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Explanatory Notes for the Energy-Resources Map of the Circum-Pacific Region, Arctic Sheet

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CIRCUM-PACIFIC COUNCIL FOR ENERGY AND MINERAL RESOURCES

2000
U.S. Department of the Interior
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EXPLANATORY NOTES FOR THE ENERGY-RESOURCES MAP OF THE CIRCUM-PACIFIC REGION, ARCTIC SHEET

By Kenneth J. Drummond, George W. Moore, and Theresa R. Swint-Iki

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ABSTRACT

The Energy-Resources Map of the Circum-Pacific Region, Arctic Sheet, covers the North Pacific Ocean, the Arctic Ocean, part of the North Atlantic Ocean, and the surrounding land. It includes areas between northern China, northern Scandinavia, and northern Mexico. The map shows oil and gas fields, oil sand and oil shale, coal deposits, geothermal energy sites, onshore and offshore thickness of sedimentary rocks, and active tectonic plate boundaries. Background geology is adapted from the companion geologic map. Water areas also contain seafloor contours, and land areas contain streams, important cities, and national boundaries. Major submarine and topographic features are named throughout the map.

INTRODUCTION

CIRCUM-PACIFIC MAP PROJECT

The Circum-Pacific Map Project was established in 1973 to produce a comprehensive set of maps to combine the earth-science information of land areas with that only recently available from the deep sea. This international project is an activity of the Circum-Pacific Council for Energy and Mineral Resources. It receives its direction from six regional panels of geologists and geophysicists who represent national earth-science organizations around the Pacific Ocean. The six panels and their chairs during preparation of this map were as follows: Northwest, Tomoyuki Moritani (Japan); Northeast, Kenneth J. Drummond (Canada); Southwest, R.W. Johnson (Australia); Southeast, José Corvalán D. (Chile); Arctic, George W. Moore (United States); and Antarctic, Campbell Craddock (United States). George Gryc (United States) is general chair of the project.

Six complete seven-sheet map series have now been issued by the Circum-Pacific Map Project. They are the base, geographic, geodynamic, plate-tectonic, geologic, and energy-resources series. Still in the course of preparation and publication are the tectonic and mineral-resources map series.

The seven sheets in the base map series (1977-1989) are printed in two colors and show closely spaced latitude and longitude lines to aid in the accurate plotting of data. The sheets in the geographic series (1978-1990) are printed in four colors and show cultural features and newly compiled submarine contours and topography tinted in shades of blue and orange respectively. The sheets in the geodynamic series (1984-1990) include gravity anomalies, lithospheric stress, earthquake mechanisms, historical faulting, volcanoes, and crustal thickness. The sheets in the plate-tectonic series (1983-1992) depict active plate boundaries, major faults within the plates, present-day directions and rates of plate motion, earthquake epicenters, young volcanoes, and seafloor magnetic lineations. The sheets in the geologic series (1983-2000) include geologic-age and lithologic units on land and seafloor sediment type at sea. The sheets in the energy-resources series (1986-2000) depict oil and gas fields, oil sand and oil shale, coal deposits, and geothermal energy sites.

ENERGY-RESOURCES MAP OF THE CIRCUM-PACIFIC REGION

The Energy-Resources Map of the Circum-Pacific Region was issued 1986-2000 as a series of six colored overlapping equal-area sheets at a scale of 1:10,000,000, and one composite sheet at a scale of 1:17,000,000.

The six 1:10,000,000 sheets are designated the Northwest, Northeast, Southwest, and Southeast Quadrants, and the Arctic and Antarctic Sheets. The centers of the azimuthal equal-area projections are at the centers of the sheets, so distortion at the margin of each sheet is only about 5 percent. Therefore, a variety of analyses can be undertaken on the sheets with almost the precision provided by a globe.

The 1:17,000,000 Pacific Basin Sheet, also equal-area, but with greater marginal distortion, shows the regional relations around the entire Pacific Basin. It covers 220° of longitude, or more than half the Earth.

An explanation printed on the energy-resources map identifies the symbols used to depict the various map elements. This text explains the map elements further and provides additional information.

BACKGROUND GEOLOGY

By Kenneth J. Drummond and George W. Moore

The background data on land are lithologic units generated from the geologic-age units on the Arctic Sheet geologic map (Moore, 2000). Significant tectonic and lithologic units have been combined into six divisions. The classification is designed to show the significance of host-rock units or terranes to the occurrence of energy resources. The background units are depicted in pale colors so as not to detract from the resource data. The faults depicted are selected from the Arctic Sheet plate-tectonic map (Moore, 1993).

The chief tectonic features within the Arctic Sheet are (1) parts of the Canadian and Russian Shields, which have as their nuclei the Laurentia and Siberia Cratons (figure 1); (2) broad belts of essentially undeformed, younger sedimentary rocks that constitute platform cover over the shields; and (3) foldbelts, complex zones of sedimentary and extrusive and intrusive igneous rocks that extend along the entire margin of the continents facing the Pacific and Arctic Oceans. The foldbelts have been involved in interactions between continental and oceanic plates at least since late Paleozoic time and possibly longer. Many of the foldbelt terranes are now interpreted as a collage of fragments that originated elsewhere and were accreted to the cratons by plate motions.

The background units include (1) crystalline basement rocks (2) metamorphic rocks, (3) plutonic rocks, (4) volcanic rocks, and (5) sedimentary rocks and surficial deposits.

CRYSTALLINE BASEMENT ROCKS

The basement terrane variously comprises crystalline rocks, both on the shields and within foldbelts, sedimentary rocks, metamorphic complexes, oceanic basement terrane, accreted island-arc terrane, and igneous intrusions, all of Archean to Middle Proterozoic age. The rocks classified as crystalline basement include mixed felsic and mafic gneisses, granitoid and more mafic intrusive rocks, and Middle Proterozoic or older "greenstone belts" of stratified sedimentary and volcanic rocks. Formed over a period of some 3 billion years, they had a long history of deformation, and in places, of repeated metamorphism. Orogenic activity was essentially completed by the Middle Proterozoic.

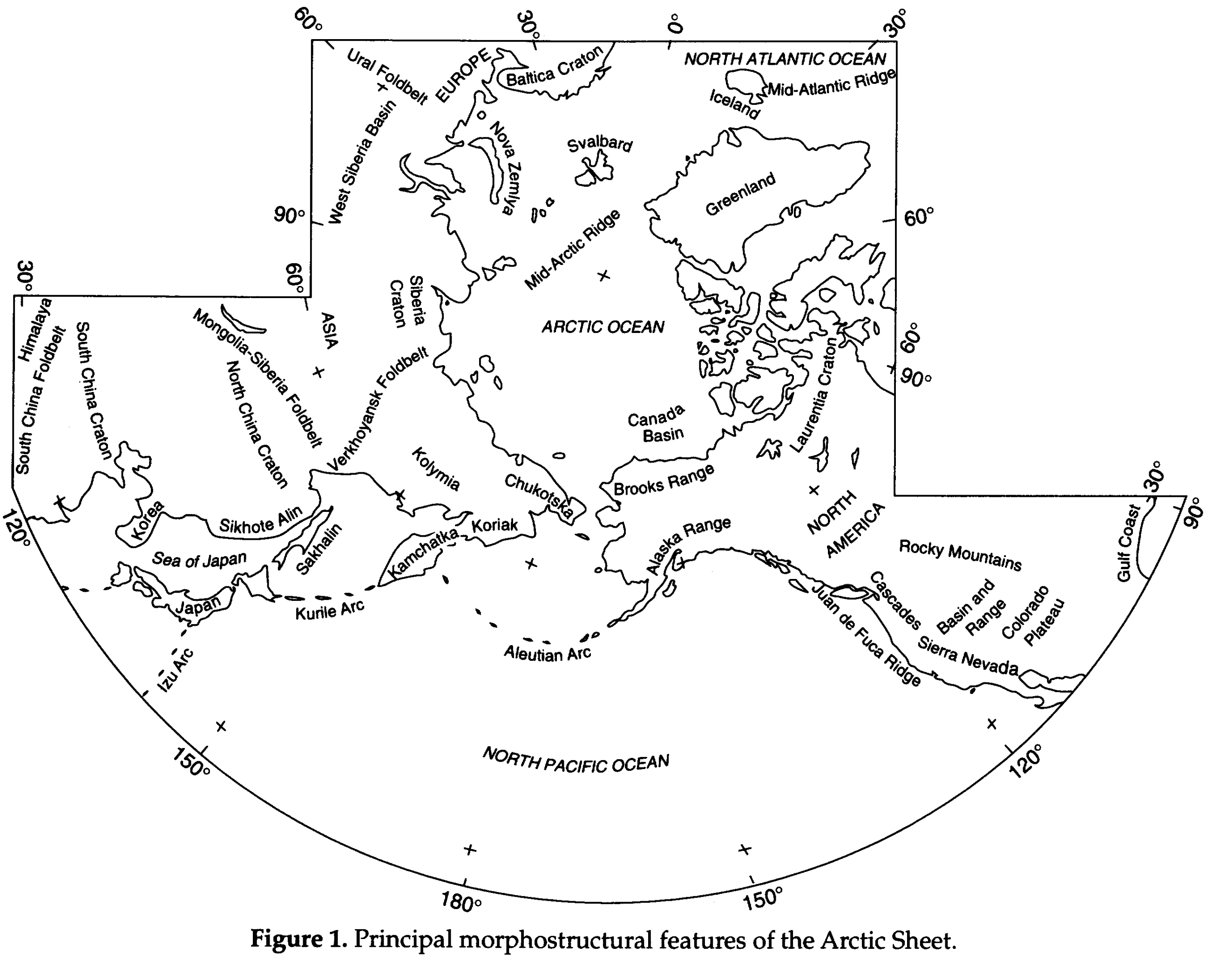


Figure 1. Principal morphostructural features of the Arctic Sheet.

Since then, except for minor faulting and some postorogenic intrusive and extrusive magmatism, slow warping and erosion have been the dominant geologic processes in those areas of the exposed shields that lie within the Arctic Sheet. The basement extends at fairly shallow depth under the broad zones of platform-cover rocks lying north, west, and south of the shields, being exposed in only a few small uplifts.

METAMORPHIC ROCKS

Areas shown as metamorphic complexes include a variety of rocks ranging in age from Late Proterozoic to at least late Mesozoic that were highly deformed, metamorphosed, and in places intruded by granitoid rocks. They range from blueschist or greenschist facies up to and including gneiss. Their relationship is not always certain. At least some may be allochthonous (accreted). Metamorphic complexes are exposed intermittently from eastern Siberia to British Columbia. Ultramafic rocks (fragments of the Earth's mantle) are mapped separately in black.

PLUTONIC ROCKS

Intrusive rocks ranging in age from Late Proterozoic to Tertiary, and in composition from gabbro to granite and syenite, are widespread and abundant throughout the area. Most of the major batholiths are of Mesozoic or Paleogene age and have an average composition of granodiorite. In detail, however, they are composite and resulted from repeated magmatic events over extended periods of time. Intrusive rocks are less abundant, and individual plutons generally are much smaller, east of the main batholithic belt.

VOLCANIC ROCKS

This map unit essentially shows only the extensive plateau basalts and other volcanic cover where the nature of the underlying rocks is unknown. Volcanic rocks overlying basement are treated as part of the basement unit.

