

## **The Historical Resource and Recovery Growth in Developed Fields on the Arctic Slope of Alaska**

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### **Introduction**

Early exploration and oil prospecting in Alaska was driven by surface oil seeps noted on the Alaska Peninsula, Western Cook Inlet and on the North Slope. Historically, oil seeps were observed by Inupiat Eskimos, and according to archaeological evidence, oil shale was used for fuel by the indigenous peoples of the Arctic. As early as 1853, during the Russian period, oil was reported on the west side of Cook Inlet in the vicinity of the Iniskin Peninsula and in 1882, a Russian named Paveloff took the first samples of oil. Early traders on the North Slope also reported seeps along the Arctic coast.

On the North Slope, the first geologic and topographic studies date back to 1901 and the first formal descriptions were recorded by the U.S. Geological Survey in 1919. By 1921, prospecting permits were filed, and in 1923 President Harding established by executive order the Naval Petroleum Reserve No. 4 (NPR-4), now known as the National Petroleum Reserve-Alaska (NPR-A). The Geological Survey conducted reconnaissance mapping 1923 through 1926 and published the results in 1930.

On the Arctic Slope, the first exploration phase of NPR-4 started in 1943 and ended in 1953. The United States Navy drilled 35 core test and exploration wells and found three oil accumulations and six gas accumulations within the reserve. Only one of these discoveries was considered sizable, Umiat, with an estimated 50 million barrels (8 million cubic meters) of recoverable oil.

Alaska was granted statehood in 1959 and began selecting lands as part of its statehood entitlement. Land selection was sometimes controversial and subject to delays for issue resolution with federal agencies. In 1964 Alaska was granted 1.5 million acres on the North Slope and immediately conducted its first lease sale. From 1964 through 1978, 123 exploration wells were drilled in the Arctic areas resulting in 22 oil discoveries. The next 25 years, 1979 through 2004, saw 263 exploration wells drilled and 31 oil discoveries documented. Through the end of 2004, 26 of 53 oil discoveries had begun development and production.

### **Current Known Recovery as of 12/31/2004**

The focus of this poster is on the developed reservoirs and fields on the Arctic Slope of Alaska. Fifty-three oil reservoir discoveries have been documented on the Arctic Slope since exploration drilling began in 1945. Through the end of 2004, 26 reservoirs in seven fields have begun development and are producing. The total resource under development from 26 discoveries is 44,000 million barrels (6,995 million cubic meters) oil in-place. Cumulative production from these reservoirs is 14,789 million barrels (2,351 million cubic meters) including natural gas liquids (494 million barrels, 79 million cubic meters), according to production data on file at the Alaska Oil & Gas Conservation Commission.

Ultimate recovery volumes were derived from public forecasts by the Alaska Department of Revenue<sup>1</sup> and Department of Natural Resources<sup>2</sup> - Division of Oil and Gas that are published on a periodic basis. Ultimate recovery is calculated by summation of Remaining Reserves and

Cumulative production at the end of each year. Latest ultimate recovery estimates from 26 developed reservoirs amounted to 20,790 million barrels of liquids (3,305 million cubic meters). In general, remaining reserves are based on projection of production history with additional increments added for known development projects. The latest definition of reserves is found in the Alaska Oil & Gas Report, May 2006 "...Remaining Reserves are oil or gas that are economic and technologically feasible to produce and are expected to produce revenue in the foreseeable future."<sup>3</sup> Details of the proved undeveloped and probable or possible reserve categories are not detailed in the forecasts. At year end 2004, Estimated Ultimate Recovery from the developed fields on the Arctic Slope totals 20,879 million barrels (3,319 million cubic meters) liquids.

### **Increased Known Recovery from 1980-2004**

#### **Additions to known reservoirs (Pre-1979)**

The Prudhoe Bay reservoir was the only producing Arctic Slope reservoir prior to 1979. At that time the Estimated Ultimate Recovery was 9,600 million barrels (1,526 million cubic meters) including waterflood secondary recovery. Initial development plans at Prudhoe anticipated development only to the 100 foot light oil column contour as being economic or practical. Subsequent development has virtually exploited the entire light oil column. Through improved recovery techniques, reduced well spacing, enhanced recovery projects, expanded development, extended gas cycling, and improved drilling methods; an additional 4,267 million barrels (678 million cubic meters) will be recovered for a total of 13,867 million barrels (2,205 million cubic meters) of oil and natural gas liquids.

#### **Development of Pre-1980 Discoveries**

Prior to 1980 – 15 reservoirs had been discovered on the Arctic Slope including Prudhoe Bay. The other 14 reservoirs account for 5,202 million barrels (827 million cubic meters) for a total of 19,069 million barrels (3,032 million cubic meters) liquids for pre-1980 discoveries.

