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**EXPLORATION HISTORY (1964–2000) OF THE COLVILLE HIGH,
NORTH SLOPE, ALASKA**

by

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EXPLORATION HISTORY (1964–2000) OF THE COLVILLE HIGH, NORTH SLOPE, ALASKA

by

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Abstract

The Colville High is a very large, onshore structure adjacent to the Beaufort Sea on the central North Slope of Alaska. It has more than 500,000 acres of closure at key stratigraphic levels. Since the first wildcat exploration well in 1965, at least 14 oil accumulations have been discovered on the Colville High with combined oil-in-place estimated to exceed 30 billion barrels. The commercial fields contained original reserves totaling at least 3 billion barrels. The largest of these is the Kuparuk River field with two stratigraphic reservoir components (Upper and Lower Kuparuk Formation) that total about 2 billion barrels of ultimate reserves. Eight of the oil accumulations were discovered between 1985 and 1996 on the western part of the Colville High, where more than \$37.5 million of bonus bids were spent in lease sales and at least 290,000 feet of exploration drilling took place since 1982. This compilation of lease sale outcomes, exploration drilling, exploration experiences, and exploration results for the Colville High during the period 1965 to 2000, defines an interesting and complex interplay of technical analysis and advances, business strategies, internal company challenges, and serendipity that ultimately led to the discovery of at least 539 million barrels of new reserves in the 1990s.

Three play concepts have been the foundation of the post-1982 success: (1) stratigraphically trapped mid and Late Cretaceous (Brookian) turbidites, (2) normal-fault controlled, Hauterivian (Beaufortian) sand deposits on the regional Lower Cretaceous Unconformity (LCU), and (3) large Upper Jurassic and Lower Cretaceous (Beaufortian) mudstone-encased shelf sand systems. These two stratigraphic plays and one combination structure/stratigraphic play are important to assessing the exploration potential of other North Slope areas extending along the Barrow Arch and its flanks west from the Colville High across the National Petroleum Reserve–Alaska.

The technical advances that were important to exploration success included (1) recognition that Upper Kuparuk Formation potential existed west of the Kuparuk River field (Fiord and Kalubik discoveries), (2) recognition that seismic amplitudes were important to understanding oil-charged sandstone distribution in the Upper Jurassic Kingak Shale, (3) depositional system analysis that explained how large shelf sand systems could be developed and predicted, and (4) use of three-dimensional (3D) seismic data as a predrill exploration tool.

Exploration and business strategies that became important to success were: (1) the common location of wildcats to test multiple (stacked) prospects, (2) systematic development of a dominating land position over the entire western Colville High, and (3) low-level but persevering participation in all possible exploration opportunities. Explorationists were able to overcome internal company hurdles in some cases but not in others.

INTRODUCTION

The Colville High is a very large, onshore structure adjacent to the Beaufort Sea on the central North Slope of Alaska (fig. 1). It and the adjacent Prudhoe Bay structure to the east were identified in the very first seismic data acquired along the Beaufort Sea coast in 1963 (Masterson and Eggert, 1992, p. 258). Since the first wildcat exploration well in 1965 (Sinclair Colville 1), at least 14 oil accumulations have been discovered on the Colville High, with seven currently in production (table 1). The seven producing oil fields have about 3 billion barrels of ultimate reserves. The largest of these is the Kuparuk River field with two stratigraphic reservoir components (Upper and Lower Kuparuk Formation) that total about 2 billion barrels of ultimate reserves. The geology of the Kuparuk River field has been presented by Carman and Hardwick (1983), Gaynor and Scheihing (1988), and Masterson and Eggert (1992). Information and data from the Kuparuk River field are used here where they help to

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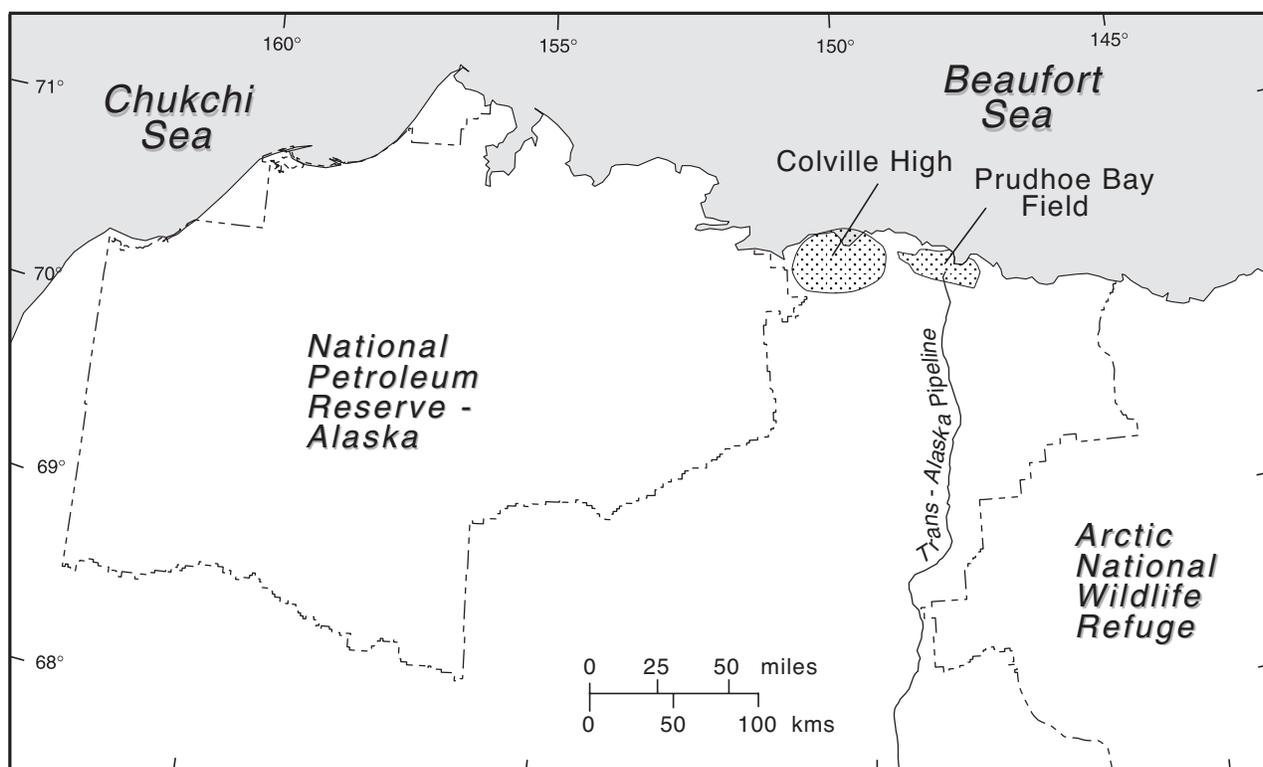


Figure 1. Map showing location of the Colville High, North Slope, Alaska.

Table 1. Selected data for known oil accumulations on the Colville High

Name	Production	Reservoir Age and Stratigraphic Setting	Oil Gravity (degrees API)	Oil-in-place (billion STB)	Ultimate Reserves (million STB)
Ugnu	N	Maestrichtian–Paleocene; Brookian shelf sand	8–12	11–19	na
West Sak	Y	Maestrichtian; Brookian shelf sand	16–22	15–25	>400
Tabasco	Y	Late Cretaceous; Brookian shelf sand	16.5	>1	>30
Moraine	N	Albian; Brookian turbidite	?	?	na
Tarn	Y	Late Cretaceous; Brookian turbidite	37	0.15	>50
Meltwater *	Y	Late Cretaceous; Brookian turbidite	37	0.15	>50
Nanuq	Y	Albian; Brookian turbidite	39–42	84–169	22–69
Kuparuk River	Y	Hauterivian–Barremian; Transgressive/lag sand on LCU	20–27	>2	~1000
Kalubik	N	Hauterivian–Barremian; Transgressive/lag sand on LCU	26	?	?
Kuukpik	N	Hauterivian–Barremian; Transgressive/lag sand on LCU	?	?	?
Fiord	Y	Hauterivian–Barremian; Transgressive/lag sand on LCU	32	0.15	50
Kuparuk River	Y	Berriasian–Valanginian; Beaufortian shelf sand	20–27	>2	~1000
Alpine	Y	Late Jurassic; Beaufortian shelf sand	40	>1	439
Nuiqsut	N	Late Jurassic; Beaufortian shelf sand	25	>2	na
Nechelik	N	Late Jurassic; Beaufortian shelf sand	29	>2	?
				>10	>3019

* Meltwater is off structure, south of the Colville High.

understand other oil accumulations but, in general, oil accumulations within the Kuparuk River unit (Ugnu, West Sak, Tabasco, and Upper and Lower Kuparuk River pools, table 1) are not the focus of this report. The early history of Colville High exploration, including discovery and delineation of the Kuparuk River field, is expertly summarized by Masterson and Eggert (1992).

Three commercial fields, with combined reserves of at least 539 mmbbls, were discovered in the 1990s and are among the North Slope's newest producing fields (Alpine, Fiord, and Tarn, table 1). They are in a group of eight oil accumulations discovered between 1985 and 1996 on the western part of the Colville High. This report investigates the exploration history of the Colville High to better understand the foundations of exploration success in the 1990s and to identify the successful play concepts that are important to assessing the National Petroleum Reserve–Alaska (NPRa) hydrocarbon potential. The information compiled for this analysis includes lease sale results, exploration drilling history, exploration experiences as ascertained from personal interviews, and exploration results that characterize the key western Colville High discoveries. Two stratigraphic plays and one combination structure/stratigraphic play have been successfully pursued on the Colville High.

The western Colville High is adjacent to NPRa (fig. 1) and at least one of the commercial discoveries, the Alpine field (table 1), appears to extend into NPRa. This discovery, and other stratigraphic plays that have been successfully pursued on the Colville High, have important implications for the petroleum potential of the NPRa (e.g., Montgomery, 1998). This potential has been recognized by Colville High explorationists as they moved westward, acquired new seismic data, and aggressively pursued prospect acreage in the Federal NPRa lease sale held in May 1999. Six highly valued prospect areas were acquired by various parties at this sale for an average high bonus bid of \$121 per acre and a total high bonus bid amount of \$104,635,728, the third highest total in State history (see below). Phillips and Anadarko Petroleum companies announced in May 2001 that six of their first seven exploration wells (including one sidetrack) in the NPRa were successful.

PETROLEUM GEOLOGY SETTING

The Colville High is a basement-cored structural culmination on the Barrow Arch, an elongate and complex regional basement high that generally marks the southern limit of the larger Jurassic and Cretaceous extensional features of the Beaufort Sea. The Colville High is a very large, subequant structure that is well defined by closure at the stratigraphic level of the Lower Cretaceous Unconformity (LCU), a regional unconformity interpreted to have developed as a consequence of breakup and sea-floor spreading that accompanied opening of the Arctic Ocean. Increasing availability of seismic data and well control over the years has enabled continued refinement of structural details on the Colville High but the basic character was defined with the very first seismic data (fig. 2). The structure has about 800 square miles or 500,000 acres of closure at the LCU stratigraphic level.

