 12). The Katalla field, a fractured shale reservoir in the Poul Creek Formation, was discovered in 1902 and produced 153,922 barrels of 40° to 44° API gravity oil from 1904 to 1933 at a depth range of 110 and 460 m (Miller and others, 1959; Blasko, 1976b). Twenty-five exploratory wells and core holes were drilled onshore from 1954 to 1963 (Plafker, 1971; Plafker and others, 1975; Rau and others, 1983). In 1969, interest in the offshore began with the drilling of the Middleton Island State 1 well. From 1975 through 1978, one continental offshore stratigraphic test (COST) well and ten offshore exploratory wells were drilled and abandoned in the west-

TABLE 7. BELUGA–STERLING GAS ACCUMULATIONS BY DISCOVERY DATE, INDICATING CUMULATIVE PRODUCTION AS OF DECEMBER 21, 1987, REMAINING RESERVES, RESERVOIR CHARACTERISTICS, AND GAS CHEMISTRY* (continued)

Res temp (°C)	Net pay (m)	Por (%)	Perm (md)	Water sat, S_{wi} (%)	Dev acres (ha)	Btu (Btu/ft³)	$\delta^{13}C$ methane (‰)	$\frac{C1}{C_{1-5}}$	Map No.
39	27	35.5	–	35	2,035	–	-57.0	0.999	1
41	18	36.5	–	35	3,060	–	-56.7	0.999	1
41	34	36.5	–	35	2,510	–	–	–	1
40	16	36.5	–	35	727	–	–	–	1
43	34	32	–	40	2,198	–	-56.5	–	1
46	65	15–20	–	40	518	–	–	–	1
62	30	18–22	–	40	1,150	–	-48.2	0.998	1
						1,005		0.989	1
51	–	30	650	35	260	1,002	-57.7	0.999	2
43	7	30	4,400	–	185	–	–	–	3
56	–	–	–	–	–	1,015	–	0.991	4
43	6	26	–	40	625	991	-60.9	0.998	5
77	8	–	–	–	260	929	–	0.921	6
43	40	28	178	40	3,360	–	–	–	7
48	9	28	175	40	1,010	–	–	–	7
–	–	–	–	–	–	993	-60.7	0.998	7
34	33	31	–	37	2,070	–	–	–	8
41	32	24	–	42	1,955	–	–	–	8
–	–	–	–	–	–	1,014	–	0.997	8
62	7	–	–	–	–	–	–	–	9
58	9	25	6	–	60	1,014	–	0.986	10
27–42	14-33	20-24	–	35-40	520	1,006	–	0.990	11
60	–	18	3.5	50	20	1,002	–	0.981	12
41–43	10	–	–	–	–	976	-62.2	0.995	13
53	11	20	1,600	45	980	1,004	–	0.989	14
42	34	30	2,000	40	1,280	–	-58.2	0.989	15
61	6	10	–	–	260	–	–	–	15
–	–	–	–	–	–	998	–	0.983	15
–	–	–	–	–	–	–	–	–	16

Res temp (°C)	Net pay (m)	Por (%)	Perm (md)	Water sat, S_{wi} (%)	Dev acres (ha)	Btu (Btu/ft^3)	$\delta^{13}C$ methane (‰)	$\frac{C_1}{C_{1\text{-}5}}$	Map No.
47	–	–	–	–	780	–	–	–	17
43	–	–	–	–	520	–	–	–	17
–	–	–	–	–	–	–	-43.7	0.994	17
44	26	–	–	–	415	–	–	–	18
–	–	–	–	–	–	–	–	–	19
40	–	–	–	–	–	–	–	–	20
–	–	–	–	–	–	–	–	–	21
52	–	–	–	–	520	–	–	–	22
79	18	–	–	–	260	–	–	–	23
54	–	–	–	–	–	–	–	–	24

*Map numbers correspond to locations shown on Figure 9. References to complete this table include: Alaska Oil and Gas Conservation Commission, 1985, 1988; Blasko, 1974; Claypool and others, 1980; R. P. Crandall, written communication, 1988. 1 ft = 0.3048 m; 1 psi = 6.895 kPa (kiloPascal); 1 acre = 0.4047 ha (hectare); 1 cubic ft = 0.0283 cubic meter; 1 Btu = 0.25198 kilogram calories; –, no information available; A, anticlinal trap; bbl, barrels; Bel-Ty, Beluga and Tyonek Formation, undivided; bcf, billion cubic feet; btu, British thermal unit; Chuit, Chuitna Member; cum prod, cumulative production through 12/31/87; D, domal trap; dev, developed; dis, discovery; FA, faulted anticlinal trap; let, letter; Mbr, member; MGS, Middle Ground Shoal Member of Debelius (1974); No Mid Grd Shl, North Middle Ground Shoal; orig press, original pressure; perm, permeability; pool B,D,E, industry pool designation; por, porosity; prod, producing; reserves, remaining reserves; res lith, reservoir lithology; res temp, reservoir temperature; sat, saturation; spec grav, specific gravity; ss, sandstone; sat, status; Ster-Bel, Sterling and Beluga Formations, undivided.

ern segment (Fig. 13). The last dry exploratory well was drilled in 1983 on a large structure in the central segment (Plafker, 1987). The history of exploration and the framework and petroleum geology in this area are discussed by several workers (Bruns, 1982a, b, 1983; Mull and Nelson, 1986; Palmer, 1976; Plafker, 1987; Plafker and others, 1980; Plafker and Claypool, 1979).