#### **New Field Discoveries 1980-2004**

Eleven reservoirs in six fields were discovered in the last 25 years. Estimated ultimate recovery is 1,836 million barrels (292 million cubic meters).

### **Summary of Province Composition by Field Size and Growth**

#### **Current known Recovery – Cumulative and EUR – Super Giant, Giant, Sub Giant**

<u>Arctic Slope Field</u>	<u>Cumulative Production 2004, Millions bbls (m3)</u>	<u>Estimated Ultimate Recovery, 2004 Millions bbls (m3)</u>
Prudhoe Bay Field	11,827 (1,880)	15,273 (2,428)
Kuparuk River Field	2,074 (330)	3,616 (575)
Milne Point Field	220 (35)	529 (84)
Endicott Field	459 (73)	585 (93)
Colville River	138 (22)	675 (107)
Other	71 (11)	200 (32)
Totals	14,789 (2,351)	20,879 (3,319)

## **Viscous Oil Resource and Current Development**

Shallow, cold, “heavy” viscous oil was discovered between 1969-1971 in the Cretaceous Schrader Bluff Formation, Tertiary Sagavanirktok Formation – Ugnu sands, and the Schrader Bluff Formation – West Sak Sands. These accumulations occur in and around the Prudhoe Bay, Kuparuk River and Milne Point Units at depths between 3500-4000 feet, below perma-frost that is located at 2000 feet. Resource estimates range from 23 to 36 billion barrels in place in those field areas. Current development in the viscous oil sands is being conducted in the West Sak pool (Kuparuk River Field); Schrader Bluff pool (Milne Point Field), Orion and Polaris pools (both in Prudhoe Bay Field). Resource estimates range from 4700 million to 6500 million barrels of oil in place in the areas under active development. The current Estimated Ultimate Recovery ranges from 900-1000 million barrels based on information through 2004 which yields a recovery factor of 15-20%.

Various industry experts have discussed the technical and economic challenges of viscous oil development in the Arctic. Activity has been cyclic, co-incident with strategic interests and oil price swings. The companies have been “experimenting and evaluating” techniques to drive cost down, increase recovery and generally improve recovery factors. The effort to date could be characterized as large scale pilot tests.

Today the industry has evolved their drilling practices from vertical and slanted to horizontal, multilateral and potentially fishbone type wells. Sand production has been an issue with screens and liners to keep sand in place evolving to producing sand and handling it on the surface. Recovery techniques have involved waterflood and are evolving to miscible gas injection, hot water injection and potential CO<sub>2</sub> injection. Cumulative production through 2004 is 60 million barrels, only 1-1.5% of the in place resource.

Predicted recovery factors for the viscous projects have ranged for 10-15% primary, 20-25% with secondary and 2-6% incremental with enhanced recovery methods. Results of current evaluations and pilot tests will be important to future development and recovery of the viscous resource.

### **Additional Development/Investment necessary to produce current “booked” proved undeveloped Reserves in individual fields**

- Selective infill drilling to drain by-passed oil
- Reduced spacing or increased reservoir contact per well
- Miscible Gas Injection
- Innovative application of Miscible gas injection
- Potential CO<sub>2</sub> Injection
- Gas Cap Water Injection
- Accelerated production methods prior to gas blowdown
- Innovative Waterflood – Low Salinity
- Extension drilling around developed reservoirs
- Expanded Miscible Gas injection including CO<sub>2</sub>
- Horizontal, Multi-Lateral Drilling
- Oil Viscosity Reduction

## Summary of Key Characteristics of Largest fields by Major Reservoirs

A comprehensive table and charts will be included in the poster to document the following:

- Size, Year of Discovery, Location (Latitude, Depth, Onshore/Offshore, Water Depth)
- Volumetric: Area, Net Thickness, Porosity, Initial Water Saturation, FVF, OOIP
- Rock: Permeability, Continuity, Original Pressure, Drive Mechanism, Trap and Seal
- Fluid: API Gravity, % Sulfur, Viscosity
- Production: Initial Year, Peak Year, Amount in Peak Year, Cumulative
- Development: Spacing and Spacing History, # Wells, Well Type (Vertical or Horizontal), Post-Primary Recovery Methods, Current Recovery Factor
- Estimated Ultimate Recovery Growth for Arctic Slope Fields
- Estimated Ultimate Reserve Recovery Growth Charts for Reservoirs

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1. Alaska Department of Revenue Spring and Fall Forecast, <<http://www.tax.state.ak.us/sourcesbook/index.asp>>, accessed August-September, 2006.
  2. Alaska Department of Natural Resources - Division of Oil & Gas, Historical and Projected Oil and Gas Consumption January 1979 – May 1999, Alaska Oil & Gas Report December 2000-May 2006, <<http://www.dog.dnr.state.ak.us/oil/products/publications/annual/report.htm>>
  3. Alaska Department of Natural Resources - Division of Oil & Gas, Alaska Oil & Gas Report May 2006, page 3-1, <<http://www.dog.dnr.state.ak.us/oil/products/publications/annual/report.htm>>