The stratigraphy of the Colville High includes components of three regional assemblages (Lerand, 1973; Hubbard and others, 1987): (1) Upper Devonian (?) to Triassic shelf carbonate and clastic systems deposited southward from emergent uplands to the north before opening of the Arctic Ocean (Ellesmerian sequence, fig. 3), (2) Jurassic and Cretaceous shelf clastic systems including transgressive and lag sandstone and overlying shale deposited during breakup and opening of the Arctic Ocean (Beaufortian sequence, fig. 3), and (3) Albian to Tertiary shelf, slope, and basin clastic systems that prograded north and east from the fold and thrust belts of the Brooks Range (Brookian sequence, fig. 3). Although Paleozoic and Triassic reservoir facies, so important at Prudhoe Bay, are present on the Colville High, they have been determined to be wet or contain only small, local oil accumulations (see below). The important reservoirs on the Colville High are Jurassic and Cretaceous sandstones of the Beaufortian and Brookian sequences.

Four of the Colville High oil accumulations are in Upper Jurassic and Early Cretaceous shelf sandstone within the upper Kingak Shale and Miluveach Formation (Nechelik, Nuiqsut, Alpine, and Lower Kuparuk River, fig. 3 and table 1), four are in Hauterivian transgressive/lag sandstone of the Upper Kuparuk Formation (Fiord, Kuukpik, Kalubik, and Upper Kuparuk River, fig. 3 and table 1), three are in Albian and Upper Cretaceous turbidite sandstone of the Torok and Seabee Formations (Moraine, Tarn, and Nanuk/Nanuq, table 1), and three are in Upper Cretaceous and Tertiary shelf sandstone of the Schrader Bluff and Sagavanirktok Formations (Ugnu, West Sak, and Tabasco, table 1). Oil-bearing sandstone on the Colville High varies from small, isolated occurrences with specific local controls to large and complex systems, but none are extensive enough to cover the entire Colville High. Therefore, all the oil accumulations are in traps that have strong stratigraphic components; sandstone gradation to siltstone and mudstone is especially important and in some accumulations entirely sufficient to trap oil.

The shallowest accumulations are very near the surface, in places affected by permafrost, and biodegraded. Until discovery of the Fiord accumulation in 1992, the typical oil on the Colville High was like that produced in the Kuparuk River field; API (American Petroleum Institute) gravity ranges from 20 to 27 degrees and averages 24

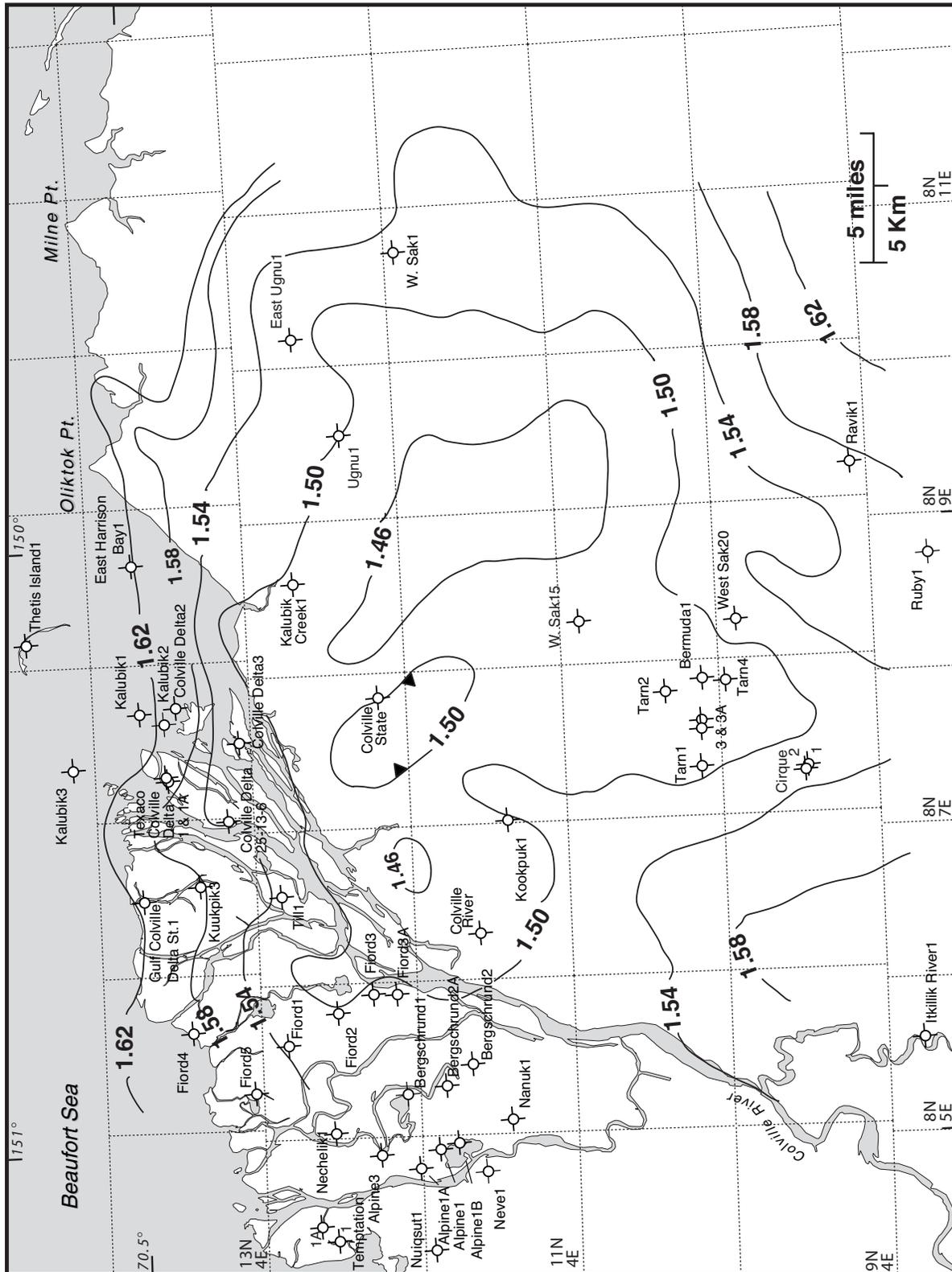


Figure 2. Early seismic structure map of the Colville High made by British Petroleum geophysicist J.S. Buchanan in 1965. Map is for the "M7" horizon, a reflector near the Lower Cretaceous Unconformity (LCU). Adapted from figure 2 of Masterson and Eggert, 1992.

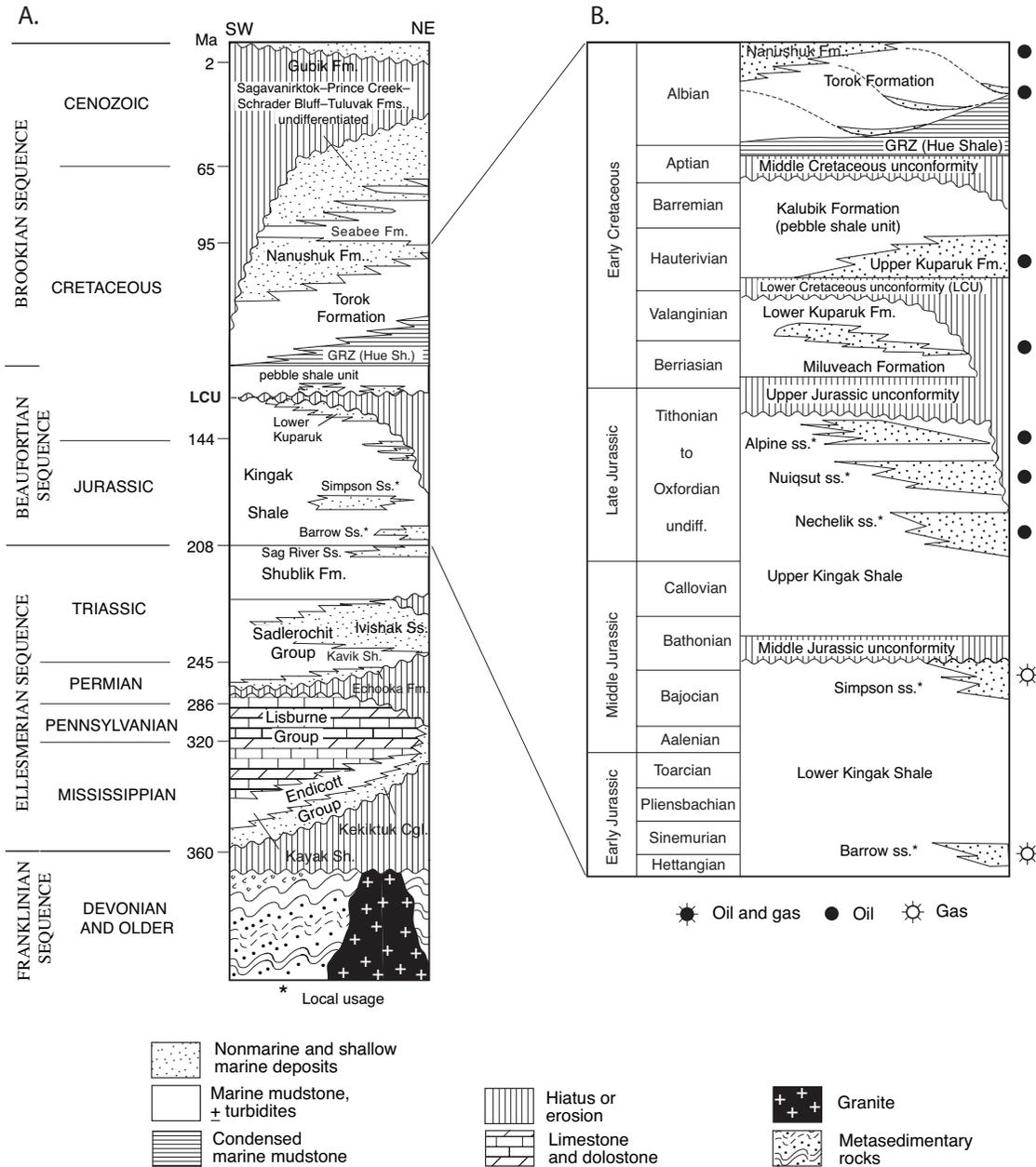


Figure 3. Generalized stratigraphic column for northern Alaska and detailed stratigraphic column showing Jurassic and Lower Cretaceous oil-bearing sandstones present in the Colville High area. Modified from figures 4 and 8 of Kornbrath and others, 1997.

degrees and initial gas-to-oil ratio (GOR) ranges from 350 to 575 standard cubic feet/stock tank barrel (SCF/STB) (Masterson and Eggert, 1992). Fiord contains the first high gravity oil discovered on the Colville High; it has an API gravity of 32 degrees and a GOR of 500 SCF/STB. Since this discovery, at least two other high gravity oil accumulations have been discovered on the Colville High: Alpine and Tarn (table 1). Another high gravity oil accumulation, Meltwater, has been discovered but it is in the southern Tarn trend and off-structure to the south of the Colville High (Petroleum News–Alaska, 2000). The Alpine oil has an API gravity of 40 degrees and a GOR of 850 SCF/STB at reservoir conditions (Alaska Oil and Gas Conservation Commission, 1999).