Extensive areas from Siberia to British Columbia are covered by volcanic rocks (flows, welded tuffs, and thin ash beds), mostly of Cenozoic age, that are flat-lying or only slightly tilted and faulted. Compositionally they range from felsic (rhyolite to andesite) to mafic (basalt). Intermediate rock types (principally andesite) predominate in some areas. Mafic flows of Neogene age are widespread.

SEDIMENTARY ROCKS AND SURFICIAL DEPOSITS

Late Proterozoic rocks, included with younger sedimentary rocks on the Arctic Sheet, are supracrustal, largely clastic sediments derived by erosion from the now stabilized crystalline basement, although carbonate sediments constitute significant proportions in some places. Volcanic rocks are minor and related to continental rifting. On and near the exposed shields, the outcrop patterns are roughly equidimensional, reflecting the undeformed flat-lying character of the rocks that comprise them, whereas in many areas, rocks of this age are exposed in linear belts that resulted from orogenic activity (folding, faulting, uplift, and erosion) during later geologic time. Metamorphism is generally absent to low grade, although in places it reaches higher grades. Some of the rocks shown on the map as metamorphic complexes are known to include rocks of Proterozoic age metamorphosed in Phanerozoic time.

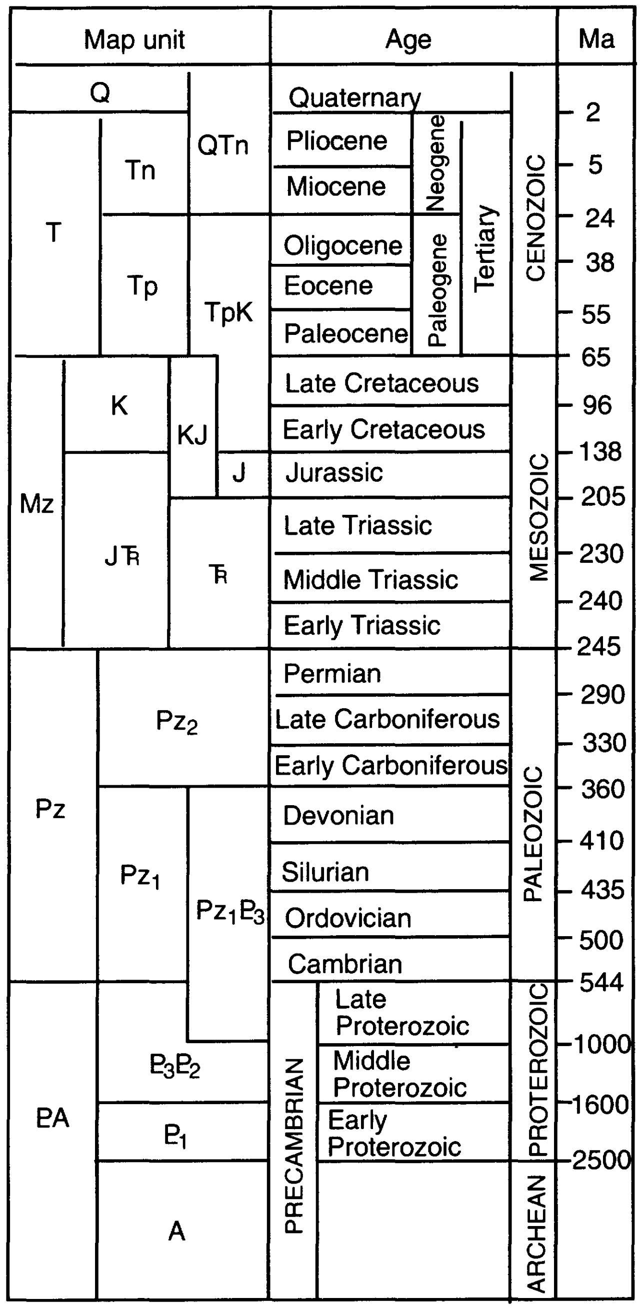


Figure 2. Geologic age of map units on the Arctic Sheet.

Table 1. Estimated initial and remaining petroleum resources by country or region

Country	Initial Resources		Cum. Production (as of 12/31/98)		Remaining Resources (as of 12/31/98)	
	Oil (MMB)	Gas (BCF)	Oil (MMB)	Gas (BCF)	Oil (MMB)	Gas (BCF)
Canada (N of 60°)	1,626	29,070	177	550	1,449	28,520
Alaska	19,637	46,636	13,458	12,684	6,179	33,952
Norway (N of 64°)	2,390	11,150	499	0	1,891	11,150
Former Soviet Union	199,692	2,481,000	133,051	576,650	66,641	1,904,350
Mongolia	-	-	-	-	-	-
China	50,240	57,650	16,720	15,290	33,520	42,360
Japan	202	3,997	142	2,617	60	1,380
North Korea	-	-	-	-	-	-
South Korea	-	-	-	-	-	-
Total	273,788	2,629,503	164,048	607,791	109,740	2,021,712

Sedimentary basins are shown by sediment isopachs, colored to indicate the age of the oldest major sedimentary unit above basement. The age and lithology of the basement is generally indicated by the surrounding bedrock geology.

OCEANIC AREAS

The basic background for oceanic regions is bathymetric contours and a light blue tint. Overprinted on this are sediment isopachs, colored to indicate the age of the underlying oceanic crust. The oceanic crustal age from which the isopach coloration was derived was completed by Xenia Golovchenko, Lamont-Doherty Earth Observatory, as an unpublished part of the magnetic lineation compilation for the Circum-Pacific Plate-Tectonic Map Series (Glovchenko and others, 1981).

PETROLEUM AND COAL RESOURCES

By Kenneth J. Drummond

OIL AND NATURAL GAS

The main oil and gas fields of the Arctic Sheet are plotted as close to real scale and location as possible. Some of the smaller fields, of necessity, have been enlarged slightly, and in some areas several small fields in close

Table 2. Oil and gas production in 1998 by country or region

Country	Yearly production		Daily production	
	Oil (MMB)	Gas (BCF)	Oil (MB)	Gas (MMCF)
Canada (N of 60°)	10	22	27	59
Alaska	429	735	1,175	2,015
Norway (country)	1,103	1,535	3,021	4,206
Russia	2,167	21,611	5,938	59,208
Mongolia	-	-	-	-
China	1,167	767	3,198	1,459
Japan	5	80	13	218
North Korea	-	-	-	-
South Korea	-	-	-	-
Total	4,881	24,749	13,371	67,807

Sources:
Russia, Riva, J.P.,Jr., OGJ, Jan. 4,1993
China, OGJ, Sept. 28, 1992
National Energy Board, National Resources Canada
Oil and Gas Journal

Table 3A. Selected oil and gas fields

Field name	Country	Basin	Year discovered	Major reservoir Age	Major reservoir Lithology	End of Year	Cum. Production Oil (MMB)	Cum. Production Gas (BCF)	Est. Ultimate Recovery Oil (MMB)	Est. Ultimate Recovery Gas (BCF)
Beaver Creek	Alaska, USA	Cook Inlet	1967	Tertiary	Sandstone	1999	5.3	145.8	6.2	241.7
Beluga River	Alaska, USA	Cook Inlet	1962	Tertiary	Sandstone	1999		666.3		1,266.3
Birch Hill	Alaska, USA	Cook Inlet	1965	Tertiary	Sandstone	1999		0.1		11.1
Cannery Loop	Alaska, USA	Cook Inlet	1979	Tertiary	Sandstone	1999		85.7		115.7
Falls Creek	Alaska, USA	Cook Inlet	1961	Tertiary	Sandstone					13.0
Granite Point	Alaska, USA	Cook Inlet	1965	Tertiary	Sandstone	1999	134.0	118.4	144.2	137.3
Ivan River	Alaska, USA	Cook Inlet	1966	Tertiary	Sandstone	1999		60.9		104.3
Kaloa	Alaska, USA	Cook Inlet	1967	Tertiary	Sandstone	1999		0.1		0.1
Kenai	Alaska, USA	Cook Inlet	1969	Tertiary	Sandstone	1999		2250.6		2,425.1
Lewis River	Alaska, USA	Cook Inlet	1975	Tertiary	Sandstone	1999		9.1		
Mcarthur River	Alaska, USA	Cook Inlet	1965	Tertiary	Sandstone	1999	595.7	1002.7	622.0	1,384.2
Middle Ground Shoal	Alaska, USA	Cook Inlet	1962	Tertiary	Sandstone	1999	183.0	89.0	190.1	111.9
Moquawkie	Alaska, USA	Cook Inlet	1965	Tertiary	Sandstone	1999		1.0		
Nicolai Creek	Alaska, USA	Cook Inlet	1966	Tertiary	Sandstone	1999		1.1		
North Cook Inlet	Alaska, USA	Cook Inlet	1962	Tertiary	Sandstone	1999		1410.5		2,327.9
North Fork	Alaska, USA	Cook Inlet	1965	Tertiary	Sandstone	1999		0.1		12.1
North Trading Bay	Alaska, USA	Cook Inlet		Tertiary	Sandstone	1999	23.7	11.3	23.7	30.3
Redoubt Shoal	Alaska, USA	Cook Inlet	1968	Tertiary	Sandstone					
Sterling	Alaska, USA	Cook Inlet	1961	Tertiary	Sandstone	1999		2.7		25.5
Stump Lake	Alaska, USA	Cook Inlet	1978	Tertiary	Sandstone			5.6		
Swanson River	Alaska, USA	Cook Inlet	1957	Tertiary	Sandstone	1999	226.2	0.0	229.8	211.0
Trading Bay	Alaska, USA	Cook Inlet	1965	Tertiary	Sandstone	1999	98.7	74.7	77.7	89.7
Walakpa	Alaska, USA	Colville	1980	Jurassic	Sandstone			7.5		
West Foreland	Alaska, USA	Cook Inlet	1962	Tertiary	Sandstone					
West Fork	Alaska, USA	Cook Inlet	1960	Tertiary	Sandstone	1999		4.2		7.2
West McArthur River	Alaska, USA	Cook Inlet	1991	Tertiary	Sandstone	1999	5.8	1.4	5.9	
Badami	Alaska, USA	Colville	1990	Tertiary	Sandstone	1999	1.9	1.9	15.7	40.5
East Barrow	Alaska, USA	Colville	1974	Jurassic	Sandstone			7.6		
Endicott	Alaska, USA	Colville	1978		Sandstone	1999	389.4	151.4	517.3	986.0
Gwydyr Bay	Alaska, USA	Colville	1969		Sandstone				45.0	
Kuparuk River	Alaska, USA	Colville	1969	Cretaceous	Sandstone	1999	1676.2	394.5	2,557.1	987.1
Lisburne	Alaska, USA	Colville	1967	Mississippian	Carbonate	1999	132.6	0.0	169.6	337.0
Milne Point	Alaska, USA	Colville	1969	Cretaceous	Sandstone	1999	125.5	62.7	344.0	
Niakuk	Alaska, USA	Colville	1985	Cretaceous	Sandstone	1999	42.7	37.4	112.4	71.4
North Prudhoe	Alaska, USA	Colville	1970	Permo-Tr	Sandstone	1999	2.1	6.5	11.1	
North Star	Alaska, USA	Colville	1984		Sandstone				150.0	
Point Mcintyre	Alaska, USA	Colville	1988	Cretaceous	Sandstone	1999	292.9	133.4	510.6	710.5
Point Thompson	Alaska, USA	Colville	1977	Cretaceous	Sandstone				350.0	5,000.0
Prudhoe Bay	Alaska, USA	Colville	1969	Permo-Tr	Sandstone	1999	10094.3	3071.2	12,796.4	25,634.8
Sag River	Alaska, USA	Colville	1969			1999	1.0		9.0	
Schrader Bluff	Alaska, USA	Colville	1969	Tertiary	Sandstone	1999	9.7		169.7	
South Barrow	Alaska, USA	Colville	1949	Jurassic	Sandstone			22.2		
Tabasco	Alaska, USA	Colville	1992	Cretaceous	Sandstone	1999	0.5	0.1	31.5	
Tarn	Alaska, USA	Colville	1991	Cretaceous	Sandstone	1999	3.5	3.3	73.5	21.3
Ugnu	Alaska, USA	Colville	1969		Sandstone				0.0	0.0
West Sak	Alaska, USA	Colville	1969	Cretaceous	Sandstone	1999	1.3	0.5	158.3	0.0
Tedgi Lake	Canada	Mainland Terr.	1974	Cambrian	Sandstone				0.0	36.0
Tweed Lake	Canada	Mainland Terr.	1985	Cambrian	Sandstone					191.0
Bele	Canada	Mainland Terr.	1986	Cambrian	Sandstone					168.0
Chance	Canada	Eagle	1960	Mississ.	Sandstone				11.7	51.1
Blackie	Canada	Eagle	1963	Mississ.	Sandstone				0.0	23.3
Norman Wells	Canada	Mainland Terr.	1921	M. Dev.	Carbonate	1999	184.3	110.2	260.0	156.0
Beaver River	Canada	Mainland Terr.	1959	M. Dev.	Carbonate	1999		7.7	0.0	7.7
Kotaneelee	Canada	Mainland Terr.	1977	M. Dev.	Carbonate	1999		145.5	0.0	250.0
Pointed Mtn.	Canada	Mainland Terr.	1966	M. Dev.	Carbonate	1999		314.5	0.0	315.4
Adgo	Canada	Mackenzie	1974	Tertiary	Sandstone				38.9	113.8
Adlartok	Canada	Mackenzie	1985	Tertiary	Sandstone				112.6	0.0
Amauligak	Canada	Mackenzie	1983	Tertiary	Sandstone	1999	0.3		235.0	1,367.3
Arnak	Canada	Mackenzie	1986	Tertiary	Sandstone				2.7	37.3
Atkinson Pt	Canada	Mackenzie	1970	L. Cret.	Sandstone				42.4	0.0
Garry	Canada	Mackenzie	1976	Tertiary	Sandstone				57.2	269.2
Hansen	Canada	Mackenzie	1986	Tertiary	Sandstone				4.3	163.1
Ikhil	Canada	Mackenzie	1986	Tertiary	Sandstone	1999		0.1	0.0	26.1
Imnak	Canada	Mackenzie	1975	Tertiary	Sandstone		0.0	0.0	10.4	0.0
Isserk	Canada	Mackenzie	1978	Tertiary	Sandstone		0.0	0.0	0.0	3.4
Issungnak	Canada	Mackenzie	1980	Tertiary	Sandstone		0.0	0.0	30.0	1,134.3
Itiyok	Canada	Mackenzie	1983	Tertiary	Sandstone		0.0	0.0	5.1	91.3
Ivik	Canada	Mackenzie	1973	Tertiary	Sandstone		0.0	0.0	10.2	0.0
Kamik	Canada	Mackenzie	1975	Tertiary	Sandstone		0.0	0.0	1.2	0.0
Kiggavik	Canada	Mackenzie	1982	Tertiary	Sandstone		0.0	0.0	0.0	120.8
Kingark	Canada	Mackenzie	1989	Tertiary	Sandstone		0.0	0.0	16.1	45.6
Koakoak	Canada	Mackenzie	1981	Tertiary	Sandstone		0.0	0.0	81.5	266.5