Because known oil and gas accumulations, seeps, and shows are associated with the Yakutat terrane, the petroleum potential in the Gulf of Alaska is restricted to this terrane (Fig. 13; Blasko, 1976b; Plafker, 1987; Plafker and others, this volume, Chapter 12). The Yakutat terrane is a large lanceolate slab pointing to the southeast that is being subducted base-first to the northwest. The base is located on the Kayak Island zone and Ragged Mountain fault; the northeast edge is marked by the Chugach–Saint Elias fault and the Fairweather fault, and the southwest edge by the Transition fault (Plafker, 1987). Structural deformation is maximum on the northwest and attenuates to the southeast.

The Pamplona and Dangerous River zones divide the Yakutat terrane into three segments: western, central, and eastern (Plafker and others, 1975; Bruns, 1983, 1985; Plafker, 1987). The basement complex for the eastern segment is Mesozoic; the basement for the central and western segments is Eocene and Paleocene(?) basalt. As much as 4,600 m of Paleogene sedimentary rocks overlie the basement complex within the central and western segments, and 4,000 to 5,000 m of Neogene sedimentary rocks is present over the entire terrane (Bruns, 1983, 1985; Plafker, 1987).

Three stratigraphic sequences in the Yakutat terrane include the essential elements for the present-day occurrence of petroleum. The oldest sequence ranges in age from early Eocene to as young as early Oligocene; it consists of the Kulthieth, Tokun, and Stillwater Formations and may be as thick as 4,600 m (Fig. 14; Miller and others, 1959; Stoneley, 1967; Plafker, 1967, 1971, 1987). The Kulthieth Formation is a nearshore paludal deltaic sequence that includes thick interfingering, coal-bearing units, sandstone, siltstone, and shale deposited in alluvial-plain, delta-plain, barrier-beach, and shallow-marine environments. The Tokun Formation is primarily a deltaic deposit, and the Stillwater Formation is a prodelta deposit. Offshore, rocks of this age were dredged from the continental slope; thus the sequence is presumed to underlie the continental shelf.

The intermediate sequence includes the Poul Creek Formation, which ranges in age from late Eocene to early Miocene (Fig. 14). This predominantly shaly unit was deposited in water depths that range from neritic to bathyal, includes glauconite and organic matter, and is intercalated with intrabasinal water-laid alkalic basaltic tuff, breccia, and pillow lava. This deep marine sequence may be as much as 2,000 m thick. This sequence was sampled in offshore wells (Lattanzi, 1981) and is also presumed to underlie the continental shelf.

The youngest sequence, the Yakataga Formation, ranges in age from late Oligocene(?) to Quaternary and unconformably overlies rock units of all three segments. This sequence includes an enormous thickness (<4,600 m) of siliciclastic strata, including