Rocks of the Colville High are within both the Ellesmerian and Torok–Nanushuk petroleum systems of Magoon (1994). The Ellesmerian petroleum system includes two source rock intervals with dominantly type II kerogen: the Triassic Shublik Formation and the Jurassic Kingak Shale. In the Torok–Nanushuk petroleum system, source rocks are mostly from the Cretaceous Torok Formation where type III kerogen dominates. The mid Cretaceous Hue Shale or Gamma Ray Zone (GRZ; fig. 3) may be a source interval that contributes some to both of these petroleum systems (Bird, 1994; Magoon, 1994). Source rocks in both petroleum systems began generating hydrocarbons as a result of deep burial in the Cretaceous and Tertiary Colville basin south of the Barrow Arch. The Ellesmerian source rocks were in the gas generation phase by the end of the Cretaceous; generation and migration in both petroleum systems was completed in the Paleogene (Bird, 1994; Magoon, 1994; Magoon and others, 2003).

LEASE SALE HISTORY

Alaska received surface and mineral rights to the Colville High in the 1959 Alaska Statehood Act. Subsequent lease sales have been by the high bonus bid method. In the 1980s and 1990s, minimum bid levels were \$5 or \$10 per acre for 10-year leases with escalating annual rental fees and retained royalty interest rates of 1/6 or 1/8. Bid levels of several times minimum generally indicate significant exploration interest and high bid levels of 10 or more times minimum indicate significant confidence in prospect or other lease value.

THE FIRST LEASE SALE—1964

The first competitive lease sale in the area of the Colville High was State Sale 13 held on December 9, 1964. Most of the Colville High was leased at this time and a 50:50 partnership of Sinclair and British Petroleum (BP) obtained the majority (88,000 acres) of the available acreage (Masterson and Eggert, 1992, fig. 2). Subsequent mergers between Atlantic Refining and Richfield (1966) and Atlantic Richfield and Sinclair (1969) effectively established BP and ARCO as the principal leaseholders on the Colville High. Because the leased area had not yet been conveyed from the Federal government to Alaska, these original leases had a conditional, non-expiring status. A large part of the original lease holdings became part of the Kuparuk River Unit in 1981. BP and ARCO held their original western Colville High leases without obligation until the 1990s when these companies reached a drill-or-release agreement with Alaska. As a result, the lands available for lease after 1964 were largely areas in the westernmost Colville High, along the Colville River and in the Colville River delta, or areas contracted out of the Kuparuk River Unit as this large field was developed.

LEASE SALES—1983 TO 1998

Renewed interest in the Colville High surfaced in State Sale 39 (1983) when a group including Texaco, Placid, Diamond Shamrock, and Amerada Hess (the original “Texaco Group”) acquired a few low-cost leases in the Colville River delta area. These leases were over a deep structural prospect that was tested by Texaco Colville Delta 1 in 1985. Union Texas Petroleum (UTP) joined this group in 1984. Between 1984 and 1998 there were 14 lease sales that included areas on or adjacent to the Colville High. During this time, a total of \$37.5 million of high bonus bids were spent to lease 410,500 acres (fig. 4). The lease sale results show significant expenditures in the mid 1980s by a partnership of Amerada Hess (AH) and Union Texas Petroleum (UTP) with or without others; in the early 1990s by ARCO Alaska Inc. (AAI); and in the late 1990s by a partnership of AAI, UTP, and Anadarko Petroleum (APC).

AH and UTP Colville River delta prospects (1984–1988)

During this period, AH and UTP (in cases including various Hunt family interests) acquired 52,268 acres for a total high bonus bid of \$9,056,179 or an average high bonus bid of \$173 per acre. The leased area was on the northwest flank of the Colville High in the Colville River delta area (fig. 2). The Texaco Group went to State Sale 54 (January 26, 1988) with proprietary information from five wells (including one sidetrack) drilled in the north-

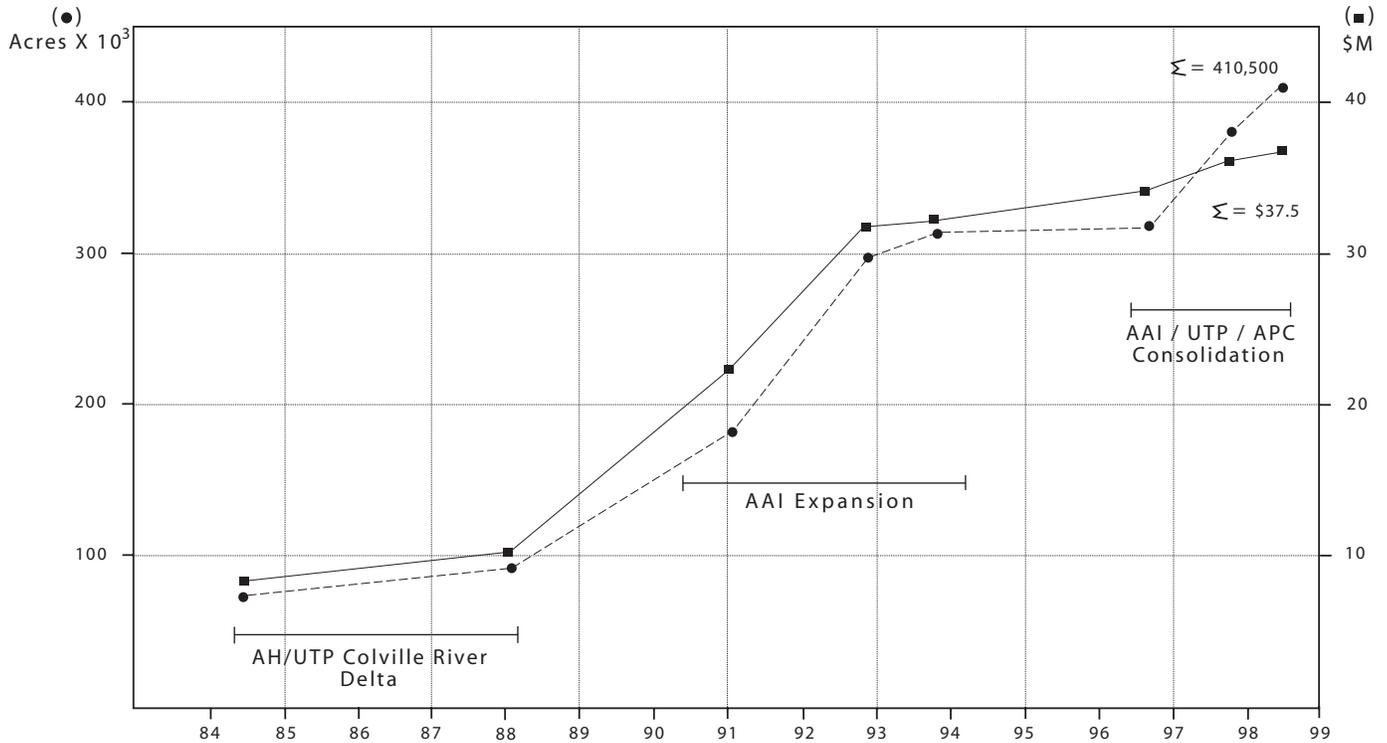


Figure 4. Diagram showing cumulative lease sale expenditures and acres leased on the Colville High from 1984 to 1999.

ern Colville River delta in 1985 and 1986 (see below). Placid was a partner in drilling the western Colville High wildcats in 1985 and 1986 but did not join with the others in State Sale 54. This sale marked a difference in prospect valuation among these exploration partners with AH and UTP being much more encouraged by the previous drilling results. This difference led to individual bids in State Sale 54 by an AH-UTP team and farm-in opportunities for others. AAI farmed into the Texaco acreage in the Colville River delta in 1990 (see below). Based on these lease sale results, AH and UTP continued to have large and highly valued prospects in the Colville River delta area.

AAI Expansion (1991–1993)

AAI, operator of the Kuparuk River Unit on the east half of the Colville High, became an aggressive western Colville High explorer during this period. AAI acquired a total of 159,654 acres for a total high bonus bid of \$19,996,443 or an average high bonus bid of \$125 per acre. Much of the leased acreage was peripheral to the west and southwest Kuparuk River Unit or tracts that had recently been contracted out of this unit but it also included 34,113 acres along the Colville River on the westernmost flank of the Colville High (fig. 2). State Sale 75A (September 21, 1993) included small tracts scattered across the central and southern Colville River delta (fig. 2). AAI acquired seven tracts totaling 9,863 acres for \$253,053 or \$26 per acre. This bid level marks a significant lowering of AAI interest or prospect value from that of previous lease sales during this period.

AAI/UTP/APC consolidation (1996–1998)

Lease sales during this period offered small, scattered tracts along the Colville River and a few expired tracts on the west-central Colville High. Several irregular tracts offered in State Sale 86A (October 1, 1996) were acquired by AAI/UTP/APC, the only bidding group that participated in this sale. This group selectively leased a total of 5,900 acres with an average high bonus bid of \$343 per acre. These acres covered possible extensions of the recently discovered and delineated Alpine field (Hannon and others, 2000; Gingrich and others, 2000; see below). This effectively completed the leasing of lands considered prospective along the Colville River adjacent to north-western NPRA and enabled final consolidation of lease ownership among the three participating companies.

Westward Continuation: NPRA Oil and Gas Lease Sale 991 (May 5, 1999)

As a result of exploration success on the western Colville High, especially at Alpine, the Federal government offered tracts in the eastern half of NPRA (fig. 5) for lease on May 5, 1999. In several ways, much of the recent exploration in NPRA is a continuation of western Colville High exploration. A total of 866,450 acres were leased for a total high bonus bid of \$104,635,728 or an average high bonus bid of \$121 per acre. The total high bonus bid level is the third highest in Alaska history. This sale is also important because very high prospect values guided bid levels in six different areas; these areas were leased with average high bonus bids ranging from \$169 to \$405 per acre. At the time of this sale, AAI had acquired UTP and the AAI/APC partnership was the continuation of the western Colville High team that had delineated the Alpine field. Phillips Petroleum competed alone and with BP and others in several areas. After its acquisition of AAI in 2000, Phillips (now ConocoPhillips) holds significant land positions on all of the highly valued prospects leased in this sale.