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## Arctic Slope Alaska, Development Highlights

### Prudhoe Bay Field

**Recovery Growth, Cumulative Production, Remaining Reserves**

**Recovery Growth**

- 1982 Initial Drilling - 0.2 Billion Barrels
- Oil Handling Expansion increased recovery -
  - 1990 - OREX - 0.6 to 1.4 BCF (200) - 0.4 Billion Barrels
  - 1994 - OREX - 0.6 to 1.4 BCF (200) - 0.4 Billion Barrels
- Waterflood Recovery - 1.3 Billion Barrels
- 1987 On-Cycle and Compressional Recovery (includes NOLA & Mischelka Injection) - 1.3 Billion Barrels
- Waterflood Expansion - 0.5 Billion Barrels
- 1982-1992 Water Alternating Miscible Gas Injection - 0.6 Billion Barrels
- 2002 Gas Cap Water Injection (650 MMWP Injection) - 0.2 Billion Barrels
- Possible Increased Gas Cap Water Injection in the future
- Operational Applications - MBT, Uplift MVAQ and Gravity Drainage area - 0.1 Billion Barrels

**Prudhoe Satellite Development**

- Ownership Redesign of Gas Rim and Oil Rim interests completed 2000
- Facilities during agreements allow development of Satellite Reservoirs
- Satellites add low EUR and low water cut wells - "best player play" in competition for gas in facilities
- Facility access for direct cost of recovery
- Five Western Satellites - 0.5 billion barrels EUR (Schneider Bluff, Tabasco, West Sak, Meliwater, and Tam)
- Midland Sun, Aurora, Barabara, Polaris and Orion
- Schneider Bluff Viscous Oil
- Delaware Technology Improvements
  - 2000 - Tri-Lateral, 2004 - Quadri-Lateral, 2005 - Tri-Lateral
  - 2006 - Four Source Water Flooding
  - Lean Oil Recovery
  - MVAQ planned
- Likewise Production Center - add 10 Billion Barrels - Ft. McHenry, Tidal, West Sak and North Prudhoe Pools
- Waterflood
- Gas Injection
- MVAQ Projects

**Prudhoe Oil Pool**

- Largest Oil Reservoir in North America
- 2007 Recovery started the North Slope Oil Boom
- CO2P - 23 Billion Barrels
- Initial Recovery circa 1977 - 9.6 Billion Barrels with Waterflood
  - Primary - Gravity Drainage, Gas Expansion - 1.6 Billion Barrels
  - Waterflood - 1.3 Billion
  - On-Cycle - 1.0 Billion
- 1977 Initial Development estimated 500 wells -
  - No development beyond 100' light oil column
  - Comprehensive Pressure, GOC, OWC and Fluid-Surface-volume programs have added optimization of Recovery
  - Top Fluid-Ratios of Production facilities by Tracking Interest Owners
- 2004 - 1300 production wells in area 200+ acre recovery -
  - Bores oil columns within 40' to 40' are in some areas
  - Bores and Gas Taking Drilling, three existing well have length tapered off

### Kuparuk River Field

**Recovery Growth, Cumulative Production, Remaining Reserves**

**Recovery Growth**

- Second largest reservoir in the US and Alaska - 5.1 billion barrels in place
- Differential initial development with early waterflood - 1982
- Primary Recovery - 4.6 Billion Barrels
- Waterflood Recovery - 1.3 Billion Barrels
- 1988 - Miscible Water Alternating Gas (MVAQ) Injection - 8700 acres - COEP 500 Million Barrels
- EUR Pool Barabara Water Alternating Gas (WVAG) (0.01 pad) - 70 Million Barrels
- 1995 - Large Scale EUR - expanded MVAQ at 18700 AC drilled - 50000 acres - COEP 2.9 Billion Barrels
- August 100 million barrel NOLA (1.0 MCF acre-ft)
- 200 million barrels EUR (1 barrel = 6 MCF Miscible Injection)
- Initial drilling and infill development expanded recovery area
- Intended reach drilling
- Collaborative drilling and well work applications
- Miscible Water Alternating Gas Injection 1985 for EUR and gas storage
- Extensive well volume program for pressure, production profiles and well rate tests added optimization of development
- EUR Pool and expanded reservoir will recover nearly 2,900 million barrels

**Wear Sak Pool**

- Resource list - 16 billion barrels in place direct pilot viscous oil development in 1983 including waterflood
- Field development - Conventional vertical wells - featured to improve productivity - waterflood to improve recovery
- Field abandoned in 1986 as uneconomic
- Development estimated at 2 billion barrels in 1997 including waterflood
  - 500 million barrels in place where earlier development
  - Standard project MVAQ Injection started in 2003
  - Expanded development results of pilot area - added 1500 million barrels in place
  - Horizontal drilling and well work help drive development out and improve well rates from 200-300 to 1800-2000 barrels per day
  - Upper basin drilling operations through North Slope viscous oil development in pushing technology ahead
  - EUR, about 500+ million barrels of the current resource under development