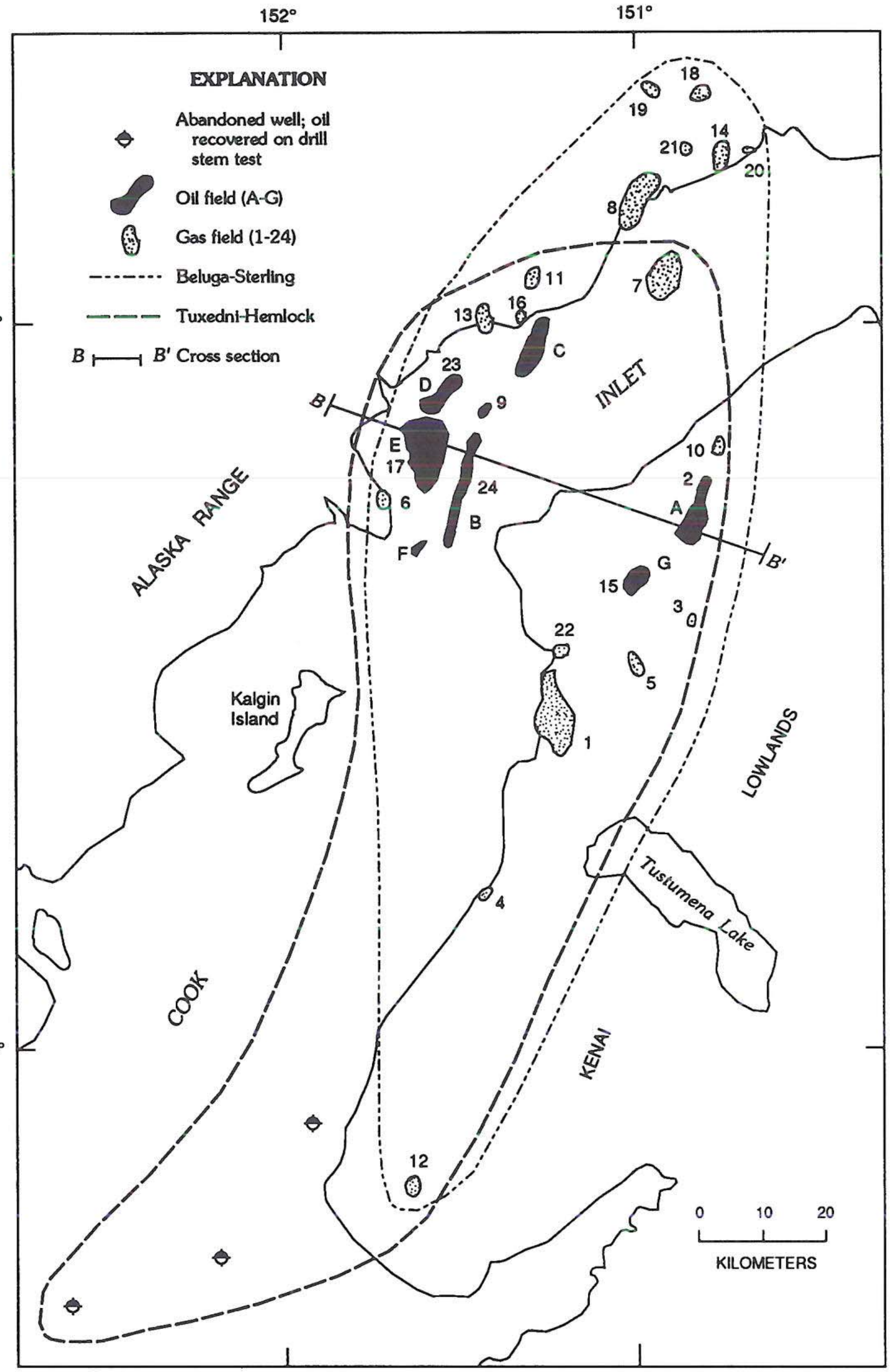

Figure 9. Cook Inlet oil and gas fields, boundaries of petroleum systems, and location of cross section B-B′.

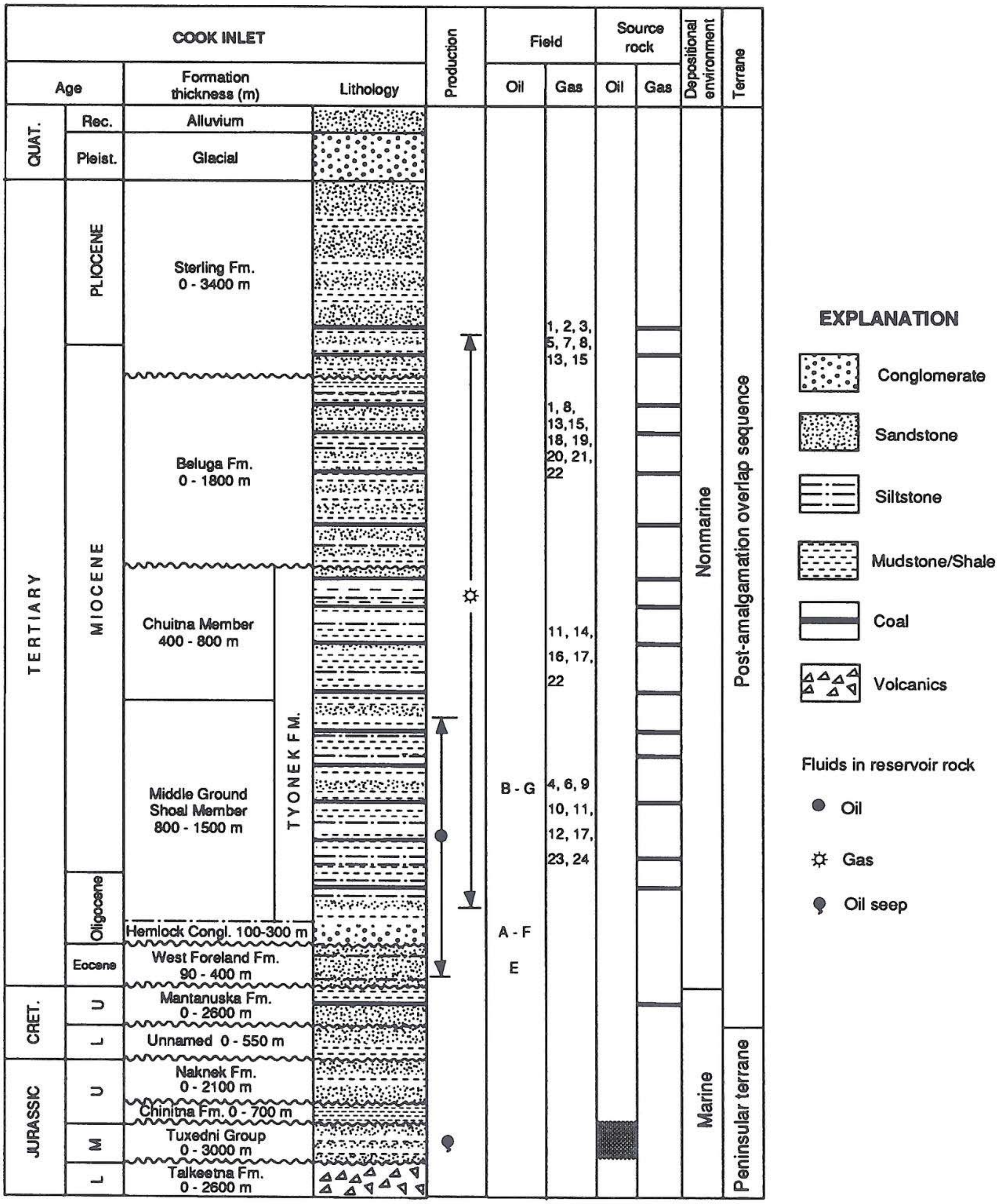

Figure 10. Generalized stratigraphic column for Cook Inlet (modified from Alaska Oil and Gas Conservation Commission, 1985, p. 182) showing petroleum in reservoir rocks and source rock intervals. See Tables 6 and 7 for oil and gas field names.