Summary

The lease sale history from 1983 to 1998 indicates an evolving understanding of prospect potential on the western Colville High. Significant prospect value was recognized in the mid 1980s by a group led by AH and UTP, in the early 1990s by AAI, and finally in the late 1990s by an AAI/UTP/APC partnership. The lease sale expenditures reflect (1) early enthusiasm for prospects in the Colville River delta area, (2) recurring interest along the

Figure 5(a)

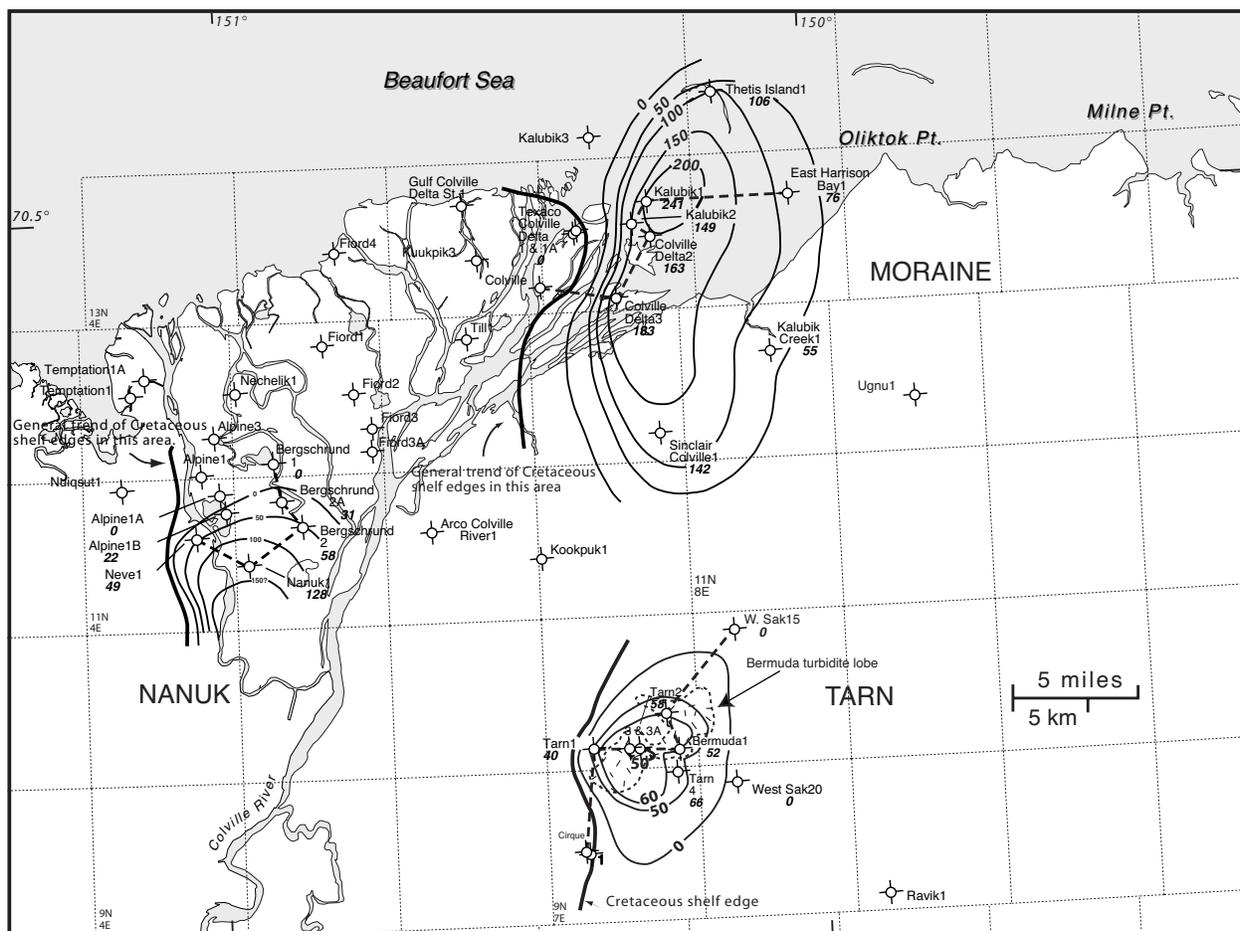
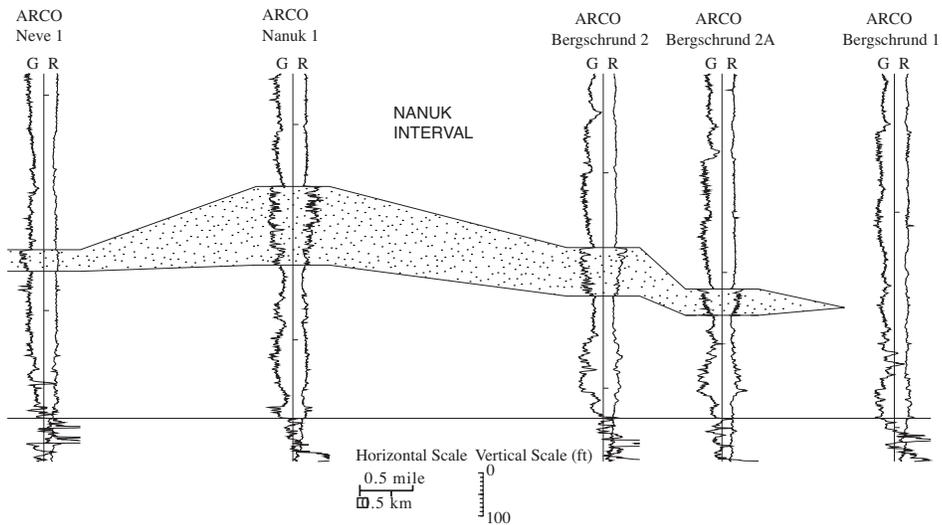
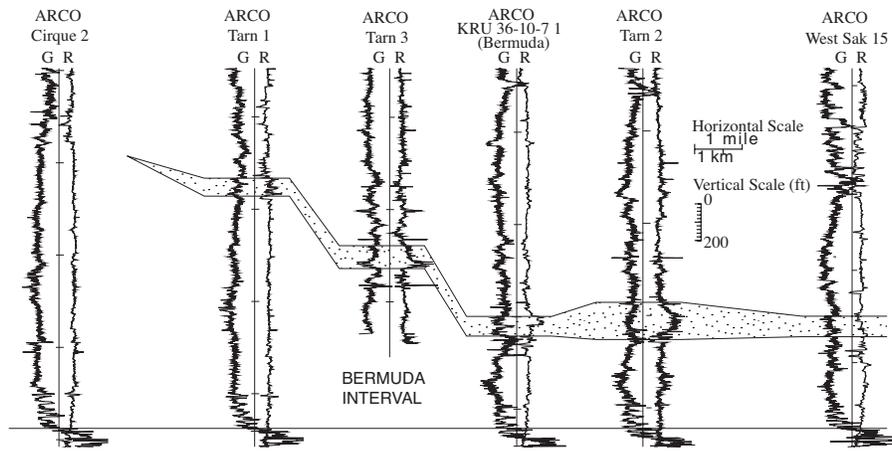
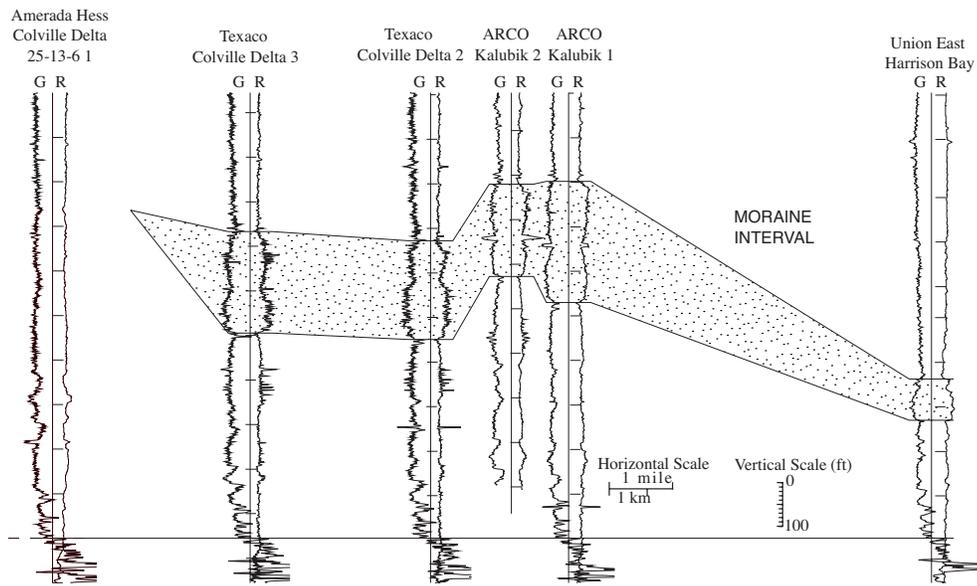


Figure 5. (a) Map showing general Brookian shelf margins, gross sand thickness in the Moraine, Tarn, and Nanuk oil accumulations, and location of corresponding well log sections (b).

Figure 5(b)



southwest periphery of the Kuparuk River Unit, and (3) continuing commitments to western Colville High prospects since 1991 and especially since 1996 after initial delineation of the Alpine field. The lease sale results also indicate that there was one sale (75A, September 21, 1993) in which prospect values appear to have been lower than in previous or subsequent lease sales in nearby areas. Exploration success on the western Colville High eventually led to renewed Federal leasing and continued aggressive exploration westward from the Colville High into NPRA.

EXPLORATION DRILLING HISTORY

Exploration drilling on the Colville High started in 1965 and continues to the present. This drilling has included more than 40 wildcat and related delineation wells (table 2) with cumulative drilled footage of almost 400,000 feet (fig. 6). The wells included in table 2 and figure 6 do not include 11 that delineated the Kuparuk River field between 1974 and 1979 when the decision to place this field in production was reached (Masterson and Eggert, 1992) nor many others drilled within the Kuparuk River Unit to evaluate other stratigraphic intervals. The exploration drilling history shows that there are five periods of significant wildcat and related delineation drilling on the Colville High.