Table 3B. Selected oil and gas fields

Field name	Country	Basin	Year discovered	Major reservoir Age	Lithology	End of Year	Cum. Production Oil (MMB)	Gas (BCF)	Est. Ultimate Recovery Oil (MMB)	Gas (BCF)
Kopanoar	Canada	Mackenzie	1979	Tertiary	Sandstone		0.0	0.0	68.3	27.4
Kugpik	Canada	Mackenzie	1973	Tertiary	Sandstone		0.0	0.0	4.0	0.0
Kumak	Canada	Mackenzie	1974	Tertiary	Sandstone		0.0	0.0	12.2	24.8
Mallik	Canada	Mackenzie	1972	Tertiary	Sandstone		0.0	0.0	0.0	26.8
Mayogiak	Canada	Mackenzie	1971	M. Dev.	Carbonate		0.0	0.0	4.1	0.0
Nektoralik	Canada	Mackenzie	1976	Tertiary	Sandstone		0.0	0.0	14.1	66.7
Nerlerk	Canada	Mackenzie	1979	Tertiary	Sandstone		0.0	0.0	30.6	0.0
Netserk	Canada	Mackenzie	1975	Tertiary	Sandstone		0.0	0.0	0.0	115.3
Niglintgak	Canada	Mackenzie	1973	Tertiary	Sandstone		0.0	0.0	21.4	483.5
Nipterk	Canada	Mackenzie	1985	Tertiary	Sandstone		0.0	0.0	16.8	14.2
Parsons	Canada	Mackenzie	1973	L. Cret.	Sandstone		0.0	0.0	11.8	1,258.7
Pitsiulak	Canada	Mackenzie	1984	Tertiary	Sandstone		0.0	0.0	25.1	0.0
Reindeer	Canada	Mackenzie	1973	Tertiary	Sandstone		0.0	0.0	0.0	15.9
Taglu	Canada	Mackenzie	1971	Tertiary	Sandstone		0.0	0.0	39.2	2,700.0
Tarsiut	Canada	Mackenzie	1979	Tertiary	Sandstone		0.0	0.0	46.6	29.6
Titalik	Canada	Mackenzie	1973	Tertiary	Sandstone		0.0	0.0	0.0	56.5
Tuk	Canada	Mackenzie	1984	Tertiary	Sandstone		0.0	0.0	1.2	183.1
Ukalerk	Canada	Mackenzie	1977	Tertiary	Sandstone		0.0	0.0	0.0	102.3
West Atkinson	Canada	Mackenzie	1982	L. Cret.	Sandstone		0.0	0.0	6.1	0.0
Ya Ya	Canada	Mackenzie	1973	Tertiary	Sandstone		0.0	0.0	0.0	101.4
Balaena	Canada	Sverdrup	1980	L. Cret.	Sandstone		0.0	0.0	16.5	0.0
Bent Horn	Canada	Sverdrup	1974	M. Dev.	Carbonate	1998	2.3	0.0	2.3	0.0
Cape Allison	Canada	Sverdrup	1985	Jurassic	Sandstone		0.0	0.0	44.5	614.0
Char	Canada	Sverdrup	1980	Jurassic	Sandstone		0.0	0.0	3.0	377.0
Cisco	Canada	Sverdrup	1981	Jurassic	Sandstone		0.0	0.0	175.2	204.0
Drake Point	Canada	Sverdrup	1969	Jurassic	Sandstone		0.0	0.0	0.0	5,369.0
Hecla	Canada	Sverdrup	1972	Jurassic	Sandstone		0.0	0.0	12.1	3,720.0
Jackson Bay	Canada	Sverdrup	1976	Jurassic	Sandstone		0.0	0.0	0.0	1,074.0
King Christian	Canada	Sverdrup	1970	Jurassic	Sandstone		0.0	0.0	0.0	588.0
Kristoffer	Canada	Sverdrup	1972	Jurassic	Sandstone		0.0	0.0	0.0	1,107.0
Maclean	Canada	Sverdrup	1981	Triassic	Sandstone		0.0	0.0	48.8	604.0
Macmillan	Canada	Sverdrup	1983	Jurassic	Sandstone		0.0	0.0	0.2	76.0
Roche Point	Canada	Sverdrup	1978	Triassic	Sandstone		0.0	0.0	0.0	427.0
Sculpin	Canada	Sverdrup	1982	Jurassic	Sandstone		0.0	0.0	0.0	58.0
Skate	Canada	Sverdrup	1981	Jurassic	Sandstone		0.0	0.0	29.0	221.0
Thor	Canada	Sverdrup	1972	Jurassic	Sandstone		0.0	0.0	3.0	715.0
Wallis	Canada	Sverdrup	1973	Jurassic	Sandstone		0.0	0.0	0.0	98.0
Whitefish	Canada	Sverdrup	1979	Jurassic	Sandstone		0.0	0.0	0.0	2,731.0
Draugen	Norway	Norwegian Sea	1984	Jurassic	Sandstone	1999	334.8	0.0	702.3	0.0
Heidrun	Norway	Norwegian Sea	1985	Jurassic	Sandstone	1999	320.3	56.8	1,156.6	706.3
Mikkel	Norway	Norwegian Sea	1986	Jurassic	Sandstone	1999			10.1	692.1
Njord	Norway	Norwegian Sea	1986	Jurassic	Sandstone	1999	35.2	282.0	178.7	282.0
Norne	Norway	Norwegian Sea	1992	Jurassic	Sandstone	1999	94.4	0.0	506.0	532.4
Asgard	Norway	Norwegian Sea	1984	Jurassic	Sandstone	1999	24.5	0.0	406.5	7,031.3
Trestakk	Norway	Norwegian Sea	1986	Jurassic	Sandstone	1999			54.1	0.0
Tyrihans	Norway	Norwegian Sea	1983	Jurassic	Sandstone	1999			0.0	815.3
Kristin	Norway	Norwegian Sea	1997	Jurassic	Sandstone	1999			0.0	1,387.8
Lavrans	Norway	Norwegian Sea	1995	Jurassic	Sandstone	1999			0.0	2,218.4
Ragnfrid	Norway	Norwegian Sea	1998	Jurassic	Sandstone	1999			0.0	1,384.3
Alve	Norway	Norwegian Sea	1990	Jurassic	Sandstone	1999			10.1	301.7
Snovhit	Norway	Barents Sea	1984	Jurassic	Sandstone	1999			130.9	6,257.5
Snovhit North	Norway	Barents Sea	1985	Jurassic	Sandstone	1999			0.0	3,920.0
Beta	Norway	Barents Sea	1986	Jurassic	Sandstone	1999			19.5	117.1
Chub'yu	Russia	Timan-Pechora	1930							
Layavozh	Russia	Timan-Pechora								
Salyukhin	Russia	Timan-Pechora								
Usa	Russia	Timan-Pechora	1962	Permian	Carbonate				3,100.0	
Vosey	Russia	Timan-Pechora							700.0	
Vuktyl	Russia	Timan-Pechora	1964	Permian	Carbonate				340.0	17,500.0
Zapadno-Tebuk	Russia	Timan-Pechora								
Badaranskoye	Russia	Vilyuy	1963	Tri-Jur	Sandstone					
Iktekhskoye	Russia	Vilyuy		Tri-Jur	Sandstone		10.0			
Irelyakhshoye	Russia	Vilyuy	1981	Tri-Jur	Sandstone					
Machchobinskoye	Russia	Vilyuy		Tri-Jur	Sandstone					
Nizhne-Khamakinskoye	Russia	Vilyuy		Tri-Jur	Sandstone					
Nizhne-Vilyuiskoye	Russia	Vilyuy		Tri-Jur	Sandstone					
Ozernoye	Russia	Vilyuy	1963	Tri-Jur	Sandstone	1988	14.0			
Sobolokh-Nedzhelinskoye	Russia	Vilyuy		Tri-Jur	Sandstone					
Sredne-Botuobinskoye	Russia	Vilyuy	1970	Proteroz	Sandstone				149.0	17,290.0
Sredne-Tyungskoye	Russia	Vilyuy	1976	Tri-Jur	Sandstone					
Sredne-Vilyuiskoye	Russia	Vilyuy	1963	Tri-Jur	Sandstone					
Talakanskoye	Russia	Vilyuy		Tri-Jur	Sandstone					