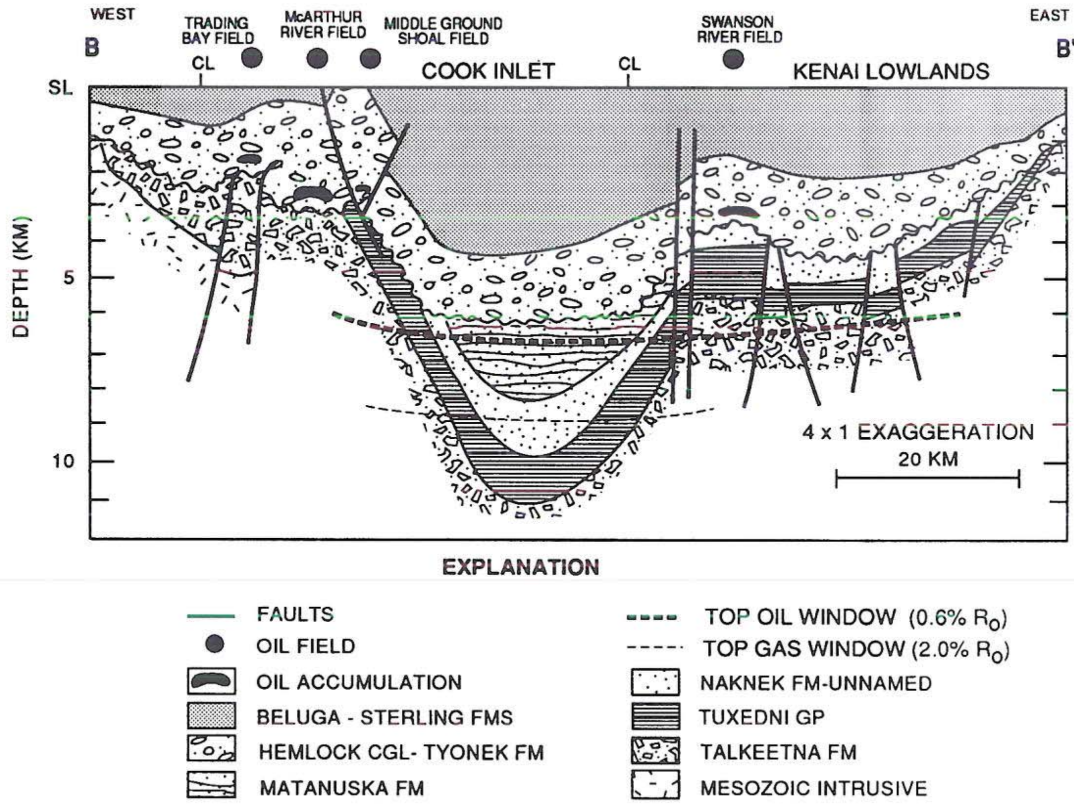

Figure 11. Cross section B–B′ showing structural and stratigraphic relations and field locations. See Figure 9 for location of section.

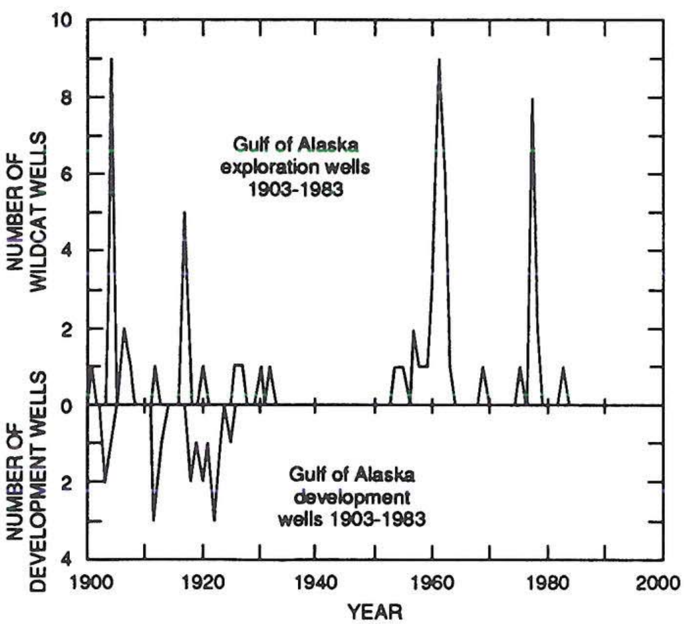

Figure 12. Exploration and development drilling history for the Yakutat terrane, Gulf of Alaska. Wells are plotted at year they reached total depth.

abundant glaciomarine sediment derived from the adjacent Fairweather Range and Chugach Mountains (Fig. 13). The Yakataga Formation is an essential element of the Gulf of Alaska petroleum systems because it is inferred to provide the burial depth necessary to generate the oil and gas.