INITIAL EXPLORATION DRILLING (1965–1972)

Initial exploration drilling on the Colville High included eight wildcat wells that were completed between 1966 and 1972. These wells all penetrated deep stratigraphic intervals, bottoming in the Lisburne Group or basement rocks. The cumulative drilled footage for these eight wells is 84,344 feet (fig. 6). Although hydrocarbon shows were detected in the deeper stratigraphic targets, commercial quantities of oil were not found. The lack of commercial quantities of oil in the deeper Paleozoic and Triassic reservoirs, which are so important at Prudhoe Bay, continues to be a perplexing outcome of exploration drilling on the Colville High. One of these wells, Sinclair Ugnu 1, is the discovery well for the Kuparuk River field, the biggest discovery in Sinclair history (Masterson and Eggert, 1992). Sinclair Ugnu 1 flowed 1,056 barrels of oil per day from 20 feet of Lower Kuparuk Formation sandstone (Carman and Hardwick, 1983).

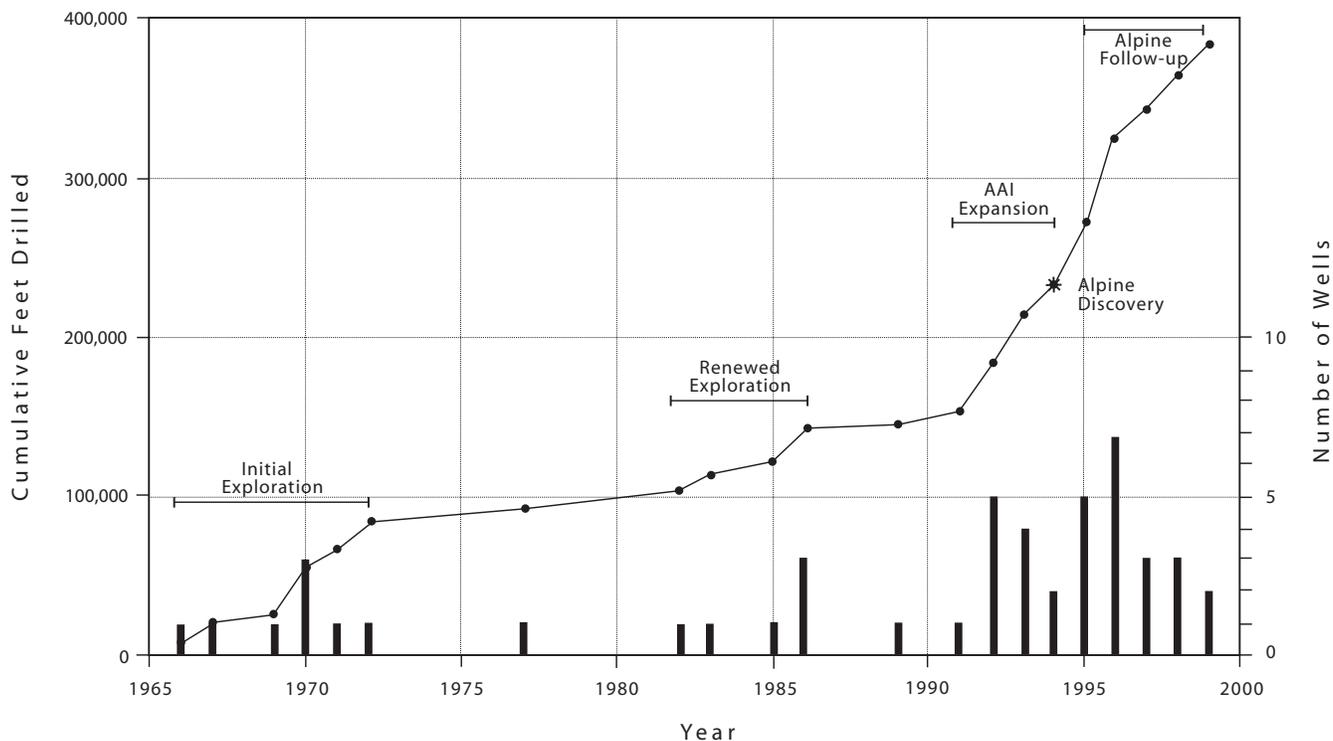


Figure 6. Diagram showing cumulative drilled footage and number of exploration wells on the Colville High from 1965 to 1999.

Table 2. Data for wildcat and selected other wells drilled on the Colville High

API Number	Well Name	No.	Operator	Total Depth (ft)	Completion date	Period	Well No.	Cumulative footage
50 103 10002	Colville State	1	Sinclair Oil	9930	03/08/66	1	1	
50 103 10003	Kookpuk	1	Union Oil	10193	03/10/67	1	2	
50 029 20009	Ugnu	1	Sinclair Oil	9428	05/09/69	1	3	
50 103 20001	Kalubik Creek	1	Union Oil of CA	10107	03/27/70	1	4	
50 103 20002	Colville Delta	1	Gulf Oil	9299	04/22/70	1	5	
50 029 20052	East Ugnu	1	BP Alaska Expl.	9775	05/04/70	1	6	
50 029 20090	West Sak River	1	Atlantic Richfield	10290	04/26/71	1	7	
50 103 20003	Itkillik River	1	Atlantic Richfield	15321	07/23/72	1	8	84343
50 703 20001	East Harrison Bay State	1	Union Oil Of CA	9809	04/06/77	2	9	9809
50 103 20020	Nechelik	1	Sohio Pet.	10018	03/17/82	3	10	
50 029 20888	Ravik State	1	Arco O & G	8200	04/03/83	3	11	
50 103 20038	Colville Delta	1	Texaco Inc.	9457	04/26/85	3	12	
50 103 20054	Colville Delta 25-13-6	1	Amerada Hess	6871	03/04/86	3	13	
50 103 20047	Colville Delta	2	Texaco Inc.	6800	03/16/86	3	14	
50 103 20048	Colville Delta	3	Texaco Inc.	6800	03/31/86	3	15	48146
50 103 20104	Ruby State	1	Union Oil of CA	3850	03/20/89	4	16	
50 103 20149	Bermuda (KRU 36-10-7)		Arco Alaska	6800	02/02/91	4	17	
50 103 20163	Tarn	1	Arco Alaska	6709	03/23/92	4	18	
50 103 20162	Fiord	1	Arco Alaska	10250	04/18/92	4	19	
50 103 20167	Cirque	2	Arco Alaska	7660	04/25/92	4	20	
50 103 20165	Kalubik	1	Arco Alaska	8273	05/01/92	4	21	
50 103 20189	Till	1	Arco Alaska	6975	03/18/93	4	22	
50 103 20188	Colville River	1	Arco Alaska	6700	04/07/93	4	23	
50 103 20187	Kuukpik	3	Arco Alaska	6880	04/14/93	4	24	
50 103 20190	Thetis Island	1	Exxon	8460	04/28/93	4	25	
50 103 20201	Fiord	2	Arco Alaska	8400	03/07/94	4	26	
50 103 20207	Bergschrund	1	Arco Alaska	7502	04/14/94	4	27	88459

Table 2. Data for wildcat and selected other wells drilled on the Colville High, continued

API Number	Well Name	No.	Operator	Total Depth (ft)	Completion date	Period	Well No.	Cumulative footage
50 103 20211	Alpine	1	Arco Alaska	7500	02/16/95	5	28	
50 103 2021101	Alpine	1A	Arco Alaska	9940	03/01/95	5	29	
50 103 2021102	Alpine	1B	Arco Alaska	8850	03/23/95	5	30	
50 103 20210	Fiord	3	Arco Alaska	7030	04/04/95	5	31	
50 103 2021001	Fiord	3A	Arco Alaska	9147	04/12/95	5	32	
50 103 20232	Bergschrund	2	Arco Alaska	8600	02/26/96	5	33	
50 103 20238	Nanuk	1	Arco Alaska	7630	03/24/96	5	34	
50 103 20234	Alpine	3	Arco Alaska	7649	03/11/96	5	35	
50 103 20233	Temptation	1	Arco Alaska	7750	04/04/96	5	36	
50 103 2023201	Bergschrund	2A	Arco Alaska	7896	04/17/96	5	37	
50 103 20231	Neve	1	Arco Alaska	7700	04/23/96	5	38	
50 103 2023301	Temptation	1A	Arco Alaska	8950	04/23/96	5	39	
50 103 20248	Tarn	3	Arco Alaska	5750	02/28/97	5	40	
50 103 20249	Tarn	4	Arco Alaska	6150	03/22/97	5	41	
50 103 20247	Tarn	2	Arco Alaska	7650	04/17/97	5	42	
50 103 20251	Kalubik	3	Arco Alaska	7000	03/06/98	5	43	
50 103 20252	Kalubik	2	Arco Alaska	5650	03/09/98	5	44	
50 103 20253	Nuiqsut	1	Arco Alaska	7650	04/19/98	5	45	
50 103 20289	Fiord	4	Arco Alaska	7171	03/13/99	5	46	
50 103 20292	Fiord	5	Arco Alaska	7490	04/23/99	5	47	153153

KUPARUK RIVER FIELD DELINEATION (1974–1981)

Exploration drilling during this period was limited to one wildcat by Unocal (East Harrison Bay 1) on the north flank of the Colville High. This well was a deep test that reached 9,809 feet in the Lisburne Group. As with previous wildcats on the Colville High, the deeper stratigraphic targets in this well did not contain commercial quantities of hydrocarbons. In 1974, ARCO initiated delineation drilling of the Kuparuk River pool on the eastern Colville High. After completing 11 delineation wells, ARCO reached a positive production decision in 1979 (Masterson and Eggert, 1992). These 11 wells are not included in table 2 and figure 6. Assuming an average total depth of 6,650 feet, the total cumulative footage drilled in the 11 Kuparuk delineation wells is 73,150 feet. The Kuparuk River field was unitized and began production in 1981. Several hundred wells have subsequently been drilled within the Kuparuk River Unit, including many to further evaluate the West Sak, Tabasco, Tarn, and Kuparuk River oil pools.

RENEWED WILDCAT DRILLING (1982–1986)

Exploration drilling resumed on the Colville High after the Kuparuk River field production began. Seven wells, including one sidetrack, were drilled outside the Kuparuk River Unit from 1982 to 1986 (table 2, fig. 6). Two of these wells were deeper tests like previous wildcats. The two deeper wildcats, drilled in the Colville River delta area, were not successful at deeper stratigraphic intervals but both encountered oil-bearing sandstone in the Jurassic Kingak Shale. A sidetrack and three offset wells were drilled to evaluate the Kingak oil-bearing interval encountered in Texaco Colville Delta 1 (Texaco Colville Delta 1A, 2, 3, and Amerada Hess Colville Delta 25-13-06 1). Although oil-bearing Upper Jurassic sandstones were encountered in five wells during this period, poor reservoir quality has been a significant handicap to commercial production from these intervals (see below).