Table 3C. Selected oil and gas fields

Field name	Country	Basin	Year discovered	Major reservoir Age	Lithology	End of Year	Cum. Production Oil (MMB)	Gas (BCF)	Est. Ultimate Recovery Oil (MMB)	Gas (BCF)
Tas-Yurakhskoye	Russia	Vilyuy	1981	Tri-Jur	Sandstone					
Tolon-Mastakhskoye	Russia	Vilyuy		Tri-Jur	Sandstone					
Ust-Vilyuiskoye	Russia	Vilyuy	1956	Tri-Jur	Sandstone					
Verhne-Vilyuchanskoye	Russia	Vilyuy	1975	Proteroz	Sandstone				260.0	10,500.0
Verkne-Chopskoye	Russia	Vilyuy		Tri-Jur	Sandstone					
Vilyuisko-Dzherbinskoye	Russia	Vilyuy	1977	Tri-Jur	Sandstone					
Urengoy (Samburg,Yevo-Ya	Russia	West Siberian	1966	Cretaceous	Sandstonee				6,617.3	269,991.0
Samotlor (Vata, Megion, Po	Russia	West Siberian	1961	U.Jur-L.Cret	Sandstonee				24,661.0	15,041.8
Yamburg	Russia	West Siberian	1969	Cretaceous	Sandstonee				0.0	117,806.6
Bovanenko	Russia	West Siberian	1971	Cretaceous	Sandstonee				0.0	99,681.2
Zapolyarnoye	Russia	West Siberian	1965	Cretaceous	Sandstonee				0.0	78,083.0
Medvezhye	Russia	West Siberian	1966	M.Jur-Cret	Sandstonee				0.1	54,896.6
Sovetskoye	Russia	West Siberian	1962	Pz,U.Jur,L.Cre	Sandstonee				6,050.6	1,579.3
Pokachevsko-Ur'yevskoye (	Russia	West Siberian	1970	U.Jur-L.Cret	Sandstonee				5,281.9	1,507.6
Tarasovskoye (Ayvasedopu	Russia	West Siberian	1967	Cretaceous	Sandstonee				4,117.2	5,867.2
Verkhne-Kolikyeganskoye	Russia	West Siberian	1981	M.U.Jur-Cret	Sandstonee				3,443.2	9,628.5
Semakovskoye-Anderpayut	Russia	West Siberian	1971	Cretaceous	Sandstonee				0.0	30,198.3
Priobskoye	Russia	West Siberian	1982	U.Jur-L.Cret	Sandstonee				4,219.8	1,202.6
Vat'yegan	Russia	West Siberian	1970	U.Jur-L.Cret	Sandstonee				3,987.5	1,087.7
Komsomol' (Barsukovskoye	Russia	West Siberian	1966	Cretaceous	Sandstonee				0.0	23,190.3
Urengoy Severnyy	Russia	West Siberian	1970	Cretaceous	Sandstonee				0.0	23,117.3
Kharampur (Kharampur Yu:	Russia	West Siberian	1978	U.Jur-Cret	Sandstonee				634.4	18,413.2
Var'yegan	Russia	West Siberian	1967	U.Jur-Cret	Sandstonee				2,091.6	8,833.0
Sugmutskoye	Russia	West Siberian	1987	L.Cretaceous	Sandstonee				3,327.1	768.6
Bol'shoye Kruzenshternsko	Russia	West Siberian	1976						0.0	20,287.4
Russkoye	Russia	West Siberian	1968						2,702.1	3,206.9
Vartovskoye-Sosino	Russia	West Siberian	1962	L.Cretaceous	Sandstonee				3,001.8	1,079.5
Kharasavey	Russia	West Siberian	1974	Cretaceous	Sandstonee				0.0	16,783.4
Sredneyamal	Russia	West Siberian	1970	Cretaceous	Sandstonee				0.0	16,678.7
Sutorminskoye	Russia	West Siberian	1975	L.Cretaceous	Sandstonee				2,480.0	1,364.6
Russkoye Yuzhnoye	Russia	West Siberian	1969	U.Cretaceous	Sandstonee				0.0	16,121.3
Lyantor (Taybinskoye)	Russia	West Siberian	1966						2,321.6	686.0
Pravdinsk-Salym	Russia	West Siberian	1964	U.Jur-L.Cret	Sandstonee				2,255.2	656.1
Povkhovskoye	Russia	West Siberian	1972	M.Jur-L.Cret	Sandstonee				2,100.7	797.1
Ust-Balyk-Mamontovo	Russia	West Siberian	1961	L.Cretaceous	Sandstonee				2,134.4	454.2
Muravlenko	Russia	West Siberian	1978	Cretaceous	Sandstonee				1,546.7	3,529.1
Fedorovskoye	Russia	West Siberian	1971	M.Jur-L.Cret	Sandstonee				1,792.5	1,942.1
Antipayuta	Russia	West Siberian	1978	U.Cretaceous	Sandstonee				0.0	12,294.0
Agan	Russia	West Siberian	1965	U.Jur-L.Cret	Sandstonee				1,792.7	523.3
Vengapur	Russia	West Siberian	1968	U.Jur-Cret	Sandstonee				595.9	7,537.1
Gubkinskoye (Gubkin Sev.,	Russia	West Siberian	1965						0.2	10,575.8
Yamsovey	Russia	West Siberian	1970	Cretaceous	Sandstonee				0.0	9,937.2
Var'yegan Severnyy	Russia	West Siberian	1971						1,292.9	2,112.4
Surgut Yuzhnny(Federovo)	Russia	West Siberian	1973						1,540.9	356.3
Nivagalskoye(Pokachev-Ur'	Russia	West Siberian	1968	U.Jur-L.Cret	Sandstonee				1,487.9	384.8
Myldzhinskoye	Russia	West Siberian	1964	M.Jur-L.Cret	Sandstonee				0.0	8,959.9
Nong'yegan	Russia	West Siberian	1974	L.Cretaceous	Sandstonee				1,338.0	580.9
Rogozhnikovskoye	Russia	West Siberian	1988	Carbon,L.Cret	Sandstonee				1,388.2	246.2
Van'yegan	Russia	West Siberian	1974	U.Jur-Cret	Sandstonee				1,135.7	1,722.0
Druzhnoye	Russia	West Siberian	1982	L.Cretaceous	Sandstonee				1,354.1	264.7
Arkticheskoye	Russia	West Siberian	1968	Cretaceous	Sandstonee				0.0	7,831.8
Tyanovskoye	Russia	West Siberian	1986						1,237.8	392.6
Bystrinskoye (Bystrin)	Russia	West Siberian	1964	M.Jur-L.Cret	Sandstonee				1,261.3	250.2
Yubileynoye (Tyumen)	Russia	West Siberian	1969	Cretaceous	Sandstonee				115.9	6,961.3
Taz	Russia	West Siberian	1962	M.Jur,U.Cret	Sandstonee				462.5	4,641.7
Yaroyakha	Russia	West Siberian	1984	L.Cretaceous	Sandstonee				0.0	7,271.2
Novoportovskoye	Russia	West Siberian	1964	Pz,Jur,Cret	Sandstonee				134.7	6,452.8
Yagunskoye Yuzhnoye	Russia	West Siberian	1979	U.Jur-L.Cret	Sandstonee				1,151.1	320.7
Vatinskoye	Russia	West Siberian	1964	L.Cretaceous	Sandstonee				1,130.2	306.2
Utrenneye	Russia	West Siberian	1980	Cretaceous	Sandstonee				0.0	7,041.4
Urengoy (Pestsovoye)	Russia	West Siberian	1970	Cretaceous	Sandstonee				293.6	5,185.7
Olen'ye (W Siberia)	Russia	West Siberian	1967	U.Jurassic	Sandstonee				1,089.2	351.8
Vengayakha (Vengayakha \	Russia	West Siberian	1968						501.3	3,824.7
Tarko-Sale Vostochnyy	Russia	West Siberian	1971	Cretaceous	Sandstonee				422.8	4,254.1
Beregovoye (W. Siberia)	Russia	West Siberian	1982	L.M.Jur-U.Cret					130.1	5,879.4
Yermakovo	Russia	West Siberian	1974	U.Jur-L.Cret	Sandstonee				1,032.8	290.2
Vengapur Yuzhnyy	Russia	West Siberian	1973	L.Cretaceous	Sandstonee				899.5	366.0
Yetypur	Russia	West Siberian	1971	Jur-Cret	Sandstonee				143.6	4,781.0
Yurkharovskoye	Russia	West Siberian	1970	Cretaceous	Sandstonee				0.0	5,491.0
Teplovskoye (W Siberia)	Russia	West Siberian	1966	L.Cretaceous	Sandstonee				868.0	185.7
Konitlor Yuzhnyy	Russia	West Siberian	1988	M.U.Jur-U.Cre	Sandstonee				818.7	373.1
Yaunlor	Russia	West Siberian	1967	L.Cretaceous	Sandstonee				820.1	234.1

Table 3D. Selected oil and gas fields

Field name	Country	Basin	Year discovered	Major reservoir Age	Major reservoir Lithology	End of Year	Cum. Production Oil (MMB)	Cum. Production Gas (BCF)	Est. Ultimate Recovery Oil (MMB)	Est. Ultimate Recovery Gas (BCF)
Suzun	Russia	West Siberian	1971	L.Cretaceous	Sandstonee				389.4	2,618.6
Surgut Zapadnyy(Federovo	Russia	West Siberian	1962	M.Jurassic	Sandstonee				787.0	177.3
Geofizicheskoye	Russia	West Siberian	1975	M.Jur-Cret	Sandstonee				0.0	4,832.8
Uryevskoye(-Potochnoye)(F	Russia	West Siberian	1971	U.Jurassic	Sandstonee				735.8	205.2
Barsukov	Russia	West Siberian	0	U.Cretaceous					0.0	4,531.1
Kholmogory	Russia	West Siberian	1973						722.9	190.8
Kalinovoye	Russia	West Siberian	1973						191.6	3,368.3
Samburg(Urengoy)	Russia	West Siberian	1975						692.0	344.6
Stakhanovskoye	Russia	West Siberian	1988	M.U.Jur-L.Cre	Sandstonee				661.3	244.0
Alekhin	Russia	West Siberian	1971	M.Jur-L.Cret	Sandstonee				651.3	194.6
Komsomolskoye Severnoye	Russia	West Siberian	1969	U.Cretaceous	Sandstonee				0.0	4,052.3
Ay-Yaun	Russia	West Siberian	1968	U.Cretaceous	Sandstonee				524.2	879.9
Megion	Russia	West Siberian	1964	L.Cretaceous	Sandstonee				630.2	193.8
Nakhodka	Russia	West Siberian	1974	U.Cretaceous	Sandstonee				0.0	3,857.1

proximity have been grouped as one. Oil fields are shown with a solid green color, and gas fields are shown in solid red. Estimated reserves of oil and gas for countries of the Arctic Sheet are shown in Table 1.