Paleogene rocks in the Yakutat terrane increase in thermal maturity to the northwest (Plafker, 1987). The thermal maturity pattern is interpreted from coal beds, visual kerogen, Rock-Eval, and vitrinite reflectance data from outcrop, dredge, and well samples (Barnes, 1967; Palmer, 1976; Plafker and others, 1980; Mull and Nelson, 1986; Plafker, 1987). No thermal maturity information is available for the eastern segment. Coal rank indicates that the Paleogene is immature (0.4 to 0.6 percent R_o) west of Yakutat Bay (Plafker, 1987) to mature and overmature (0.6 to 2.5 percent R_o) in the Katalla area (Mull and Nelson, 1986). The Poul Creek Formation in the Katalla field is mature enough to have generated oil. Visual kerogen in two onshore wells (Socal, Riou Bay No. 1; Richfield, Duktoth No. 1) also indicates an increase in thermal maturity to the northwest in both the Paleogene and Neogene (Palmer, 1976). Thermal maturity of Paleogene dredge samples from the central segment along the Transition fault is immature (0.4 to 0.6 percent R_o; Plafker,

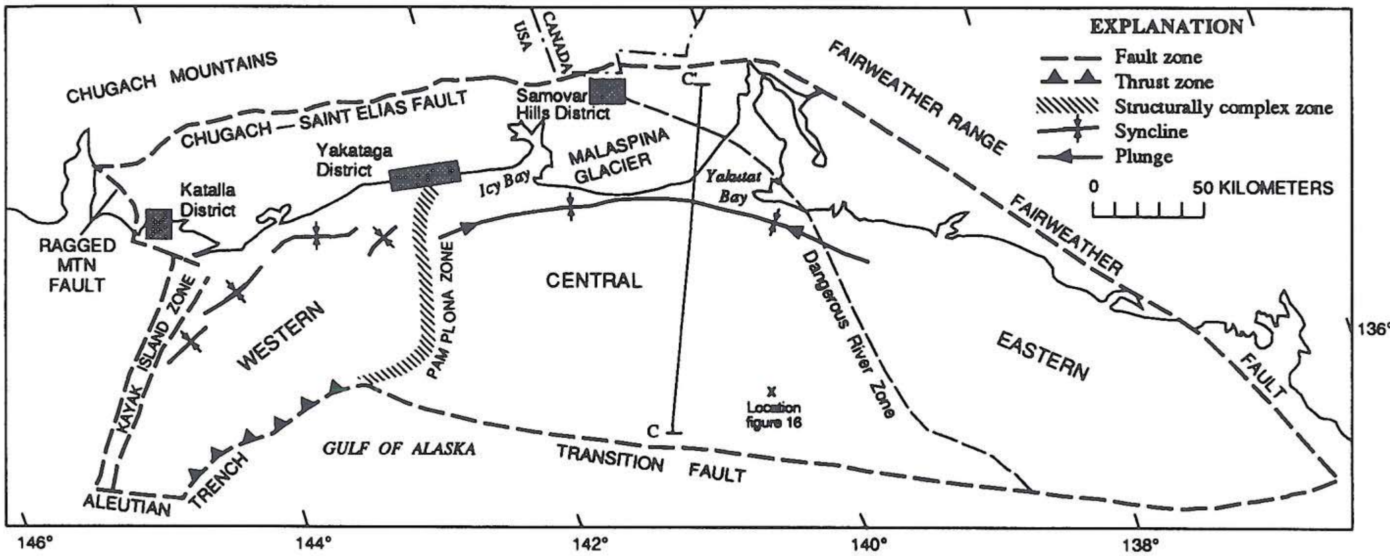

Figure 13. The Yakutat terrane in the Gulf of Alaska showing the western, central, and eastern segments. Also shown are locations of the Katalla, Yakataga, and Samovar Hills Districts, where oil and gas seeps are located, and the location of cross section C-C′.