AAI EXPANSION (1989–1994)

AAI became an aggressive wildcat driller during this period; it operated 10 of the 12 wildcats completed between 1989 and 1994. The total drilled footage in the AAI-operated wells was 76,149 feet or 86 percent of the cumulative drilled footage (88,459 feet) during the period. The only wildcat well drilled within the Kuparuk River Unit that is included in table 2 is the ARCO KRU (Bermuda) 36-10-7 well drilled in the southwest corner of the unit just preceding and offsetting sale 70A (January 29, 1991). The Bermuda well is the discovery well for the Tarn field.

The other nine wells drilled by AAI during this period were located west and southwest of the Kuparuk River Unit. Oil-bearing sands were discovered in the Upper Kuparuk Formation in the Fiord 1 and Kalubik 1 wells. Upper Cretaceous turbidites were oil-bearing in the Tarn 1 and Kalubik 1 wells and Upper Jurassic oil-bearing shelf sandstones were encountered in several of the western Colville High wells. The Bergschrund 1 well (completed on April 14, 1994) discovered the Alpine field in the Upper Jurassic part of the Kingak Shale. The Alpine field and other stratigraphic plays have been the focus of most of the subsequent exploration drilling on the western Colville High.

ALPINE FOLLOW-UP (1995–1999)

Fifteen wells and five sidetracks were drilled on the western Colville High during this period (table 2) and most were delineation wells for the Alpine field. These wells were all drilled by ARCO and its partners, range in total depth from 5,650 to 9,940 feet, and have cumulative drilled footage of more than 120,000 feet. Most bottomed in the Jurassic Kingak Shale. The longer wells are sidetracks that do not test significantly deeper stratigraphic intervals.

SUMMARY

The early exploration drilling history of the Colville High has been well summarized and explained by others (e.g., Jamison and others, 1980; Specht and others, 1986; Bowsher, 1987; Masterson and Eggert, 1992); exploration drilling between 1965 and 1972 preferentially tested mapped structural closures at Paleozoic and Triassic stratigraphic levels. Masterson and Eggert (1992) also excellently presented the next phase of exploration history that led to the recognition and evaluation of the Kuparuk River oil field. Figure 6 shows the several periods of exploration activity that totaled almost 400,000 feet of exploration drilling since 1966. Since unitization of the Kuparuk River field in 1981, exploration drilling has primarily been on the western Colville High and its northern and southern flanks. This drilling included a short period of significant activity led by Texaco and its partners in the Colville River delta area (1985/86) and an aggressive episode of exploration drilling led by AAI in the 1990s.

Since 1996 about \$1 billion was spent to develop the Alpine field and several exploration wells were subsequently drilled in northwest NPRA. In effect, Colville High exploration has continued westward into NPRA and the cycle of increased exploration activity since 1990 illustrated in figure 6 continued.

EXPLORATION RESULTS

The \$37.5 million expended in lease sales and almost 300,000 feet of exploration drilling since 1982 enabled discovery and/or evaluation of nine oil accumulations. The combined oil-in-place for these nine accumulations is probably more than 5 billion barrels and the three that were determined to be economic by 2000 contain at least 539 millions of barrels (mmbbls) of reserves (table 1). These results reflect the importance of two stratigraphic plays and one combination structure/stratigraphic play that have been successfully pursued on the Colville High. From younger to older, these plays are (1) mid and Late Cretaceous (Brookian) turbidites, (2) normal-fault controlled, Hauterivian (Beaufortian) sandstone on the LCU, and (3) large Upper Jurassic and Lower Cretaceous (Beaufortian) mudstone-encased shelf sandstone systems. Known Colville High oil accumulations in each of these plays, all discovered and/or evaluated between 1982 and 2000, are described below.

OIL ACCUMULATIONS IN BROOKIAN TURBIDITES

The prograding clastic wedges of the mid Cretaceous Torok and Nanushuk Formations and the Upper Cretaceous Colville Group (fig. 3) have well defined shelf, slope, and basal components. These are clearly expressed in even older vintage two-dimensional (2D) seismic data that readily allow mapping of specific shelf margins. These shelf margins generally migrated to the north and east across the western and central North Slope through the Albian to the Latest Cretaceous (fig. 5). At low sea level stands, sediment bypass of the shelf led to sand and mud influxes to slope and basin settings as part of turbidite systems. At least three such turbidite systems are known to be charged on the Colville High: Moraine, Tarn, and Nanuk/Nanuq (fig. 5). Another charged turbidite system is present at Meltwater, a recent discovery on the Tarn trend south of the Colville High that will be produced through Kuparuk River field facilities (Petroleum News—Alaska, September, 2000).

Moraine

Distal parts of this accumulation were encountered in a few of the early wildcats on the Colville High such as the Sinclair Colville 1 and the Union East Harrison Bay 1 wells (fig. 5). This oil-bearing sandstone was later encountered in more proximal settings at the Texaco Colville Delta 2 and 3 wells. The Moraine sandstone was cored in Sinclair Colville 1 and also cored and tested in Texaco Colville Delta 3. It is very fine grained, very thin bedded to laminated, and lacks bioturbation. Porosities are as high as 24 percent and permeabilities are as high as 50 md but the better reservoir quality is restricted to a thin zone near the middle of the interval. The Moraine sandstone was artificially stimulated in Texaco Colville Delta 3 and tested 200 barrels of oil per day. AAI further evaluated this accumulation with the ARCO Kalubik 2 and 3 wells in 1998 (table 2, fig. 5). The Moraine accumulation continues to be sub-economic mostly due to insufficient reservoir quality.

Tarn

The Tarn oil field (Morris and others, 2000) was discovered in the KRU (Bermuda) 36-10-7 well, which was drilled for Kuparuk Formation data gathering purposes, in the southwest corner of the Kuparuk River Unit just preceding and offsetting State Sale 70A (January 29, 1991). ARCO Tarn 1, drilled the next winter, encountered and cored the Tarn sandstone in an upper slope location updip from the Bermuda well; this core showed the Tarn sandstone to have low permeability in its upper slope setting due to an abundance of ductile, lithic (volcanic) fragments and the interval was not tested. The Tarn prospect encountered internal ARCO hurdles (see below) and it was not until BP became a partner that 3D seismic data were acquired and the Tarn 2, 3, and 4 delineation wells were eventually drilled in the winter of 1997. The Tarn 2 well flowed 2,000 BOPD of 38 degree API gravity oil after stimulation. The Kuparuk River Unit was expanded to include the Tarn field and production started in mid July 1998. The produced oil has an API gravity of 37 degrees and the original GOR was 712 SCF/STB. The field will have peak production of about 30,000 BOPD and at least 50 million barrels of reserves.

The Tarn sandstones are a composite section of turbidites deposited on the slope and basin floor at a time of low sea level in the Late Cretaceous (Morris and others, 2000). Clear onlap and downlap features were observable in older vintage 2D seismic data and the general distribution of the turbidites was mappable in 1992. Lobes of Tarn turbidites composite to a gross sandstone/mudstone interval up to a few hundred feet thick but average gross sandstone thickness is about 50 feet (fig. 5). The sandstone has porosities between 18 and 27 percent and average

21 percent; permeability ranges from 1 to 45 md and averages about 10 md (Alaska Oil and Gas Conservation Commission, 1998). The Tarn sandstones are on the south flank of the Colville High but are completely shale-encased and stratigraphically trapped. They are basinward of a Late Cretaceous shelf margin (fig. 5) that trends approximately north-south in the Tarn area. Along this trend, 10 miles to the south of the Tarn field, the Meltwater 1 wildcat was drilled in early 2000; an interval at a true vertical depth subsea of about 5,000 feet flowed 4,000 BOPD of 37 degree API gravity oil in this well (Petroleum News – Alaska, 2000; AOGCC online pool statistics). The Meltwater discovery was deemed commercial in May, 2000 with reserves of at least 50 million barrels. Meltwater is a satellite development to the Kuparuk River field and another example of stratigraphically trapped, slope and basin turbidite systems in the North Slope Brookian section.

Nanuk (Nanuq)

The Nanuk (Nanuq) oil accumulation (spelled “Nanuq” after the Nanuk 2 well was drilled in early 2000) is in Albian turbidites of the Torok Formation that spatially overlap the southern part of the Alpine field (fig. 5). It was first encountered in the Bergschrund 1 well in a thin distal interval between a wet turbidite section above (the Neve prospect, see below) and the regional pebble shale/Hue Shale section (fig. 3). At this location, the potential of the Nanuk (Nanuq) interval is not readily apparent. The prospect was developed through seismic data analysis and was officially discovered by Nanuk 1, drilled during the same drilling season as the Bergschrund 2 and 2A wells delineating the southern part of the Alpine field. The Neve prospect was the primary target for AAI and APC in the Bergschrund 1 well, the discovery well for Alpine (see below). Nanuk (Nanuq) oil is trapped in a similar depositional setting but slightly older and slightly south of the original Neve prospect.

The main Nanuk (Nanuq) oil accumulation lies south of the first well intersections (fig. 5). The original well data show encouraging characteristics such as the presence of individual sandstone packages several feet in thickness and the composite gross sand thickness of 128 feet in the Nanuk 1 well. Core measurements on very fine to fine-grained sandstone from Nanuk 1 show permeability increasing from 0.1 to 10 md as porosity increases from 12 to 18 percent. AAI/Phillips and APC drilled the Nanuk 2 delineation well in early 2000. In 2001, Alpine production data indicated that the Nanuk (Nanuq) oil accumulation had been tested through Alpine facilities and a total of 6,404 barrels of oil and 97,646 mcf of gas were recovered from this interval (Petroleum News–Alaska, 2001). Since Nanuk 2, three delineation wells were drilled and in 2005 ConocoPhillips applied to establish pool rules for this accumulation (Alaska Oil and Gas Conservation Commission, 2005). The high gravity oil (39–42 degrees API) helps production rates from these fine grained and low to moderately permeable sandstones. The average porosity is 17 percent, permeability averages about 2.5 md, and the average net pay is 35 feet.

Summary

The Brookian turbidite play is one that can be readily identified and mapped in seismic data. Starting with the Tarn prospect in the mid 1990s, the use of 3D seismic data has been especially important to mapping the general distribution of the turbidites as well as revealing internal complexities important to understanding reservoir thickness and character. Most importantly, the oil accumulations that are known in this play clearly illustrate the stratigraphic trapping capability of these base-of-slope settings. Because this depositional setting developed repeatedly during the evolution of Torok–Nanushuk prograding clastic systems, large parts of NPRA and other parts of the North Slope are in this play. Another important characteristic is the wide distribution of very distal, thin sandstones in these systems. Thin turbidites in very distal, basinal settings can be indicators of significant sand accumulations at the base of the coeval slope. The field sizes in this play are indicated by the few discoveries now known; the Tarn and Meltwater oil fields contain at least 50 million barrels of reserves each. The Torok accumulation at Nanuk (Nanuq) contains 22 to 69 million barrels of recoverable oil. The economics of these accumulations is greatly enhanced by the low viscosity, high gravity oils they contain.