OIL SAND

Oil sand is defined as those oil-impregnated sands from which the oil cannot be recovered by conventional borehole methods. The gravity of the oil is generally about 10 degrees API or less. Significant oil-sand deposits are shown by a green stippled pattern on the map. Major deposits of oil sand occur in Canada; minor deposits occur in the United States (Utah, California, and New Mexico).

OIL SHALE

Oil shale is depicted on the map by a green lined pattern. The most significant oil-shale resources of the Pacific Basin occur in Colorado, Utah, and Wyoming, of the western United States.

COAL

Coal deposits of the Arctic Sheet are shown in brown patterns indicating rank and general areal extent of the deposits. The smaller deposits, are indicated by symbols.

The classification of coals by rank is based on the percentage of fixed carbon and calorific value (expressed in BTUs per pound) calculated on a mineral-matter-free basis. Although there may be some differences between countries, in general the rank classification used is that established by the American Society for Testing and Materials (1966).

Major coal deposits occur throughout much of the Arctic Region. Most of the significant deposits and production are associated with interior basins and bordering foreland-thrust belts.

Coal resources of the Canadian Arctic Islands are in Triassic and Late Cretaceous to Tertiary rocks of the Sverdrup Basin, and in Devonian strata of the Franklinian Foldbelt.

Indicated coal resources are 25.5 billion tonnes of lignite, 20.0 billion tonnes of subbituminous, and 5.5 billion tonnes of high-volatile bituminous coal (Bustin and Miall, 1991).

Major coal resources of the Russian Arctic occur in the eastern Siberia region, in the Tunguska, Vilyuy and Zyryanka Basins. The main producing areas such as Kuznetsk and Kansk-Achinsk are located in more southern areas of Russia.

SEDIMENTARY BASINS OF THE ARCTIC SHEET

By Kenneth J. Drummond

The Arctic Sheet has extensive areas of overlap with the Northeast and Northwest Quadrants. The reader is referred to the Energy-Resources Map of the Circum-Pacific Region, Northeast Quadrant (Drummond, 1986) and Northwest Quadrant (Sumii, 1992), and the accompanying Explanatory Notes. The sedimentary basins of the overlap areas are discussed in the respective notes. The main sedimentary basins of the Arctic areas of the Arctic Sheet are shown in figure 3. These basins in general occur north of 60° N. The general characteristics for the basins of the Arctic Sheet are summarized in table 5. The major productive basins of the Arctic area include; Cook Inlet, Colville, Canada Territories Mainland, West Siberian, Timan-Pechora, Vilyuy, Anabar-Khatanga, and Mid-Norway. Areas with significant discoveries with no production include Beaufort-Mackenzie Basin, Sverdrup Basin, Labrador Shelf, and Barents Sea (Norway and Russia). Areas with mi-

Table 4. Coal production and reserves, Arctic areas of the Arctic Sheet, Circum-Pacific region

	Million Short Tons				
	Production			Reserves	Resources
Country/Region	1997	1998	1999	12/31/98	12/31/98
Alaska	1.5	1.3	1.6	2,544	
USA Lower 48 States	1,088.4	1,116.2	1,092.4	272,598	
USA Total	1,089.9	1,117.5	1,094.0	275,143	
Canada					
Mainland (N of 60°N)	0.0	0.0	0.0	0	2,880
Arctic Islands	0.0	0.0	0.0	0	15,550
W. Canada	85.0	81.8	79.2	9,018	168,172
E. Canada	3.1	2.7	2.0	640	3,375
Canada - Total	88.1	84.4	81.2	9,658	189,977
Greenland	0.0	0.0	0.0	202	
Russia	289.6	272.5		173,074	
China	1,460.8	1,351.3		126,215	
Japan	4.4	4.1		865	
South Korea	5.0	4.8		90	
North Korea	67.6	67.6		661	
Norway	0.2	0.4		7	

Sources: Bustin, R.M. and Miall, A.S., 1991
DOE/EIA, 2000
Freme, F.L. and Hong, B.D., 2000
Natural Resources Canada, 2000
Smith, G.G., 1989, GSC Paper 89-4
Sagers, M.J., 1993

One Short Ton = .90703 Tonnes

nor discoveries of oil and gas include Eagle Plains Basin and Anadyr Basin. A number of the Arctic basins are relatively unexplored, and many of these have significant hydrocarbon potential.

1. COOK INLET BASIN

Cook Inlet Basin is a fault-bounded basin, 420 kilometers long by 110 km wide, with an area of 44,800 square kilometres. The basin is in an arc-trench-gap setting between the volcanic arc represented by the volcanic and igneous rocks of the southern Alaska Range and a deformed Upper Cretaceous wedge of sediment to the southeast. Basin fill comprises more than 7,000 meters of Middle and Late Jurassic, Late Cretaceous, and Tertiary sediment. The Lower Cretaceous section was removed by erosion during the middle of the Cretaceous. Upper Cretaceous rocks are mainly marine shale with only minor sandstone. The main basin fill is composed of thick Tertiary alluvial clastics of the Kenai Group. The major oil and gas fields follow north-trending anticlines.

2. BRISTOL AND ST. GEORGE BASIN

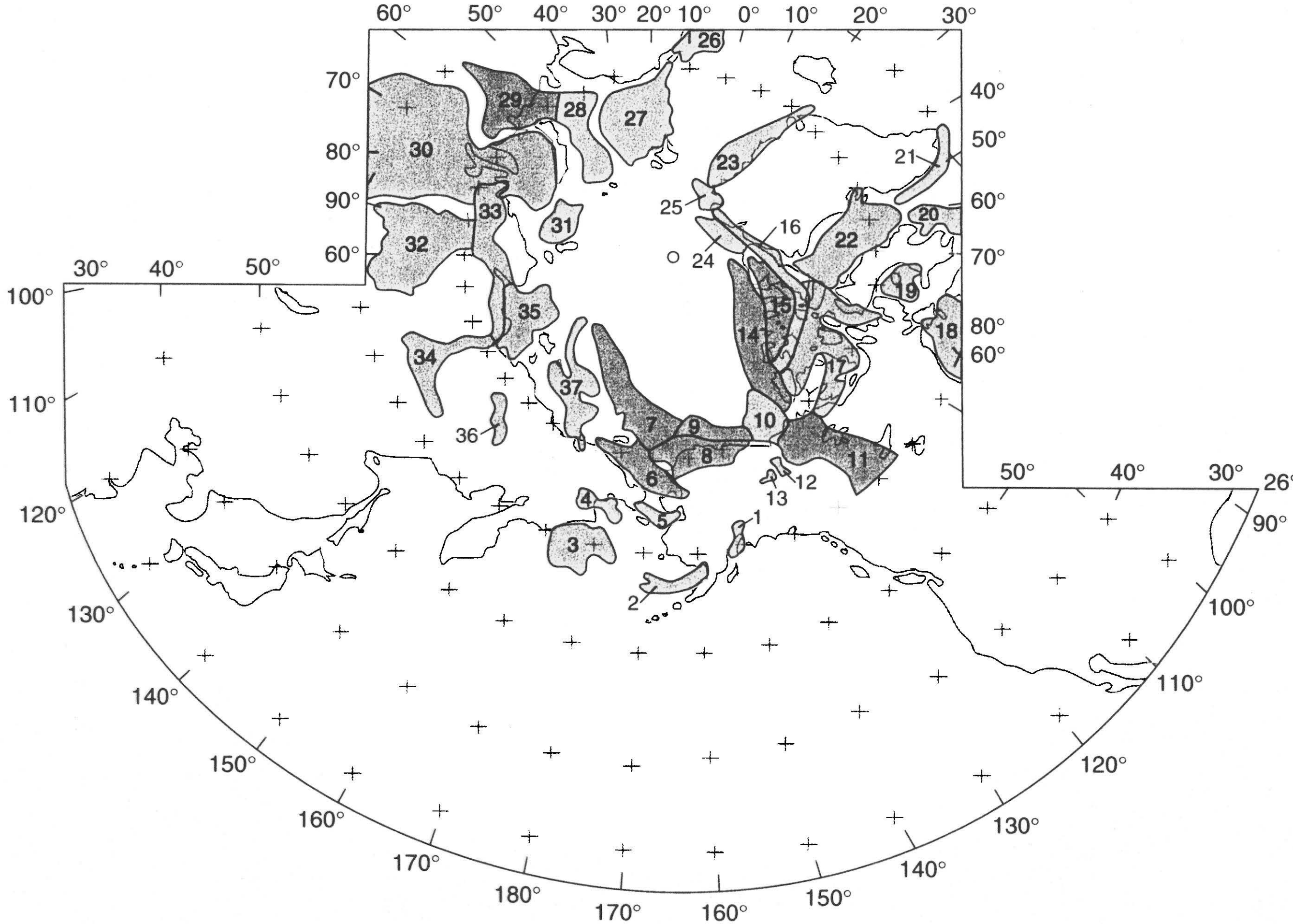
The Bristol and St. George Basins contain up to 5000 m of marine and nonmarine deposits of Cenozoic age. These are deep-water forearc basins that lie north of the Aleutian Islands adjacent to the Bering Sea continental shelf. The basins, about 166,800 square kilometers in size, are underlain by a flat-lying sequence of mostly Cenozoic sediment 2 to 5 km thick that rests on a pre-Cretaceous basement.

3. NAVARIN BASIN

The Navarin Basin, a large structural forearc basin filled with more than 5,000 m of sediment, underlies the Bering Sea continental shelf about 100 km from the coast of Russia. The shelf in this region is relatively flat with a pronounced shelf-slope break at about 200 m. The basin initially formed as a result of extensional deformation associated with oblique subduction of the Kula Plate beneath the North America Plate during the Late Cretaceous to early Tertiary. The Navarin Basin COST 1 well suggests that since the late Eocene, sedimentation within the basin consisted of predominantly marine mudstone and siltstone and minor amounts of sandstone. Eocene and early Oligocene marine sediments have good liquid-hydrocarbon source potential and favorable levels of thermal maturity.

4. ANADYR BASIN

The Anadyr basin is a large (75,100 km^2) structural depression filled with Upper Cretaceous and Tertiary sedimentary rocks, primarily volcaniclastic. The onshore part of the basin underlies the Anadyr Lowlands and is flanked on the north, west, and south by folded Mesozoic rocks. To the east and southeast, the basin extends into the offshore. The basin onshore covers approximately 33,000 km^2, and 42,100 km^2 offshore. The deepest parts of the basin contain at least 6 km of mildly deformed sedimentary rocks. Minor oil and gas discoveries have been made onshore. The offshore Anadyr Basin possibly offers better prospects for commercial hydrocarbons.