**Tam, Tabasco, Meliwater Pools**

- Operational developments within or near large infrastructure
- 400 million barrels of EUR recovery
- EUR about 100 million barrels

### Colville River Field

**Recovery Growth, Cumulative Production, Remaining Reserves**

**Recovery Growth**

- First major stratigraphic reservoir development
- Initial Development estimated mostly vertical or slanted wells
- Development plan was abandoned for horizontal wells prior to startup
- Initial observations well to monitor early depletion
- Enhanced recovery Water Alternating Gas Injection began at startup
- Reservoir has unanticipated design specifications - 40-45% to 60% recovery
- Excellent Mobility Ratio - 5, after waterflood could be as low as 34-40%
- Field's recovery increased from 8000 bopd to 135,000 bopd by deconsolidating and remodeling
- Alpine EUR has grown to 100 million to 400 million barrels

**Satellite Reservoirs**

- Reservoirs expansion will feed into the infrastructure - 5 additional reservoirs discovered and in development added
- 100-200 million barrels of oil in place
- Satellite EUR expected 5-20 million barrels
- Recovery other discoveries are being evaluated

### Endicott Field (Duck Island Unit)

**Recovery Growth, Cumulative Production, Remaining Reserves**

**Recovery Growth**

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- Initial Development estimated mostly vertical or slanted wells
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### Milne Point Field

**Recovery Growth, Cumulative Production, Remaining Reserves**

**Recovery Growth**

- Second largest reservoir in the US and Alaska - 5.1 billion barrels in place
- Differential initial development with early waterflood - 1982
- Primary Recovery - 4.6 Billion Barrels
- Waterflood Recovery - 1.3 Billion Barrels
- 1988 - Miscible Water Alternating Gas (MVAQ) Injection - 8700 acres - COEP 500 Million Barrels
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  - Upper basin drilling operations through North Slope viscous oil development in pushing technology ahead
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- EUR about 100 million barrels

### Arctic Slope, Alaska Summary of Current Province Size and Recent Growth

Field	Reservoir	Discovery Year	EUR Discovered & Developed	EUR Added & Developed	EUR Built	EUR Remaining	12/31/2006	12/31/2007	12/31/2008		
Prudhoe Bay Field	Orion	1987	-	-	-	-	209	2	2		
	Polaris	1989	-	-	209	48	4	4	4		
	Aurora	1989	-	-	63	11	11	11	11		
	Barabara	1989	-	-	154	114	31	31	31		
	Midnight Sun	1987	-	-	117	11	11	11	11		
	Niukuk	1985	-	-	28	117	81	81	81		
	Pi Meliwater	1989	-	-	563	563	384	376	376		
	W Beach	1987	-	-	3	2	2	2	2		
	Prudhoe	1967	8,800	4,287	9	13,887	11,144	10,689	10,689		
	No Prudhoe	1976	-	-	3	2	2	2	2		
Kuparuk River Field	West Sak	1987	-	-	541	541	16	16	16		
	Tabasco	1998	-	-	23	23	10	10	10		
	Meliwater	2000	-	-	44	44	8	8	8		
	Tam	1991	-	-	126	126	65	65	65		
	Kuparuk	1982	-	-	2,881	2,881	1,876	1,876	1,876		
Colville River	Nanuk	1992	-	-	69	69	0	0	0		
	Fjord - Kuparuk	1992	-	-	48	48	0	0	0		
	Nanuk - Kuparuk	2000	-	-	28	28	0	0	0		
	Alpine	1994	-	-	485	485	138	138	138		
	Fjord - Nechika	1992	-	-	65	65	0	0	0		
Endicott Field	Sig Delta North	1978	-	-	8	8	8	8	8		
	Elder	1989	-	-	5	5	3	3	3		
	Endicott	1978	-	-	572	572	448	448	448		
Milne Point Field	Schneider Bluff	1989	-	-	117	117	38	38	38		
	Kuparuk	1989	-	-	405	405	180	180	180		
	Sig River	1989	-	-	8	8	2	2	2		
North Star Field	NorthStar	1984	-	-	196	196	87	87	87		
	Badami	1990	-	-	4	4	4	4	4		
Badami Field	Badami	1990	-	-	8,800	4,287	5,210	1,902	20,879	14,789	14,295
	Alaska's total accumulated OI	Fields are modest in number but have had a large impact on energy supplies in North America. Arctic Slope exploration began in the 1940's did not yield significant results until discovery of the Prudhoe Oil field in 1967. The subsequent development of Prudhoe brought an influx of new technology for Arctic Regions and spurred a relatively aggressive exploration effort over the next decade. Beyond Prudhoe, Arctic Slope recovery growth more than doubled in the 25 years since production started. The Prudhoe, Kuparuk, Endicott and Milne Point discoveries provided a foundation for offset exploration and development of smaller but promising reservoirs. The western push in the early 1990's led to the Giant Alpine discovery. Exploration potential remains high in the NPR-A and ANWR regions of Alaska as well as known shallow viscous resources within the Central North Slope.									