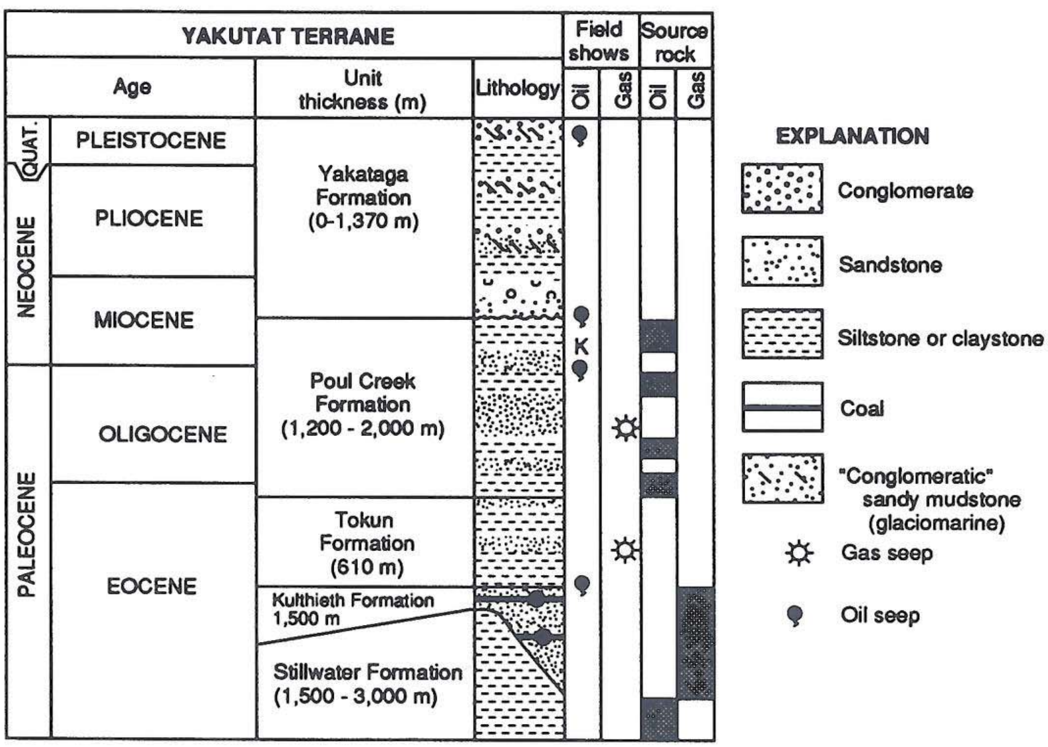

Figure 14. A generalized stratigraphic column for the Yakutat terrane in the Katalla area (modified from Plafker, 1987). Included are oil and gas shows (Plafker, 1987), and source rock intervals; K indicates oil production from the Katalla oil field.

1987), but the samples indicate an increase in thermal maturity to the northwest. The increase in thermal maturity to the northwest indicates that the uplift for the western segment is greater than the uplift for the central segment. Based on burial history calculations on the central segment (Bruns, 1983), the Neogene strata provided the overburden necessary to mature the Paleogene rocks in early Miocene time (~22 Ma) (Figs. 15 and 16).

Gas and oil seeps occur in three onshore areas—Katalla, Yakataga, and Malaspina Districts—in the northern part of the western and central segments (Miller and others, 1959; Blasko, 1976b; Plafker, 1971, 1987). The composition of the gas and oil indicates that the source rock is predominantly terrestrial or type III organic matter. Gas analyses from seeps in all three areas (Blasko, 1976b) show some ethane and higher hydrocarbons that strongly suggest that most of the gas is thermal, not microbial (Table 8). The unaltered oil from the Katalla oil field has high gravity (30 to 44° API), low sulfur (<0.1 wt percent), and a high pristane/phytane index (4.8; Table 9). Oils from the Yakataga and Samovar Hills Districts lack normal alkanes, have lower API gravities (13 to 37.4 °API), and higher sulfur content (0.1 to 0.3 percent; Table 9); these properties indicate that the oil is biodegraded.

On the basis of oil-source rock correlations, two petroleum systems, the Stillwater-Kulthieth and the Poul Creek, are present in the Yakutat terrane.

Stillwater-Kulthieth system

The Stillwater-Kulthieth petroleum system is based on the interpreted facies relations between the Kulthieth, Tokun, and Stillwater Formations and on the oil-source rock correlation of Fuex (written communication, 1987). On the basis of the age of dredge samples from the continental slope, the dredged rocks are assumed to be the offshore equivalents of these onshore sequences (Plafker, 1987). The organic carbon content of the dredge samples ranges from 0.4 to 1.9 wt percent, averages over 1.0 wt percent, and has a high percentage of herbaceous organic matter (Plafker, 1987). Hydrogen and oxygen indices from Rock-Eval indicate that the dredge samples are type III kerogen (Plafker and Claypool, 1979; Bruns and Plafker, 1982), typical of deltaic depositional environments. In the central segment of the Yakutat terrane coal deposits onshore (Barnes, 1967) and vitrinite reflectance data from offshore dredge samples (Plafker, 1987) indicate that thermal maturity is immature but increases to the northwest. On the basis of Lopatin burial history (Bruns, 1983), these rocks should be mature in the deepest part of the central segment (Fig. 15).