Map No.	Basin
1.	Cook Inlet
2.	Bristol/St. George
3.	Navarin
4.	Anadyr
5.	Norton
6.	Hope
7.	Vilkitskii-North Chukchi
8.	Colville
9.	Alaska Beaufort Shelf
10.	Mackenzie Delta/Beaufort Sea
11.	Canada Mainland Territories
12.	Eagle Plains
13.	Kandik
14.	Arctic Islands Shelf
15.	Sverdrup Basin
16.	Franklinian-Greenland Fold Belt
17.	Arctic Islands Platform
18.	Hudson Bay
19.	Foxe
20.	Labrador Shelf
21.	Southwest Greenland
22.	Baffin Bay
23.	East Greenland
24.	Lincoln Sea
25.	Wandel Sea
26.	Mid-Norway Shelf
27.	Barents Sea Norway Basin
28.	Russian Barents Shelf
29.	Timan-Pechora
30.	West Siberian
31.	North Kara Sea
32.	Tunguska
33.	Anabar-Khatanga
34.	Vilyuy
35.	Laptev Sea
36.	Zyryanka
37.	East Siberian Sea

Figure 3. Index map of sedimentary basins of the Arctic Sheet north of 60°N, Circum-Pacific Region

Table 5. General characteristics of sedimentary basins of the Arctic Sheet north of 60°N, Circum-Pacific region

MAP_NO	BASIN_NAME	COUNTRY / STATE	SQ_KM AREA	METRES AV_THICK	METRES MAX_THICK	AGE_FILL	AGE_BASEMENT	DOMINANT LITHOLOGY
1.	COOK INLET	ALASKA	44,800	4,600	7,600	JUR,U CRET,TERT	PRE-JURASSIC	CLASTICS
2.	BRISTOL/ST. GEORGE	ALASKA	166,800	2,900	5,000	TERT-QUAT	PRE-CRET	CLASTICS
3.	NAVARIN	ALASKA	109,800	3,400	5,300	TERT-QUAT	PRE-CRET	CLASTICS
4.	ANADYR	RUSSIA	75,100	3,000	6,700	U CRET, TERT	PRE-CRET	CLASTICS
5.	NORTON BASIN	ALASKA	98,400	1,500	6,500	TERTIARY	PRE-CRET	CLASTICS
6.	HOPE	ALASKA	218,900	2,000	3,000	U CRET, TERT	PRE-CRET	CLASTICS
7.	VILKITSKII-NORTH CHUKCHI	ALASKA, RUSSIA	385,500	2,300	6,000	JUR-CRET,TERT	PRE-MESOZOIC	CLASTICS
8.	COLVILLE	ALASKA	291,200	4,900	9,100	U PALEOZ-TERT	PRECAMB	CLASTICS & CARBONATES
9.	ALASKA BEAUFORT SHELF	ALASKA	134,600	3,000	9,100	U CRET, TERT	L PALEOZOIC	CLASTICS
10.	MACKENZIE DELTA/BEAUFORT SEA	CANADA	388,500	3,000	9,100	U PZ,JUR-CRET,TERT	PRE-MESOZOIC	CLASTICS & CARBONATES
11.	CANADA TERRITORIES MAINLAND	CANADA	489,500	1,500	4,900	CAMB-U PZ, U CRET	PRECAMB	CARB, CLASTICS & EVAP
12.	EAGLE PLAINS	CANADA	26,200	5,800	7,000	PZ,JUR-CRET	PRECAMB	CARB, CLASTICS
13.	KANDIK BASIN	CANADA, ALASKA	20,800	3,000	5,500	PZ,JUR-CRET	PRECAMB	CLASTICS & CARBONATES
14.	ARCTIC ISLANDS SHELF	CANADA	388,500	3,000	6,100	CRET,TERT,QUAT	PRE-CRET	CLASTICS
15.	SVERDRUP BASIN	CANADA	313,100	4,700	10,700	U PZ,MZ,TERT	L PALEOZOIC	CARB, CLASTICS, SOME EVAP
16.	FRANKLINIAN-GREENLAND FOLD BELT	CANADA, GREENLAND	349,600	4,600	9,100	L PALEOZ	PRECAMB	CARB, CLASTICS, SOME EVAP
17.	ARCTIC ISLANDS PLATFORM	CANADA	782,400	1,600	4,600	L PALEOZ	PRECAMB	CARB, CLASTICS, SOME EVAP
18.	HUDSON BAY	CANADA	971,200	700	2,400	L PZ, CRET	PRECAMB	CARB, MINOR CLASTICS
19.	FOXE	CANADA	168,300	300	600	L PALEOZ	PRECAMB	CARB, MINOR CLASTICS
20.	LABRADOR SHELF	CANADA	396,300	4,900	9,100	U PZ,MZ,TERT	PRECAMB-L PZ	CLASTICS, MINOR CARB
21.	SOUTHWEST GREENLAND	GREENLAND	230,500	2,600	7,000	U PZ,MZ,TERT	PRECAMB-L PZ	CLASTICS
22.	BAFFIN BAY	CANADA, GREENLAND	569,800	2,700	6,100	U PZ,MZ,TERT	PRECAMB-L PZ	CLASTICS
23.	EAST GREENLAND	GREENLAND	297,900	2,700	9,000	U PZ,MZ,TERT	PRECAMB-L PZ	CLASTICS, CARBONATES
24.	LINCOLN SEA	GREENLAND	85,500	3,000	7,000	U PZ,MZ,TERT	L PALEOZOIC	CLASTICS, CARBONATES
25.	WANDEL SEA	GREENLAND	41,400	2,000	4,600	U PZ,MZ,TERT	L PALEOZOIC	CLASTICS, CARBONATES
26.	MID-NORWAY BASIN	GREENLAND	157,800	3,300	8,200	TRIAS,JUR,CRET	PRE-TRIASSIC	CLASTICS, CARBONATES
27.	NORWAY BARENTS SEA	NORWAY	466,800	2,700	4,600	U PALEOZ, MZ, TERT	L PALEOZ	CLASTICS, CARBONATES
28.	RUSSIA BARENTS SEA	RUSSIA	384,500	10,000	11,000	U PALEOZ, MZ, TERT	L PALEOZ	CLASTICS, CARBONATES
29.	TIMAN-PECHORA	RUSSIA	443,700	7,000	10,000	PALEOZ, MZ	PRECAMB	CLASTICS, MINOR CARB
30.	WEST SIBERIAN	RUSSIA	1,932,100	9,000	16,000	MESOZ, TERT	PRECAMB	CLASTICS, MINOR CARB
31.	NORTH KARA SEA	RUSSIA	349,900	6,700	7,000	U PZ - TERT	PRECAMB-L PZ	CLASTICS, MINOR CARB
32.	TUNGUSKA	RUSSIA	699,500	3,700	7,500	U PROT,PZ,JUR-TRIAS	PRECAMB	CLASTICS, CARBONATES
33.	ANABAR-KHATANGA	RUSSIA	390,600	4,600	9,000	PZ,MZ	PRECAMB-L PZ	CLASTICS, CARBONATES
34.	VILYUY	RUSSIA	313,000	3,000	11,000	U PZ,TRIAS,JUR	PRECAMB	CLASTICS, CARBONATES
35.	LAPTEV SEA	RUSSIA	326,500	3,700	7,000	PZ, JUR-CRET	L PALEOZ	CLASTICS
36.	ZYRYANKA	RUSSIA	115,000	2,100	4,000	PZ,MZ,TERT	PRECAMB	CLASTICS
37.	EAST SIBERIAN SEA	RUSSIA	136,800	3,000	5,800	PZ,PM-TR,JUR-CRET,TERT	PRECAMB-L PZ	CLASTICS

5. NORTON BASIN

Norton basin underlies the northern part of the Bering Sea Shelf north of St. Lawrence Island. It is an east-trending trough filled with terrestrial and neritic deposits as much as 6,500 m thick of probable Cenozoic age, although some uppermost Cretaceous rocks could be present. The basement for the Norton Basin is most likely of Precambrian and Paleozoic age. Upper Cretaceous and Paleogene sediments contain coal- and volcanic-rich rocks, overlain by mainly clastic nonmarine sedimentary deposits. The Neogene and Quaternary basin rocks apparently were deposited in a marine environment. Gas and condensate are the most likely hydrocarbons to be present in the basin.. Numerous potential traps for hydrocarbons exist in the Norton Basin; the traps include fractured or weathered basement rocks in horsts, strata in alluvial fans on the flanks of horsts, and arched strata over horsts.

6. HOPE BASIN

The Hope Basin, a tensional pull-apart basin, with an area of 218,900 km^2, extends from western Alaska to eastern Siberia. Maximum sediment fill is about 3,000 m, with an average of about 2,000 m. The stratigraphic section is from Upper Cretaceous through Tertiary.

7. VILKITSKI–NORTH CHUKCHI BASIN

The North Chukchi Basin lies on the continental shelf offshore from northwestern Alaska. The western extension is the Vilkitski Basin located on the East Siberian Shelf. The combined basin area is about 385,500 km^2. The stratigraphic section from Jurassic through Tertiary is probably greater than 6,000 m thick.

8. COLVILLE BASIN

The Colville Basin is a late Mesozoic-Cenozoic foredeep developed on pre-Upper Devonian argillite and greenschist basement. It is bounded to the south by the Brooks Range fold-and-thrust belt, and to the north by the Barrow Arch, an uplifted basement arch separating the Colville Basin from the Beaufort Sea to the north. The basin as defined herein includes the onshore North Slope Basin of Prudhoe Bay.The basin contains late Paleozoic to Tertiary sediments over 9 km thick in the foothills of the Brooks Range, thinning to the north. The pre-Cretaceous sediments within this trough are as old as Mississippian and were derived from a northern provenance that probably lay beyond what is now the outer continental shelf. The overlying Cretaceous to Tertiary sediments were derived largely from the south following a continent-continent collision and consequent uplift of the Brooks Range Mountains. This area, which includes the Prudhoe Bay Oil Field is one of the most petroliferous regions of North America, and the potential for additional discoveries remains bright

9. ALASKA BEAUFORT SHELF BASIN

The Alaska Beaufort Shelf Basin is a series of basins and intervening highs along the continental shelf offshore from northern Alaska. The basin extending from the Canadian border to the Chukchi shelf occupies an area of 291,200 km^2. The basin fill is greater than 9,000 m along the shelf edge. The sedimentary section comprises Upper Cretaceous through Tertiary clastics overlying a lower Paleozoic basement.

10. BEAUFORT–MACKENZIE BASIN

The Beaufort-Mackenzie Basin in northwestern Canada is a rifted continental margin and foreland basin that contains more than 9 km of Mesozoic–Cenozoic clastic sedimentary strata. Sediments were deposited in a series of prograding depositional complexes containing fluviodeltaic, shelf, slope, and basinal clastics.The basin contains large volumes of discovered oil and natural gas resources and has high potential for future discoveries. Oil and gas fields discovered in the Beaufort-Mackenzie Basin occur in a variety of stratigraphic and structural settings. Reservoirs include Lower Cretaceous nonmarine and shoreline sandstones, and highly porous Eocene and Oligocene deltaic sandstones. Oligocene and Miocene shelf and turbidite sandstone reservoirs occur in the offshore parts of the basin. Common structural traps include basement-involved Cretaceous fault blocks along the basin rift margin and Tertiary deltaic growth-fault blocks in the basin.

11. CANADA MAINLAND TERRITORIES

The Mainland Territories is a foreland to platform basin, which is essentially the northward extension of the Western Canada Sedimentary Basin that occurs north of 60° N, covering an area of 388,500 km^2. The area includes the fold and thrust belt along the western margin. The sedimentary section, up to 5 km thick, comprises strata from Cambrian to Cretaceous age, overlying Precambrian sedimentary and crystalline basement.

12. EAGLE PLAINS BASIN

The Eagle Plains Basin is an intermontane basin, bounded by the Richardson Mountains to the east and the Ogilvie Mountains to the south, west, and north. The basin area is about 24,000 km^2. The stratigraphic section, up to 6000 m thick, is from the late Paleozoic to the Late Cretaceous, with only the Triassic missing. The main reservoir targets are the Devonian, Carboniferous, Jurassic, and Cretaceous, at depths ranging from 600 to 3000 m.