### Arctic Slope, Alaska - Key Reservoir Characteristics

Field/Reservoir	Location	Volume	Rock Properties	Fluid Properties	Development														
Prudhoe Bay Unit	Orion	1987	1070-1100	1438	150,000	1950	Solution Gas	Stratigraphic	15.23	1.2	5.0	2004	2002	1,844	2	200	15%	Prudhoe Bay Unit	
	Polaris	1989	1170-1180	154	10,900	2250	Solution Gas	Stratigraphic	10.24	5.0	1900	2004	1,905	4	48	9%	Polaris		
	Aurora	1989	1170-1180	154	10,900	2250	Solution Gas	Stratigraphic	10.24	5.0	1900	2004	1,905	4	48	9%	Aurora		
	Barabara	1989	1170-1180	154	10,900	2250	Solution Gas	Stratigraphic	10.24	5.0	1900	2004	1,905	4	48	9%	Barabara		
	Midnight Sun	1987	1170-1180	154	10,900	2250	Solution Gas	Stratigraphic	10.24	5.0	1900	2004	1,905	4	48	9%	Midnight Sun		
	Niukuk	1985	1170-1180	154	10,900	2250	Solution Gas	Stratigraphic	10.24	5.0	1900	2004	1,905	4	48	9%	Niukuk		
	Pi Meliwater	1989	1170-1180	154	10,900	2250	Solution Gas	Stratigraphic	10.24	5.0	1900	2004	1,905	4	48	9%	Pi Meliwater		
	W Beach	1987	1170-1180	154	10,900	2250	Solution Gas	Stratigraphic	10.24	5.0	1900	2004	1,905	4	48	9%	W Beach		
	Prudhoe	1967	1170-1180	154	10,900	2250	Solution Gas	Stratigraphic	10.24	5.0	1900	2004	1,905	4	48	9%	Prudhoe		
	No Prudhoe	1976	1170-1180	154	10,900	2250	Solution Gas	Stratigraphic	10.24	5.0	1900	2004	1,905	4	48	9%	No Prudhoe		
Kuparuk River Unit	West Sak	1987	1070-1100	1438	150,000	1950	Solution Gas	Stratigraphic	15.23	1.8	4.8	1987	2004	4,281	16	10	40	23%	Kuparuk River Unit
	Tabasco	1998	1070-1100	1438	150,000	1950	Solution Gas	Stratigraphic	15.23	1.8	4.8	1987	2004	4,281	16	10	40	23%	Tabasco
	Meliwater	2000	1070-1100	1438	150,000	1950	Solution Gas	Stratigraphic	15.23	1.8	4.8	1987	2004	4,281	16	10	40	23%	Meliwater
	Tam	1991	1070-1100	1438	150,000	1950	Solution Gas	Stratigraphic	15.23	1.8	4.8	1987	2004	4,281	16	10	40	23%	Tam
	Kuparuk	1982	1070-1100	1438	150,000	1950	Solution Gas	Stratigraphic	15.23	1.8	4.8	1987	2004	4,281	16	10	40	23%	Kuparuk
Colville River Unit	Nanuk	1992	1070-1100	1438	150,000	1950	Solution Gas	Stratigraphic	15.23	1.8	4.8	1987	2004	4,281	16	10	40	23%	Colville River Unit
	Fjord - Kuparuk	1992	1070-1100	1438	150,000	1950	Solution Gas	Stratigraphic	15.23	1.8	4.8	1987	2004	4,281	16	10	40	23%	Fjord - Kuparuk
	Nanuk - Kuparuk	2000	1070-1100	1438	150,000	1950	Solution Gas	Stratigraphic	15.23	1.8	4.8	1987	2004	4,281	16	10	40	23%	Nanuk - Kuparuk
	Alpine	1994	1070-1100	1438	150,000	1950	Solution Gas	Stratigraphic	15.23	1.8	4.8	1987	2004	4,281	16	10	40	23%	Alpine
	Fjord - Nechika	1992	1070-1100	1438	150,000	1950	Solution Gas	Stratigraphic	15.23	1.8	4.8	1987	2004	4,281	16	10	40	23%	Fjord - Nechika
Endicott Unit	Sig Delta North	1978	1070-1100	1438	150,000	1950	Solution Gas	Stratigraphic	15.23	1.8	4.8	1987	2004	4,281	16	10	40	23%	Endicott Unit
	Elder	1989	1070-1100	1438	150,000	1950	Solution Gas	Stratigraphic	15.23	1.8	4.8	1987	2004	4,281	16	10	40	23%	Elder
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North Star Unit	NorthStar	1984	1070-1100	1438	150,000	1950	Solution Gas	Stratigraphic	15.23	1.8	4.8	1987	2004	4,281	16	10	40	23%	North Star Unit
	Badami	1990	1070-1100	1438	150,000	1950	Solution Gas	Stratigraphic	15.23	1.8	4.8	1987	2004	4,281	16	10	40	23%	Badami