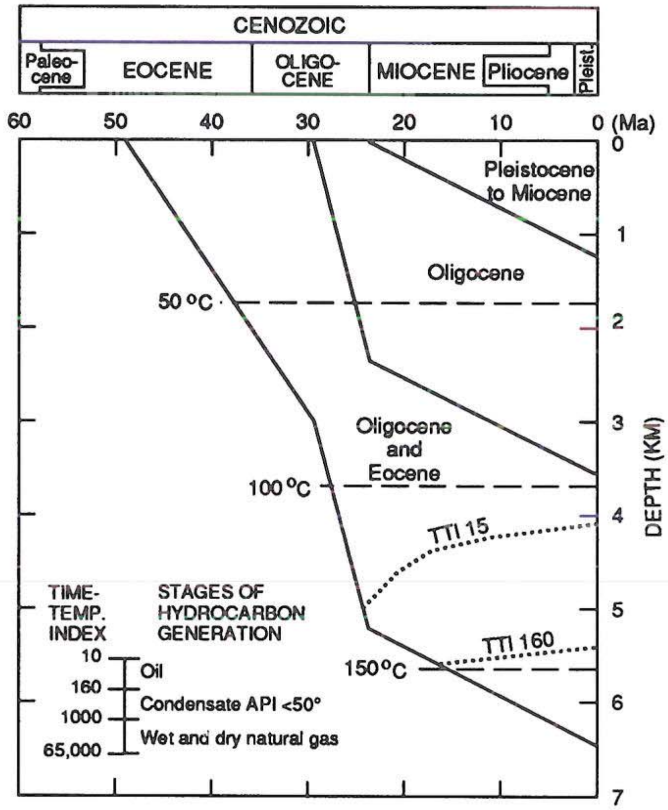

Figure 16. Lopatin burial plot and TTI values that indicate the time of oil generation in the central segment of the Yakutat terrane (Bruns, 1983). Location (x) shown on Figure 13.

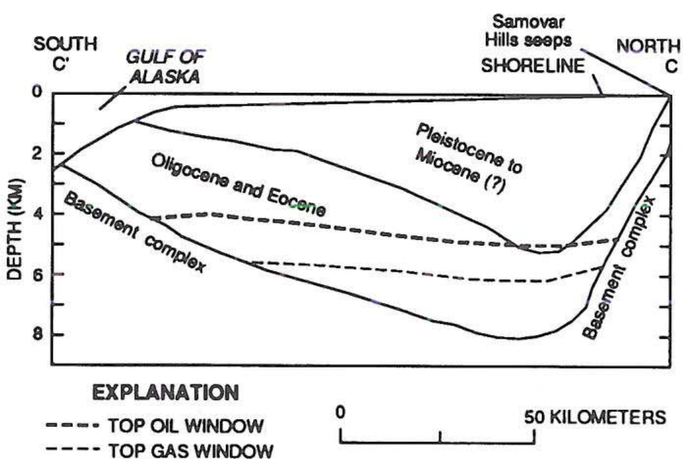

Figure 15. Cross section C-C′ showing stratigraphic units in the Yakutat terrane.

The oil attributed to this petroleum system is located in the Yakataga and Malaspina Districts, and on Wingham Island in the Katalla District (Fig. 13; Table 9). The results of the oil–source rock correlation are based on $\delta^{13}C$ of extract from a heated source rock (Kulthieth Formation) and on comparison with the topped oil (A. N. Fuex, written communication, 1987). The primary source rock for this system is interpreted to be the Stillwater Formation and its offshore equivalents that crop out on the continental slope and in the Samovar Hills; the Kulthieth Formation may be a secondary source. The Stillwater-Kulthieth is a hypothetical system because the correlation is based only on carbon isotopes and limited rock samples.

TABLE 8. U.S. BUREAU OF MINES GAS ANALYSES IN THE YAKUTAT TERRANE, GULF OF ALASKA*

Area	Sample from	C_1 (%)	C_2 (%)	C_3 (%)	nC_4 (%)	*iso*-C_4 (%)	nC_5 (%)	*iso*-C_5 (%)	Cyclo-C_5 (%)	C_{6+} (%)	Total (%)
					KATALLA AREA						
Katalla oil field	seep	67.3	14.0	11.0	3.2	2.9	0.6	0.4	0.1	0.3	99.9
Bering Lake	seep	99.9	tr	tr	0.0	0.0	0.0	0.0	0.0	0.0	99.9
Rathbun well	well	99.8	0.1	tr	tr	tr	tr	tr	tr	tr	99.9
					YAKTAGA AREA						
Crooked Creek	seep	97.2	2.1	0.5	tr	0.1	0.0	0.1	tr	tr	100
Munday Creek	seep	99.3	0.7	tr	0.0	0.0	0.0	0.0	0.0	0.0	100
Johnston Creek	seep	99.3	0.6	0.1	tr	tr	tr	0.0	tr	tr	100
Johnston Creek	seep	99.9	tr	tr	0.0	0.0	0.0	0.0	0.0	0.0	99.9
					SAMOVAR HILLS						
Oily Lake	seep	95.5	3.7	0.8	0.0	0.0	0.0	0.0	0.0	0.0	100
Oily Lake	seep	99.9	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100

*From Blasko, 1976b; gas analyses normalized to include only hydrocarbons.

The reservoir rocks are included within the Kulthieth and Tokun Formations. Although there is a high percentage (60 percent) of thick (15 to 600 m), moderately porous (2 to 23 percent) sandstone, the sandstones have low permeability (0 to 43 md; Table 10). Induration and diagenesis are primarily responsible for the loss of good reservoir characteristics (Plafker, 1987).

The surface maturity pattern indicates that the western segment has undergone considerable uplift and the central segment is at maximum burial depth. Mature Paleogene rocks are exposed at the surface on the western segment. Obduction or uplift of the Yakutat terrane in late Cenozoic time would bring deeply buried Paleogene rocks to the surface in late Cenozoic time. An alternative interpretation requires high heat flow related to ridge subduction during Eocene time (Plafker, 1987) that may have resulted in early maturation in parts or all of this sequence (Plafker and Gilpin, this volume). In the central and western segments, the Eocene to Miocene Poul Creek Formation and its offshore equivalent is probably of insufficient thickness to mature the underlying regressive sequence. Therefore, the time of migration is based on the age of the post-Paleogene overburden, which is primarily the Yakataga Formation. The Yakataga Formation is sufficiently thick to provide the necessary overburden depending on the geothermal gradient (Bruns, 1983).