13. KANDIK BASIN

The Kandik Basin is an intermontane basin bounded by mountain ranges, situated across the Alaska–Yukon border. The basin area is about 20,800 km^2. The basin is elongated to the southwest with the largest part of the basin in Alaska (60%). The stratigraphic section, up to 5,500 m thick, is from the late Paleozoic to the Late Cretaceous, with only the Triassic missing. Three wells have been drilled in the area and none encountered hydrocarbons.

14. CANADA ARCTIC ISLANDS SHELF

The extreme northern coast of the Canaduan Arctic Islands Archipelago is a coastal plain of undisturbed rocks that dip gently seaward under the Arctic Ocean. The Canadian Arctic Coastal Plain and Shelf comprise an area of about 388,500 km^2 from offshore of Banks Island to Northern Ellesmere. The shelf comprises a seaward thickening wedge of Cretaceous to Tertiary sediments onlapping the northern margin of the Sverdrup Basin. Sedimentary thickness possibly exceeds 12 km.

15. SVERDRUP BASIN

The Sverdrup Basin, which lies across the Franklinian Foldbelt, contains a conformable sequence of strata dating from Middle Pennsylvanian to early Tertiary which lies with high angular unconformity on the foldbelt. These strata may be as much as 11,000 km thick in the Axel Heiberg Island area, but they thin gradually to extinction in the Prince Patrick Island area to the southwest. Early Tertiary movements are responsible for broad open folding. Piercement domes and elongate diapirs form in the axial belt evaporites of Pennsylvanian or Permian age. Angular unconformities and transgressive formations lie on the south and west margins of the basin. The Sverdrup Basin of the Canadian Arctic Archipelago is an intracratonic rift basin initiated during the late Paleozoic.

16. FRANKLINIAN NORTH GREENLAND FOLDBELT

The Franklinian foldbelt adjacent to stable platforms on the north and west extends from Prince Patrick Island to northeastern Ellesmere, a distance of about 1,600 km, with an additional length of about 700 km to the northeast on Greenland, which is the North Greenland Foldbelt. The foldbelt comprises lower Paleozoic rocks, commonly referred to as the Franklinian Succession. Sedimentation probably began in the earliest Cambrian or latest Proterozoic, followed by deposition of Cambrian through Devonian carbonates and clastics. These rocks were deformed by the Ellesmerian Orogeny that took place between the latest Devonian and Early Mississippian.

17. CANADIAN ARCTIC ISLANDS PLATFORM

The Canadian Arctic stable platform fringes the craton on the north and west and is composed of platformal cover over Precambrian crystalline or Proterozoic platform rocks. It has been generally stable through the greater part of Proterozoic and Phanerozoic times. This structural unit is characterized by flat or very gently dipping, largely homoclinal autochthonous carbonate, evaporite, and clastic formations. At present, the stable platform contains several structural basins formed between regional elongated uplifts following sediment deposition.

18. HUDSON BAY PLATFORM

The Hudson Bay Platform covers an area of 970,000 km^2, 600,000 of which is underwater. It is a pre-Carboniferous intracratonic basin. The stratigraphic section comprises relatively undeformed rocks of Ordovician, Silurian, and Devonian age, with a composite thickness of 2500 m. Two wells have been drilled with no indication of hydrocarbons.

19. FOXE BASIN

The Foxe Basin, with an area of 120,000 km^2, is a northern outlier of the Hudson Bay Platform, separated by the Bell Arch. The sedimentary section is about 1000 m, comprising Cambrian and Ordovician sandstones and carbonates.

20. LABRADOR SHELF BASIN

The Labrador Shelf sedimentary basin comprises a seaward thickening wedge of sediments lying offshore from Labrador and southwestern Baffin Island. The basin area is 396,300 km^2. Although only the portion offshore from Baffin Island is represented on the Arctic Sheet, it is generally considered as an Arctic basin and is included here. The Labrador Shelf is comprised of a series of grabens and basins separated by intervening highs containing upper Paleozoic, Mesozoic, and Tertiary sediments. The stratigraphic section, predominantly clastic with minor carbonates, probably reaches thicknesses of 9,000 m along the shelf edge. Major gas discoveries have been made in the basin offshore from Labrador.

21. SOUTHWEST GREENLAND BASIN

Little is known of the stratigraphic section offshore from southwest Greenland. Regional geology and geophysics suggest a possible sedimentary basin 230,500 km^2

in size, of upper Paleozoic, Mesozoic, and Tertiary sediments overlying a Precambrian crystalline basement. The stratigraphic section could be up to 7,000 m thick.

22. BAFFIN BAY BASIN

Baffin Bay is a small ocean basin, comprising the area offshore from Baffin Island eastward to Greenland and including the West Greenland Basin of the Disko Island area. Sediments thicken northward, and beneath the northern margin east of Lancaster Sound, they are up to 8 km thick. Sediment-filled grabenlike structures occupy Melville Bay and Lancaster Sound, and smaller sedimentary basins lie in the southern part of Nares Straits and in Jones Sound. Extensions of the Tertiary igneous rocks of West Greenland and eastern Baffin Island are found offshore. Oceanic "basement" at the southern end of Baffin Bay rises to the surface on the northern side of Davis Strait. The basin fill includes upper Paleozoic, Cretaceous, and Tertiary. The West Greenland Shelf area between 68° and 72° is covered by lower Tertiary basalt and has so far proved difficult to explore seismically.

23. EAST GREENLAND BASIN

In East Greenland Basin more than 12 km of Devonian through Lower Permian strata are overlain by Triassic through Cretaceous. The sediments were deposited in north-northeast-trending fault-bounded basins. Onshore, the basin contains an estimated 10 km of Cretaceous to Tertiary strata overlying rifted earlier Mesozoic. There has been no exploration in this area, but it is thought to be favourable for the occurrence of oil and gas. The composite thickness of the Mesozoic sequence is 6,000–7,000 m. The sequence is dominated by clastic material deposited in shallow water.

24. LINCOLN SEA BASIN

The Lincoln Sea Basin occurs north of Greenland and Ellesmere Island, with an area of approximately 85,500 km^2. The sedimentary section, up to 7,000 m thick, is most likely upper Paleozoic carbonates and Mesozoic through Tertiary clastics overlying a lower Paleozoic basement.

25. WANDEL SEA BASIN

The Wandel Sea Basin developed on and east of the deformed strata of the underlying folded, faulted, and metamorphosed lower Paleozoic. The upper Paleozoic, Mesozoic, and Tertiary section is about 3,000 m thick onshore and thickens offshore. Favourable conditions for hydrocarbon potential probably occur, but the potential is unknown at present.

26. MID-NORWAY SHELF

The continental shelf offshore from Mid-Norway extends southward to the North Sea sedimentary basins and northward to the Barents Sea continental shelf. Pre-Triassic rocks have not yet been encountered. The main targets for the exploration drilling have been the Triassic–Jurassic succession. The Triassic consists mainly of continental red shales with sandstone and salt intervals. A change in climate to more humid conditions toward the end of the Triassic led to coastal plain deposition that persisted into the Early Jurassic. These carbonaceous sediments are important source beds for gas and condensate. A major transgression took place during the Early Jurassic, leading to deposition of a sequence of shallow marine sand, tidal-flat sand, and offshore mud of medium to low reservoir quality. A Middle Jurassic regression resulted in deposition of shallow marine sandstone presently representing the main reservoir in the area. Normal and growth faulting during the Triassic to Early Jurassic culminated with the main Kimmerian (pre-Callovian) tectonic phase that resulted in extensive horst and graben development, with subsequent erosion of structural highs. The Upper Jurassic consists of marine shale, of which the upper part is an oil-prone shale of excellent source-rock characteristics. The base of the Cretaceous is developed as a regional unconformity (late Kimmerian) onlapped by Cretaceous marine shale, marl, and minor limestone. Differential subsidence created the main platforms and basins. The Tertiary represents a period of epeirogenic subsidence leading to rapid deposition of marine clastic sediments. The northward progress of the North Atlantic Rift is seen in the sedimentary record as a series of tuffaceous layers within the upper Paleocene–lower Eocene. Along the margin, a volcanic high was formed.

27. BARENTS SEA NORWAY BASIN

The Barents Sea Basin is situated on the continental shelf between Norway, the Spitsbergen Islands, and Novaya Zemlya. Three sedimentary basins, Tromso, Hammerfest, and Nordcap, make up the overall Barents Sea Basin offshore of northern Norway. Hydrocarbon traps occur in clastic reservoirs associated with rotated fault blocks, compressional anticlines, and salt domes. Significant stratigraphic potential exists in Paleozoic carbonates. Drilling in the Hammerfest Basin has yielded large gas discoveries. The largest find is Snoehvit (Snow White) Gas Field. In the southern part of the Barents Shelf, between the Spitsbergen Platform and Norway, deep sedimentary basins have been identified, characterized by diapirism of upper Paleozoic salt, contemporaneous with Early Cretaceous growth faulting.

28. BARENTS SEA RUSSIA BASIN

The eastern Barents Shelf extends from the Baltic Shield to Franz Josef Land. The basin, filled with more than 11 km of upper Paleozoic, Mesozoic, and Cenozoic sediments, is an offshore extension of the Timan-Pechora. Paleozoic sediments are predominantly carbonate, and Mesozoic–Cenozoic sediments are mainly terrigenous. Jurassic and Lower Cretaceous sandstones are thought to be the primary potential reservoir targets in the basin. Upper Jurassic black shales are probably the main source rocks in the area. In the North Barents synclinal basin the Paleozoic–Mesozoic rock section thins, and facies changes are less favorable for the accumulation of hydrocarbons, although oil seeps have been observed on Spitsbergen and other islands.

29. TIMAN–PECHORA BASIN

The Timan–Pechora Basin is a passive-margin basin bounded by the Ural Mountains to the east, Timan Ridge on the west, and the Barents Sea to the north. The basin covers 300,000 km^2 and contains 6 to 10 km of Mesozoic and Paleozoic sediments overlying a Precambrian crystalline basement. In the Timan-Pechora, several oil and gas fields have been discovered. Productive and prospective zones are in the middle and upper Paleozoic, and possibly in the Mesozoic. Structures favorable for oil and gas accumulation extend offshore into the southern part of the Barents Sea Shelf.

30. WEST SIBERIAN BASIN

The West Siberian Basin is a composite basin that comprises Mesozoic–Cenozoic sediments overlying a Paleozoic basin deposited on crystalline basement. The basin occupies an area of 3.4 million km^2. The Paleozoic sediments are probably in excess of 10 km in thickness, and the Mesozoic–Cenozoic is up to 12 km thick. The principle reservoirs are in the Neocomian and the Cenomanian at depths from 1100 to 2800 m. The Precambrian basement is overlain by an intermediate complex of Permo-Triassic terrigenous and volcanogenic rocks, and in the eastern part of the basin, probably still older sedimentary rocks are present. The platform cover is composed mainly of clastic rocks ranging in age from Jurassic to Quaternary. Thickness of the Phanerozoic sedimentary cover ranges from approximately 3 to 5 km in the central area of the basin, to 8 to 12 km in the northern part. Cretaceous and lower Tertiary rocks are primarily shallow marine shelf, coastal plain, and lowland clastic deposits formed during several transgressive-regressive phases. Major oil accumulations, mainly in Lower Cretaceous and Jurassic sandstone reservoirs, lie in the central and west-central parts of the basin. The largest reserves of natural gas in the world are located in the northern part of the basin, primarily in Upper Cretaceous (Cenomanian) sandstone reservoirs. Oil source rocks are mainly marine Jurassic and Lower Cretaceous bituminous shales. Gas source rocks are mainly Upper Cretaceous humic and coaly shales.