### Arctic Slope, Alaska - Key Reservoir Characteristics (Continued)

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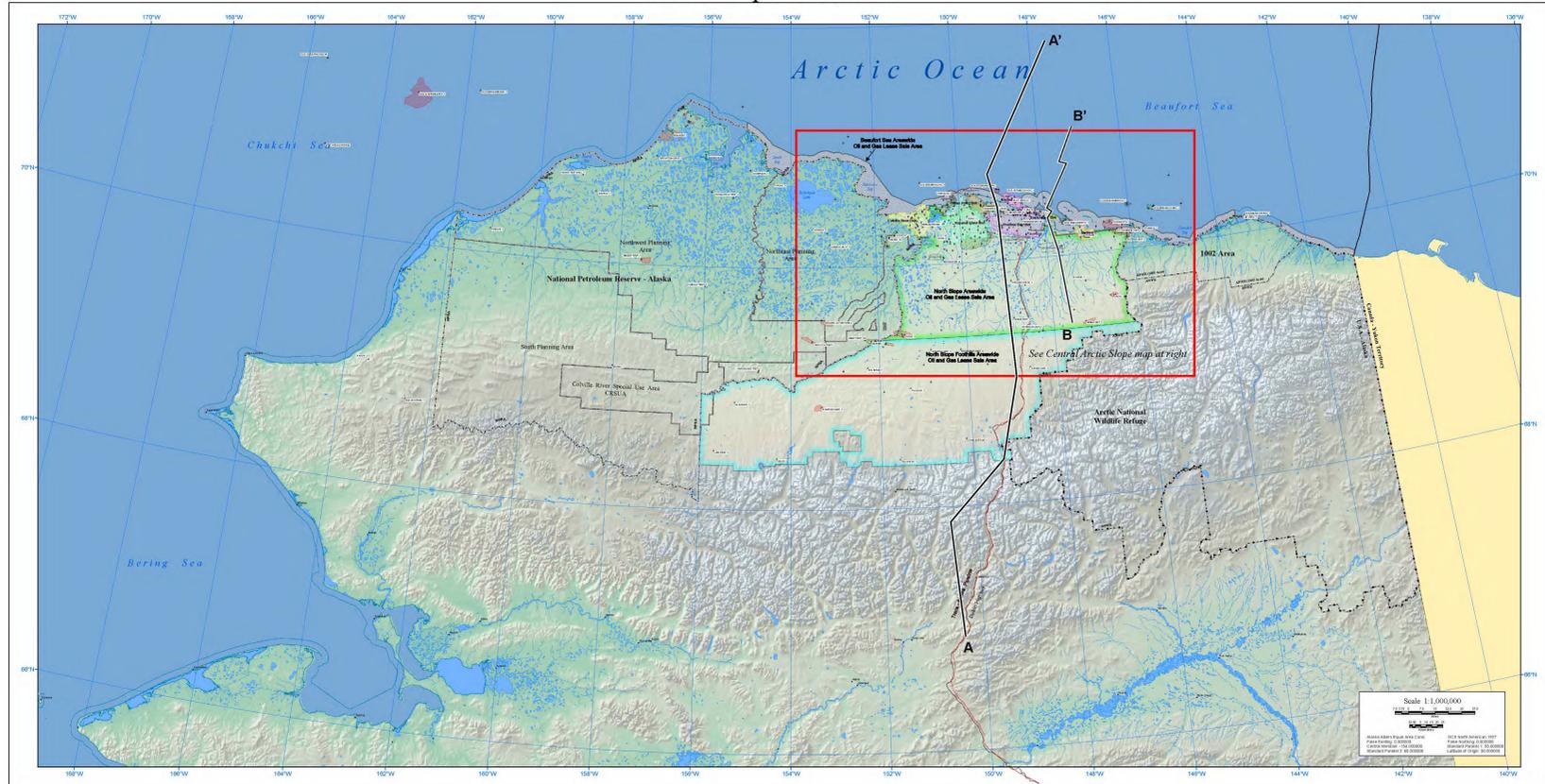