OIL ACCUMULATIONS IN BEAUFORTIAN TRANSGRESSIVE SANDSTONE

Sandstones deposited on and immediately above the LCU are correlative with the Upper Kuparuk Formation (fig. 3). In the Kuparuk River field, these Hauterivian to Barremian sandstones composite to thicknesses greater than 50 feet and are more than 10 feet thick over a large area (Masterson and Eggert, 1992); they contained 40 to 60 percent of the 2 billion barrels of original reserves in the Kuparuk River field (Kornbrath and others, 1997, p. 22). Development of the LCU during regional uplift and erosion mobilized and reworked sand from underlying formations and redeposited it in topographically low areas. One important control on development of Upper Kuparuk age topographic lows on the LCU was contemporaneous normal faulting. Such normal faults are widespread on the Colville High and known to locally control Upper Kuparuk Formation sandstone thickness in the

Kuparuk River field (Masterson and Eggert, 1992). In the Kuparuk River field, thicker Upper Kuparuk intervals are observable in seismic data on the downthrown side of normal faults where higher seismic amplitudes may also be present (Masterson and Eggert, 1992, fig. 18).

Masterson and Eggert (1992) provide excellent descriptions of these sandstones and their reservoir character in the Kuparuk River field. Original depositional complexities such as intraformational unconformities, bioturbation, and variable cementation contribute to a heterogeneous reservoir character but, in general, Upper Kuparuk sandstone has the best reservoir properties of any charged reservoir on the Colville High. They are glauconitic, highly bioturbated, very fine to very coarse grained with variable early siderite cementation. Secondary porosity is variably developed by late dissolution of carbonate cements and glauconite. These sandstones have up to 37 percent porosity and average 24 percent; permeability can be as high as 2,644 md and averages 138 md.

The normal-fault control of Upper Kuparuk thickness sets up a combination structural and stratigraphic trapping configuration. The Upper Kuparuk sandstone grades laterally to a few feet or less thickness in Kalubik Formation mudstone (fig. 3), a regional unit that completely overlaps the Upper Kuparuk River Formation on the Colville High (Carman and Hardwick, 1983) and lateral pinchout and/or cementation of thin intervals of Upper Kuparuk sandstone is important to trapping many of the known oil accumulations in them (fig. 7). In addition to the Kuparuk River and Milne Point fields, three other oil accumulations occur in Upper Kuparuk sandstone on the Colville High (Kuukpik, Kalubik, and Fiord, fig. 7). All three are examples of normal fault-controlled, Upper Kuparuk sandstone deposition and trapping.

Kalubik

The Kalubik oil accumulation is on the downthrown side of a regional normal fault that trends northwest across the northwest Kuparuk River Unit to the offshore Colville River delta area (fig. 7). This prospect had been in AAI's inventory for many years and was finally drilled in 1992 when it was the primary objective in the ARCO Kalubik 1. The 38 feet of Upper Kuparuk sandstone in Kalubik 1 was tested and flowed 1,200 BOPD of 26 degree API gravity oil with a GOR of 450 SCF/STB. A subsequent stepout to the southeast that was drilled from the Kuparuk River Unit encountered only about 10 feet of highly cemented sandstone in this interval. To the northwest of Kalubik 1, AAI subsequently drilled the Kalubik 3 delineation well (fig. 7), which penetrated 22 feet of oil-charged Upper Kuparuk sandstone. The Kalubik accumulation continues to be sub-economic.

Kuukpik

The Kuukpik oil accumulation is on the downthrown side of a west-northwest-trending normal fault in the Colville River delta area (fig. 7). This accumulation was first encountered in the Texaco Colville Delta 1 and the Amerada Colville Delta 25-13-6 1 wells. The potential for Upper Kuparuk sandstone with good reservoir properties on the western Colville High that was evidenced by the 20 feet of this sandstone in the Amerada well, was of special importance to AAI explorationists and significantly contributed to AAI's decision to farm in to Texaco's Colville High acreage in 1990 (see above). Kuukpik 3 was drilled as a stepout to the Amerada Colville Delta 25-13-6 1 well. Twenty feet of Upper Kuparuk sandstone was present in Kuukpik 3 but it was highly cemented and the interval was not tested. The Kuukpik oil accumulation remains sub-economic.

Fiord

The Upper Kuparuk Fiord oil field is on the downthrown side of a northwest-trending normal fault on the western Colville High (fig. 7). The Fiord prospect was the primary objective in the ARCO Fiord 1 wildcat drilled in 1992. The 30 feet of Upper Kuparuk sandstone in this well was tested and flowed 1,065 BOPD of 32 degree API gravity oil with a GOR of 500 SCF/STB. The first stepout on this discovery was to the southeast to ARCO Fiord 2 but only 5 feet of Upper Kuparuk River sandstone was present there (fig. 7). In 1999, the ARCO Fiord 5 was drilled to the northwest of Fiord 1 and encountered 15 feet of oil-bearing Upper Kuparuk River sandstone that flowed about 1,100 BOPD of 30-32 degree API gravity oil. The Upper Kuparuk Fiord oil accumulation was subsequently declared to be commercial and to contain at least 50 million barrels of reserves (Petroleum News-Alaska, 1999). It is to be developed in conjunction with the underlying Nechelik zone (see below) as a satellite to the Alpine field (AOGCC online Fiord Pool Rules).

Summary

The Kuukpik, Kalubik and Fiord oil accumulations are examples of normal-fault controlled distribution of Upper Kuparuk Formation sandstone. These accumulations are local features on the Colville High but their lateral thinning and cementation is probably also important to trapping. Upper Kuparuk sandstone can be widely distrib-

uted along the Barrow Arch in the central and western North Slope. The best example of a fault-controlled Upper Kuparuk River oil accumulation is the large Pt. McIntyre oil field, northwest of Prudhoe Bay, that has produced about 376 million barrels since 1993 (Alaska Oil and Gas Conservation Commission, 2005). Upper Kuparuk age flank structural settings, downthrown sides of normal faults, and local paleotopographic lows from the Colville High westward to Barrow, are prospective for this play.

OIL ACCUMULATIONS IN BEAUFORTIAN SHELF SAND SYSTEMS

There are four known oil accumulations in shelf sand systems of the Upper Jurassic and Early Cretaceous Kingak Shale and Miluveach Formation on the Colville High (fig. 3). These accumulations are large and include the Lower Kuparuk Formation pool in the Kuparuk River field. The other three, from younger to older, are Alpine, Nuiqsut, and Nechelik (fig. 8). These sand systems have northerly sources and generally prograde to the south and southeast as part of regressive depositional cycles. In places, intraformational unconformities mark temporary transgressive settings that winnowed and reworked previous sand deposits to form high-quality transgressive shoreface reservoirs. The sand-bearing systems extend along a general east–northeast strike for several tens of miles and are a few tens of miles wide. The contained sandstone, within 200- to 300-foot-thick coarsening and thickening upward cycles, can composite to over 100 feet of thickness. They grade laterally to siltstone and mudstone of the enclosing Kingak Shale and are commonly truncated to the north by regional unconformities, particularly the LCU. Although located on the Colville High, only the Lower Kuparuk Formation in the Kuparuk River field has a defined oil–water contact. As evidenced by the Alpine field, where the distribution of oil is controlled by the

Figure 7(a)