The Kara Sea Basin is a seaward extension of the West Siberian Basin. It occupies an area of about 350,000 km^2 and contains a Jurassic to Cenozoic sedimentary section of 6 to 12 km in thickness.

31. NORTH KARA SEA BASIN

The North Kara Sea Basin is separated from the South Kara Sea Basin by the Novaya Zemlya–Taymyr Foldbelt. The basin area is about 350,000 km^2. The basin, almost entirely unexplored, is thought to contain a sedimentary section in excess of 7 km ranging in age from late Paleozoic to Tertiary.

32. TUNGUSKA BASIN

The Tunguska Basin comprises an area of about 1.7 million km^2. The sedimentary section, up to 5 km in thickness, is from Late Proterozoic to Triassic in age. Deposits in the Tunguska Basin are in stratigraphic traps in Proterozoic to Cambrian clastic and carbonate sediments and in anticlinal structures in areas of salt tectonics. Source rocks are essentially Proterozoic, but younger sediments may contribute. Cambrian salt provides the most common regional seal. The poorly explored Tunguska Basin contains oil and gas in Proterozoic and Lower Cambrian clastic and carbonate rocks overlain by thick Cambrian salt. Most production is from structural traps, but reservoir pinch-outs are also important

33. ANABAR–KHATANGA BASIN

The Anabar-Khatanga Troughs contain sediments ranging in age from lower Paleozoic to Cretaceous. The basin area lies north of the Vilyuy and Tunguska Basins. Pools in the Anabar–Khatanga area are in anticlines in Triassic, Jurassic, and Cretaceous clastic sedimentary rocks. Source beds are Permian carbonaceous shale. Most discoveries have been gas. A large bitumen (tar) field lies near the southern border of the Anabar Trough, and abundant oil and bitumen shows occur through the whole section from the upper Precambrian through the Lower Cretaceous.

34. VILYUY BASIN

The Vilyuy Basin developed over a carbonate platform of Proterozoic to Early Carboniferous age. Sedimentary basin fill is Middle Carboniferous to Late Cretaceous clastics, up to 11 km in thickness. The basin occupies an area of 200,000 km^2. It is primarily a gas province with a producing section from Upper Permian to Middle Jurassic. Principal reserves are in the Upper Permian and Lower Triassic.

35. LAPTEV BASIN

The Laptev Basin comprises a sedimentary section of about 7,000 km of Devonian, late Paleozoic, and Jurassic–Cretaceous age. The Laptev Sea Shelf has a total area of about 326,500 km^2, and at the edge of the continental slope its water depth is 100–200 m. In the west, it is the drowned margin of the West Siberian Platform, but most of the shelf consists of a distinct tectonic unit—the Laptev Block Approximately 5 to 6 km of lower and middle Paleozoic deposits, mostly carbonates, cover a basement assumed to be Early Proterozoic in age. A thin section (1 km or less) of terrigenous Upper Cretaceous–Neogene rocks overlies the Paleozoic section. The most favorable oil and gas prospects are in the upper Paleozoic in the southern Laptev Trough.

36. ZYRYANKA BASIN

The Zyryanka Basin area is about 115,000 km^2. The stratigraphic section, up to 4,000 m thick, ranges in age from Devonian to Quaternary. The basin developed as an intramontane depression on the East Siberian Platform.

37. EAST SIBERIAN SEA

The East Siberian Sea Basin occupies the East Siberian Sea, extending from the New Siberia Islands to Wrangel Island. The area is characterized by a series of basin depocentres with intervening highs. The stratigraphic section is poorly known but may contain Paleozoic, Permo-Triassic, Late Jurassic to Cretaceous, and Tertiary sediments. The East Siberian basement is Archean and Baykalian.

GEOTHERMAL RESOURCES

By Theresa R. Swint-Iki

Geothermal data shown on the Energy-Resources Map of the Circum-Pacific Region, Arctic Sheet, includes geothermal fields-fields developed to generate electricity-and hot springs. Hot springs with surface temperatures greater than 50°C are shown in the United States, Canada, and Mexico by purple x's. The surface temperatures of hot springs in Russia were not available. Therefore, the hot spring symbol is only to indicate location of hot springs in Russia.

The classification scheme, showing type of hydrothermal-convection system of a geothermal field (water-dominated or vapor-dominated) and estimated reservoir temperature, is from Muffler (1978). Hydrothermal-convection systems have been further divided to distinguish between systems that are generating electic power and those that are yet to be developed. Where electric power is currently being generated, a diamond symbol in red indicates the location of the power plant.

Patrick Muffler and Manuel Nathenson of the U.S. Geological Survey are gratefully acknowledged for their assistance in designing the geothermal element of the Circum-Pacific Energy-Resources Map Series and for use of their bibliography of geothermal literature.

UNITED STATES

The largest producer of electricity from geothermal energy is The Geysers geothermal plant in the Coast Range of northern California. The hydrothermal convection system is vapor-dominated, and the power plant has a generating capacity of about 1,800 megawatts (MW) (DiPippo, 1985).

Many hydrothermal-convection systems have been identified throughout northern California, Oregon, and Washington in the volcanic Cascade Range and volcanic regions of central and southeastern Oregon. The system at Mt. Lassen in northern California, also a high-temperature vapor-dominated system, has not been developed because of its National Park status. Most of the identified systems in the Cascade Range have not been developed for generation of electricity, but in many of these areas geothermal water is being utilized for space heating.

Young volcanoes exist throughout the Snake River Plain of Idaho, and numerous hydrothermal convection systems have been identified there. The size of the reservoirs, however, is not known. Farther east, in northwestern Wyoming, another vapor-dominated system occurs in the Mud Volcano area of Yellowstone National Park, but it is withdrawn from commercial development because of its park status.

In the region of the Sierra Nevada Front of eastern California and western Nevada, the Coso geothermal area in the Long Valley Caldera is related to young volcanic features. A 25-MW plant was constructed at Coso in 1985 (DiPippo, 1985).

A small cluster of hydrothermal-convecton systems lies in southwestern New Mexico and southeastern Arizona and to the north near the Wasatch Front in Utah. The Roosevelt geothermal plant, Utah, produces 20 MW, and the Fort Cove–Sulphurdale plant, Utah, has 4 units, each of which produces 0.675 MW.

In the northern Rocky Mountains, hydrothermal-convection systems occur mainly at the Idaho Batholith in central Idaho and the Boulder Batholith in southwestern Montana. Other small systems occur in the Rocky Mountains, but they are scattered, and reservoir temperatures are lower than 90°C.

The easternmost extent of geothermal fields in the western United States is the Rio Grande Rift, which extends from New Mexico northward into the southern Rocky Mountains of Colorado. The largest identified hot-water system of this geologic province occurs within the Valles Caldera in New Mexico.

In Alaska, 3 hot-water hydrothermal-convection systems with temperatures greater than 150°C, and 25 with temperatures ranging from 90 to 150°C have been identified across central and southeastern Alaska. Because of the remoteness of those geothermal fields, none are being commercially developed at this time.

Geothermal data for the continental United States and Alaska are from Muffler (1978), and hot-spring data for Alaska are from the Alaska Department of Natural Resources (1983). Principle sources of hot-spring data are from Berry and others (1980). Computer-generated plots at 1:10,000,000 scale from Muffler (1978) and Berry and others (1980) for the Circum-Pacific Northeast Quadrant were provided by Ronald H. Smith of the National Oceanic and Atmospheric Administration. The data were transfered from the Northeast Quadrant to the Arctic Sheet.

For areas outside the United States, geothermal data were collected from the published literature, mainly from Waring (1965). Hot springs with a surface temperature of more than 50°C, or if listed by Waring as "hot", are also shown on the map. The location of these hot springs is in most cases approximate.

CANADA

Canada's high-temperature geothermal areas lie along the volcanic belts of the Cordillera (Jessop, 1985). Two identified geothermal fields are shown on the map: Mt. Meager at lat 52.5°N, long 123.5°W, and Mt. Cayley at lat 50°N, long 123.5°W. Reservoir temperatures exceed 150°C, but because the need for electric power in Canada has been declining, the pace of development of geothermal power plants has slowed. Some of the lower temperature geothermal reservoirs in sedimentary aquifers of the prairies in Canada are presently being utilized for direct heat.

Geothermal data for Canada were compiled mainly from Jessop (1985), Lewis and Souther (1978), and Crandall and Sadlier-Brown (1977).

RUSSIA

On the Kamchatka Peninsula, at Pauzhetka, lat 51°28'N, long 158°14'E, a geothermal power plant was developed with a vapor-dominated convection system. The power plant generated an initial output of 5 MW, later increased to 11 MW in 1981.

A second experimental power plant was built in 1968 at Paratunka, lat 52°57'N, long 158°14'E. Due to a high salt content of the water, the plant ceased operation 7 years later. The steam wells at Paratunka continue to supply heat for greenhouse farming at Termal'nyy.

At Mutnovskaya Volcano, installation of a 200 MW power plant was under consideration. The location is indicated on the map at lat 52°27'N, long 158°11'E (U.S. Central Intelligence Agency, 1985).

Hot springs are common throughout Russia, and the geothermal water has been used for direct heating for buildings, greenhouses, hothouse farming, and medicinal purposes. Where surface temperatures of geothermal springs are at least 40°C, the water is often utilized for greenhouses and hothouses. Winter greenhouses are heated by geothermal water near Ternair (Dagestan). At Tal'skiy, in the Okhotsk area, several thermal springs have temperatures from 35-90°C (Polevoy, 1985). This map shows the locations of hot springs taken from the map by Makarenko (1972). Temperatures of the thermal springs were not indicated.

JAPAN

In 1990, Japan had a total installed capacity of 283 MW, produced by eight large and two small plants in southern Japan. Three additional plants came on line in northeastern Japan in 1995. Hot springs in Japan are so numerous that for this map each hot spring symbol on the map represents a group of hot springs. The geothermal resources for Japan and China were compiled by Osamu Matsubayashi (1992).

CHINA

Two geothermal fields lie along the east coast of China from the Liaodong and Shangdong Peninsulas in the north to Jiangxi, Hunnan, and Guangdong in the south. Numerous thermal springs follow along an active fault system. A preliminary study of geothermal resources in the region of the Fen-Wei Rift shows potential for development of direct-heat uses of thermal water. Thermal springs lie along the length of the rift, and temperatures range from 40 to 90°C. Only one spring in the study area is greater than 90°C, at approximately lat 34°N, long 108°W, near Xi'an (Wang, 1987).

ICELAND

Besides electric power production from geothermal sources, Iceland has many other direct uses for the geothermal fluids of its numerous geothermal fields. Towns are heated by the geothermal waters for large-scale space heating. At the capital of Reykjavik, 97 percent of heating is from geothermal water, and Hveragerdi is heated solely by geothermal heat. Other uses for geothermal energy include greenhouses, hot water to homes, washing, and facilities to dry produce, fish, and grain.

Iceland has four geothermal power plants in production. Laugarnes in southwest Iceland has been in production since 1966 in a low-temperature geothermal field with a reservoir temperature of 95°C. At Svartsengi, a power plant went into production in 1977. There the geothermal field is liquid-dominated, and the reservoir temperature is 240°C. In north-central Iceland, two plants are developed at low-temperature geothermal fields where reservoir temperatures are 95°C at Laugaland and 80°C at Ytri-Tjarnir (Axelsson and Bodvarsson, 1987).

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