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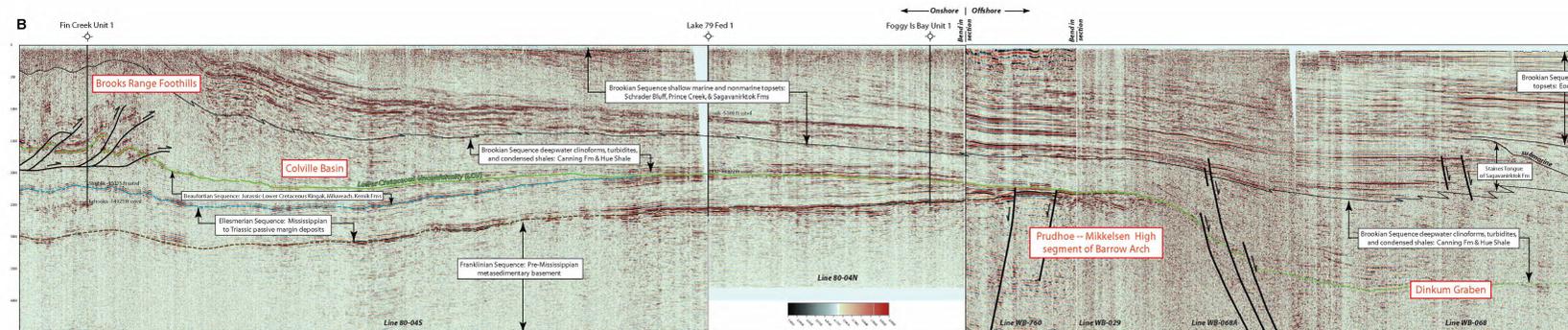
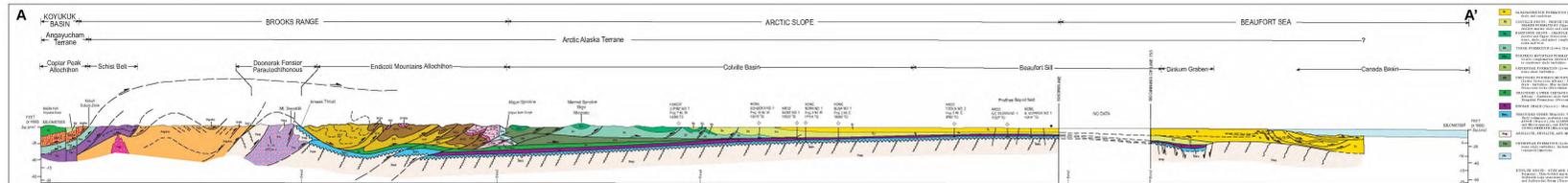
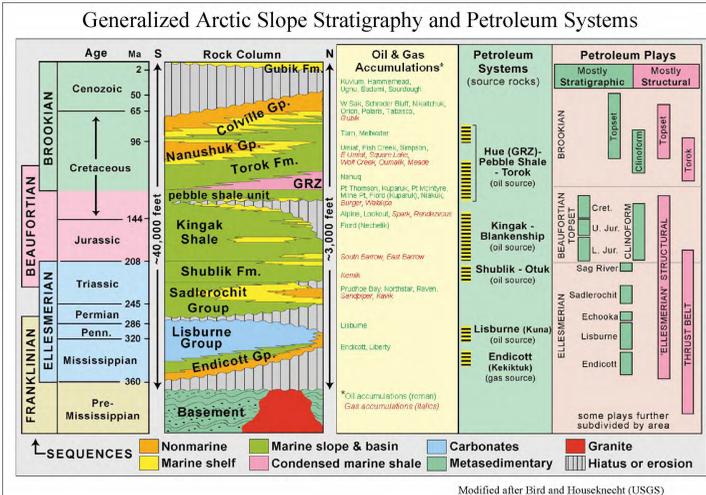
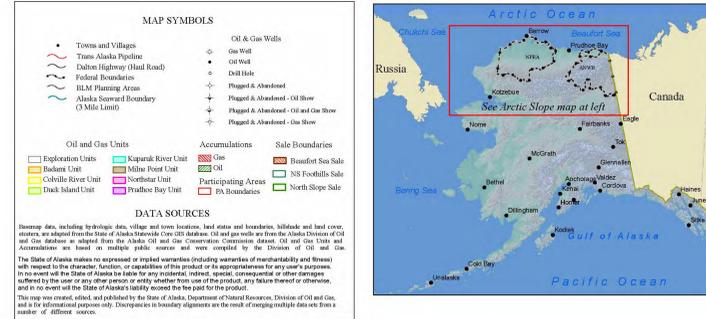
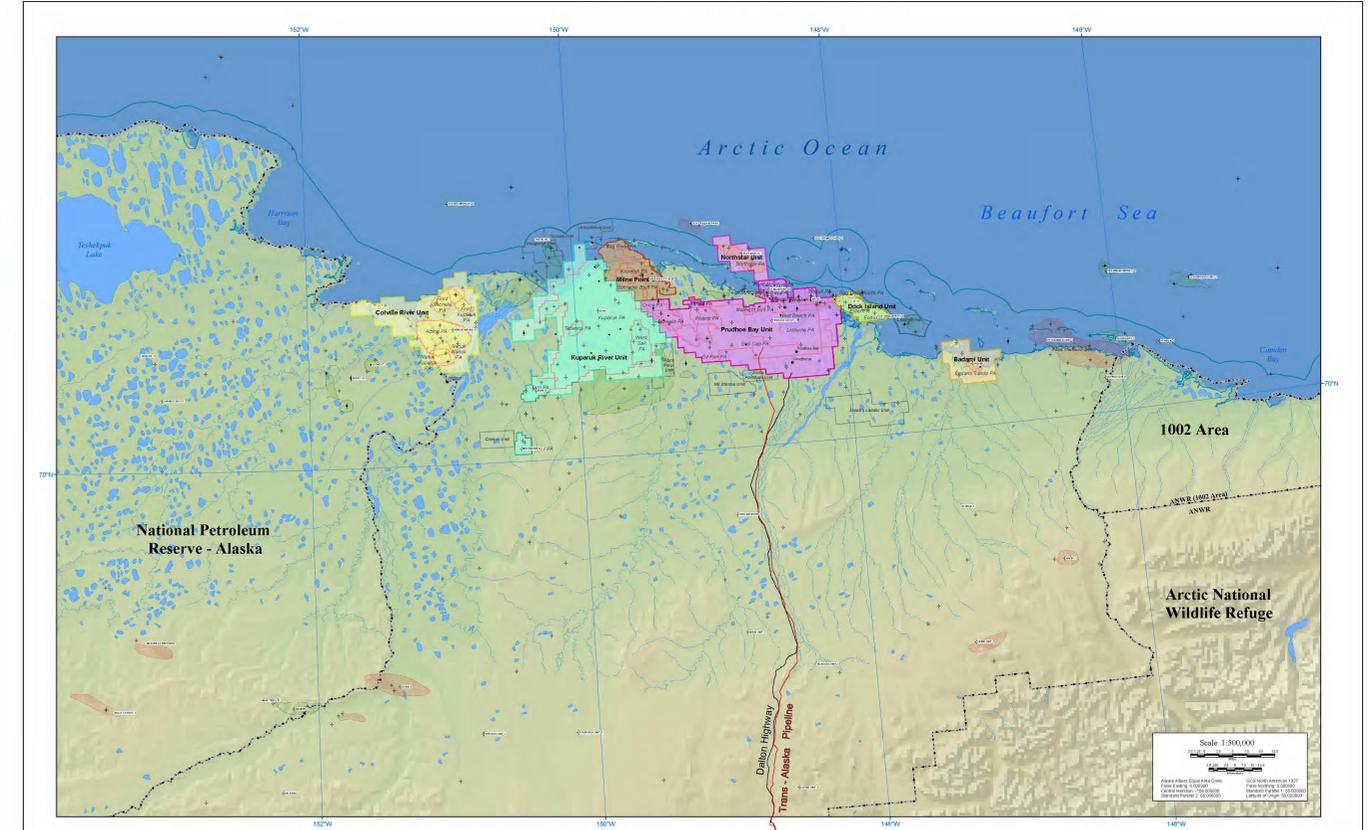
Jack Hartz, Reservoir Engineer, Paul Decker, Petroleum Geologist, and Julie Houle, Section Chief - Resource Evaluation, Alaska Department of Natural Resources, Division of Oil and Gas  
Robert Swenson, State Geologist, Alaska Department of Natural Resources, Division of Geological & Geophysical Surveys



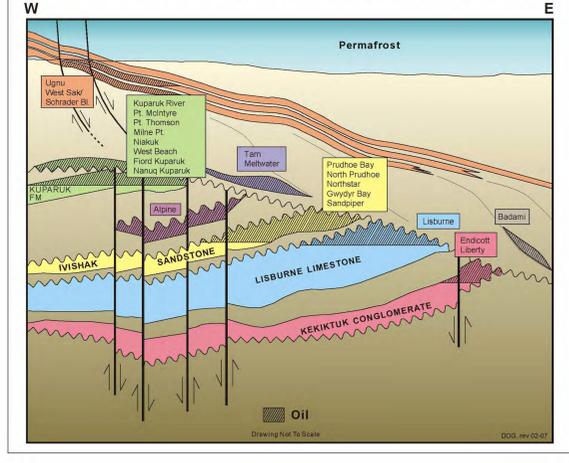
## Arctic Slope of Alaska



## Central Arctic Slope of Alaska



## Generalized Cross Section of Central Arctic Slope Fields



## Play Distribution of North Alaskan Oil and Gas Accumulations