Migration of oil commenced in Neogene time and is presently moving up the northeast flank to the outcrop (Fig. 15). A major unconformity at the base of the Yakataga Formation and a change in depositional environment from deep marine to glaciomarine indicates a major tectonic reorientation. Because structures are the result of late Cenozoic subduction and hydrocarbon migration is presently taking place, petroleum accumulations should be present if reservoirs occur in a trapping position. However, exploratory drilling to date indicates a lack of commercial petroleum accumulations in Paleogene and younger strata.

Poul Creek system

The Poul Creek Formation is the source rock and the reservoir rock for the Poul Creek petroleum system. In the Katalla area, the Poul Creek Formation has an average organic carbon content of 1.8 wt percent; the organic matter is predominantly herbaceous (Mull and Nelson, 1986). On Kayak Island the organic carbon content of four Poul Creek samples averages 4.6 wt percent (Table 4 in Plafker, 1987), and is about 50 percent herbaceous and 50 percent amorphous. Vitrinite reflectance and thermal alteration index (TAI) data indicate that this unit is mature in the Katalla area (Mull and Nelson, 1986).

On the basis of carbon isotope data for the saturated and aromatic hydrocarbons, oil from the Katalla field is within 1.2 permil of the extract from a heated source rock (Poul Creek) from eastern Kayak Island (Table 9; A. N. Fuex, written communication, 1987). According to the same type of information, the oil from Wingham Island compares more favorably with the Kulthieth Formation from the Samovar Hills (Table 9). Since the oil-to-rock correlation is based only on carbon isotope data from very few oil and rock samples, the Poul Creek is a hypothetical petroleum system.

The reservoir is formed by fractures and possibly faults in the Poul Creek Formation that could have resulted from uplift as the Yakutat block collided with the Prince William terrane to the northwest. Although the Poul Creek Formation includes as much as 30 percent sandstone with porosities as high as 19 percent, the permeability is very low (<12 md; Table 10). As in the underlying units, excessive induration and diagenesis appear to have destroyed what reservoir properties existed (Plafker, 1987).

TABLE 9. OIL TO SOURCE-ROCK CORRELATION IN THE YAKUTAT TERRANE, GULF OF ALASKA*

Area	Rock unit or age	Field or API No.	Sample from	Sample type	API gravity	Pr/ph	Sulfur (wt %)	Heating program	$\delta^{13}C$ (permil) sat.	$\delta^{13}C$ (permil) arom.
				CONTINENTAL SLOPE (TRANSITION FAULT AREA)						
Central segment	Paleogene	78-22D3	dredge	rock	–	5.1	–	–	-27.7	-26.2
Central segment	Paleogene	79-39F	dredge	rock	–	3.4	–	–	-28.2	-27.6
Central segment	Paleogene	78-44D	dredge	rock	–	0.7	–	–	-30.6	-30.4
				KATALLA DISTRICT						
East Kyak Island	Poul Creek	AKA-S-577	outcrop	rock	–	–	–	unheated	-28.3	-26.8
								3/300	-27.6	-26.6
								6/330	-26.5	-25.5
								20/330	-26.4	-25.1
Katalla oil field†	Poul Creek	5006910026	well	oil	30.9	3.6	0.1		-25.4	-23.9
Wingham Island	Poul Creek	81APr51C	seep	oil	–	5.7	–	–	-27.4	-26.3
				YAKATAGA DISTRICT						
Johnston Creek	Poul Creek	AKA-O-58	seep	oil	15.7§	–	0.2	–	-28.3	-25.3
				MALASPINA DISTRICT (SAMOVAR)						
Samovar Hills	Kulthieth	AKA-S-80	outcrop	rock	–	–	–	3/300	-29.6	-27.4
								18/330	-28.5	-26.2
Samovar Hills	Kulthieth	AKA-O-56	seep	oil	17.0	–	0.2	-	-28.1	-25.3
Samovar Hills	Kulthieth	AKA-O-57	seep	oil	13.0	–	0.3	–	-28.3	-25.9
Hubbs Creek	Kulthieth	80APr127	seep	oil	37.4	6.2	0.1	–	-27.5	-25.8

*From A. N. Fuex, written communication, 1987; Continental slope, Wingham Island, Hubbs Creek results from Plafker, 1987; sat, saturate hydrocarbons; arom., aromatic hydrocarbons; Pr/ph, pristane/phytane ratio; 3/300, heated for 3 days at 300° F.
†Unpublished data.
§API gravity is low due to high water content of sample.

TABLE 10. RESERVOIR PROPERTIES FOR STRATIGRAPHIC UNITS IN THE YAKUTAT TERRANE, GULF OF ALASKA*

Stratigraphic unit	Percent sandstone (%)	Thickness range (m)	Porosity range (%)	Permeability range (md)
Yakataga and Redwood Formations	9–53	15–600	1.2–32.2	0–597
Poul Creek Formation	1–30	15–350	2.2–19.2	0–12
Kulthieth and Tokun Formations	60	15–490	1.8–22.7	0–43

*From Winkler and others, 1976; Lyle and Palmer, 1976; Plafker, 1987.

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