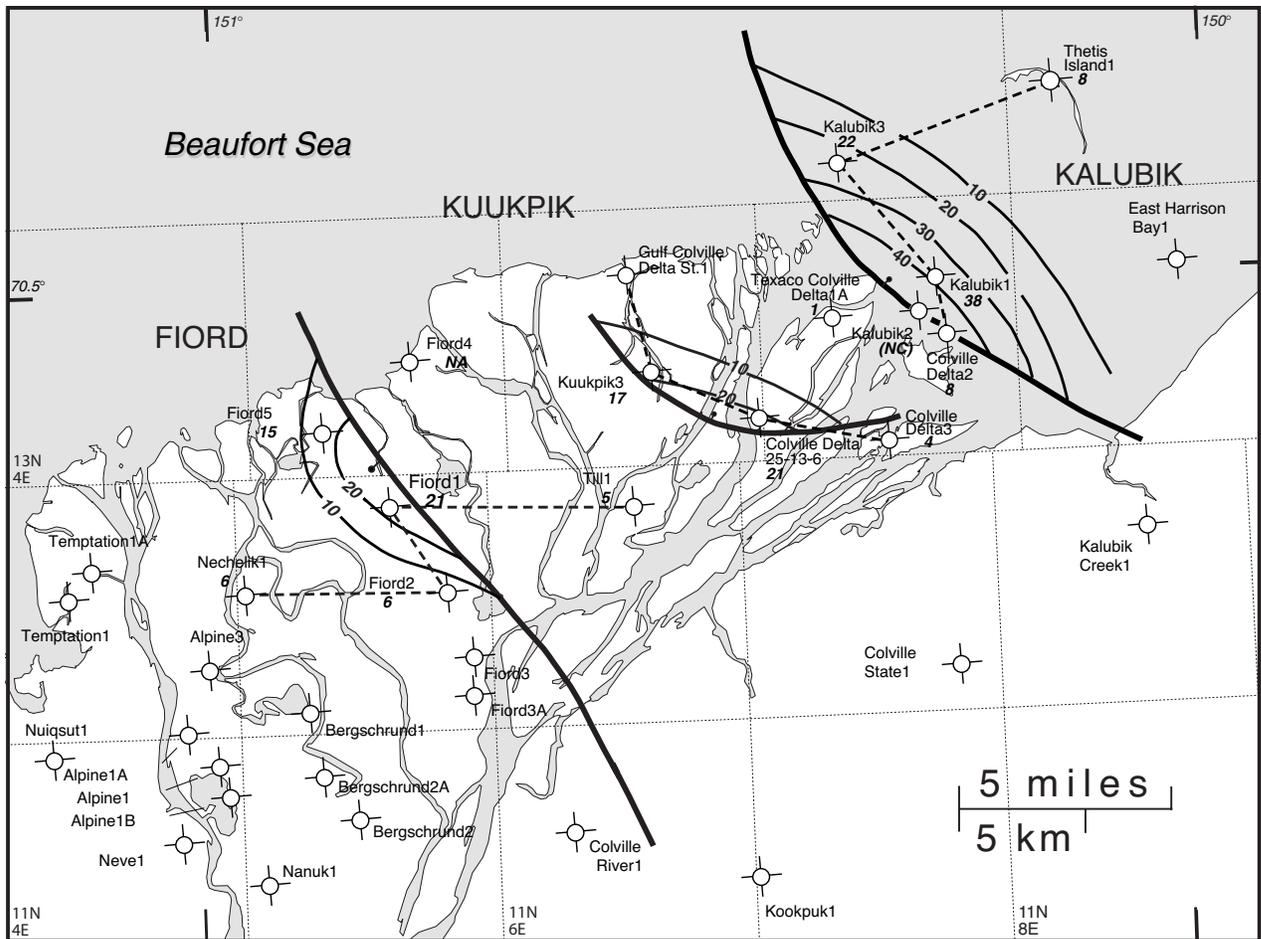
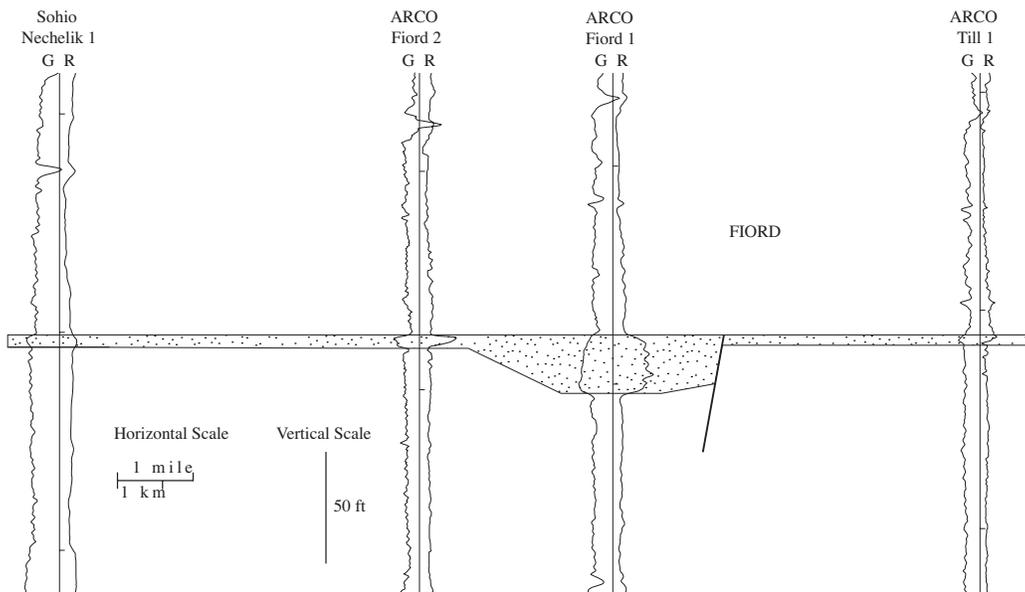
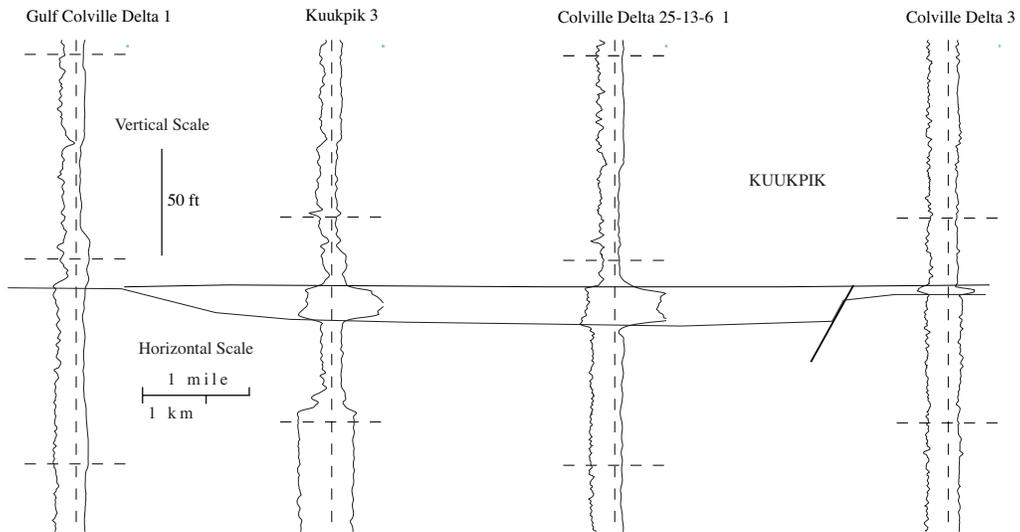
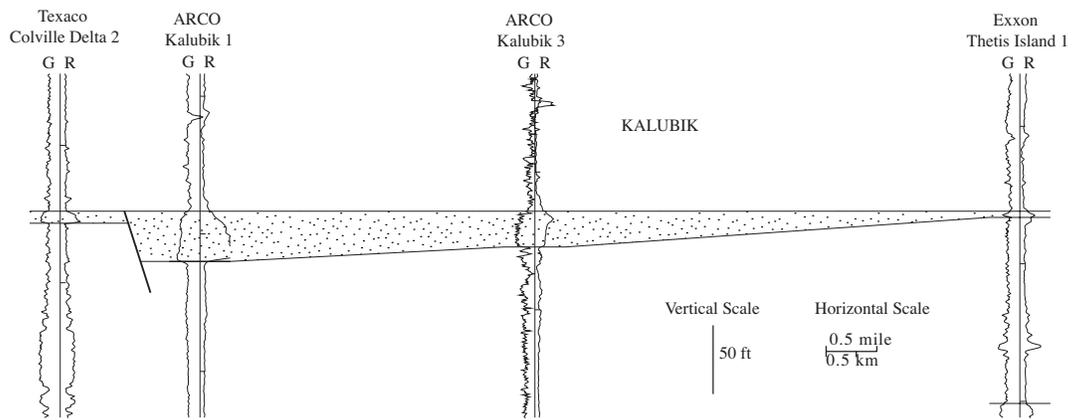


Figure 7. (a) Map showing selected faults, gross sand thickness in the Fiord, Kuukpik, and Kalubik oil accumulations, and the location of corresponding well log sections (b).

Figure 7(b)



distribution of reservoir quality sandstone, stratigraphic trapping in these systems is well developed. These sand-bearing systems are interpreted to have been deposited in distal shelf to upper shoreface settings.

The Lower Kuparuk Formation in the Kuparuk River field has been well described by Carman and Hardwick (1983), Masterson and Paris (1987), Gaynor and Scheihing (1988), and Masterson and Eggert (1992). It is a composite of several Berriasian (?) to Valanginian, sand-bearing intervals below the regional Lower Cretaceous Unconformity (LCU). The interbedded marine sandstone, siltstone, and mudstone of the Lower Kuparuk Formation include at least six lenticular and overlapping sand-bearing intervals that are elongate to the northeast and prograde to the southeast (Masterson and Eggert, 1992, figs. 9 and 10). Individual sand-bearing intervals can be up to 80 feet thick, 40 miles long, 15 miles wide and contain up to 30 feet of reservoir quality sandstone (Masterson and Eggert, 1992, p. 265). Imbricate stacking of the sandstone-bearing intervals can lead to composite reservoir sandstone thicknesses of 70 feet. The sandstones are very fine to fine grained, well sorted, quartzose, and graded, laminated, and massive bedded. Lithofacies are a primary control on reservoir properties; porosity ranges upward to 33 percent and averages 23 percent and permeability ranges upward to 1828 md and averages 113 md. The Lower Kuparuk Formation sandstones are interpreted to have been deposited in wave-dominated lower shoreface to offshore transition settings (Wilson and Posamentier, 1994). These sandstones contain about half of the 2 billion barrels of ultimate reserves in the Kuparuk River field.

Other shelf sand systems in the Upper Kingak Shale were not specifically explored for on the Colville High until Texaco and partners encountered the oil-bearing Nuiqsut sandstones in their 1985 and 1986 Colville River delta wells (see above). Now, three other very large, oil-bearing shelfal to shoreface sand systems are known on the Colville High, including the very important Alpine field (Hannon and others, 2000; Gingrich and others, 2000; 2001).

Alpine

The Alpine field is located on the western flank of the Colville High adjacent to NPRA (fig. 8). Alpine was first encountered in the ARCO Fiord 2 well, where a thin, 6-foot-thick oil-bearing sandstone is present. This encounter was especially meaningful to UTP explorationists who concluded that the Alpine sand would be tested in the subsequent ARCO Bergschrund 1 wildcat (see below, fig. 8). ARCO Bergschrund 1 discovered 44 feet of Alpine sandstone that flowed 2,380 BOPD of 40 degree API gravity oil with a GOR of 850 SCF/STB. The Alpine pool was subsequently delineated with 11 wells and 3D seismic data (ARCO Alaska Inc., 1998). It began production on November 16, 2000, has at least 429 million barrels of reserves, and a peak production rate exceeding 100,000 barrels per day. Current estimates of original oil-in-place at Alpine are 650 to 750 million barrels (Alaska Oil and Gas Conservation Commission, 2004).

The Upper Jurassic Alpine sand was deposited on a southerly prograding, shallow marine shelf. An intraformational unconformity locally complicates sand distribution and gives rise to an overlying transgressive sand unit with better reservoir quality than the underlying progradational unit. In general, the sandstone is very fine to fine grained, moderate to well sorted, quartzose, and contains variable amounts of glauconite and clay. Porosity ranges from 15 to 23 percent and averages 19 percent; permeability ranges from 1 to 160 md and averages 15 md (Alaska Oil and Gas Conservation Commission, 1999). Gross sandstone thickness is as great as 110 feet (fig. 8). The gross sandstone thickness distribution indicates a general northeast–southwest trend that is open to the southwest where it appears the Alpine field continues into NPRA (fig. 8; ARCO Alaska Inc., 1998). If southwest continuity exists, the overall size of Alpine can be larger than current reserve estimates of 429 million barrels. The high prospect values evidenced by AAI/Anadarko bid levels for four eastern tracts in the 1999 Federal NPRA lease sale probably indicates that southwest continuity of the Alpine field into NPRA is expected. Discoveries in Alpine-equivalent sands in northeastern NPRA since 2001 demonstrate the prospectivity of this interval beyond the limits of the Alpine accumulation itself (Petroleum News–Alaska, 2004).

Nuiqsut

The Nuiqsut oil accumulation is in the Colville River delta area on the northwest Colville High (fig. 8). It was first encountered in the Texaco Colville Delta 1 well that was drilled to test deeper stratigraphic levels. Texaco and partners evaluated the Nuiqsut accumulation in a sidetrack and three additional wells; flow tests in four wells ranged from 25 to 1,075 BOPD of 25 degree API gravity oil with a GOR of 430 SCF/STB. These production tests encountered several problems and the producibility of the Nuiqsut reservoir was not well constrained by them. In general, it appears that this reservoir could produce a few to several hundred BOPD after stimulation. The ARCO Kalubik 1 well also encountered the Nuiqsut accumulation; here the Nuiqsut flowed 410 BOPD of 21 degree API gravity oil after fracturing.

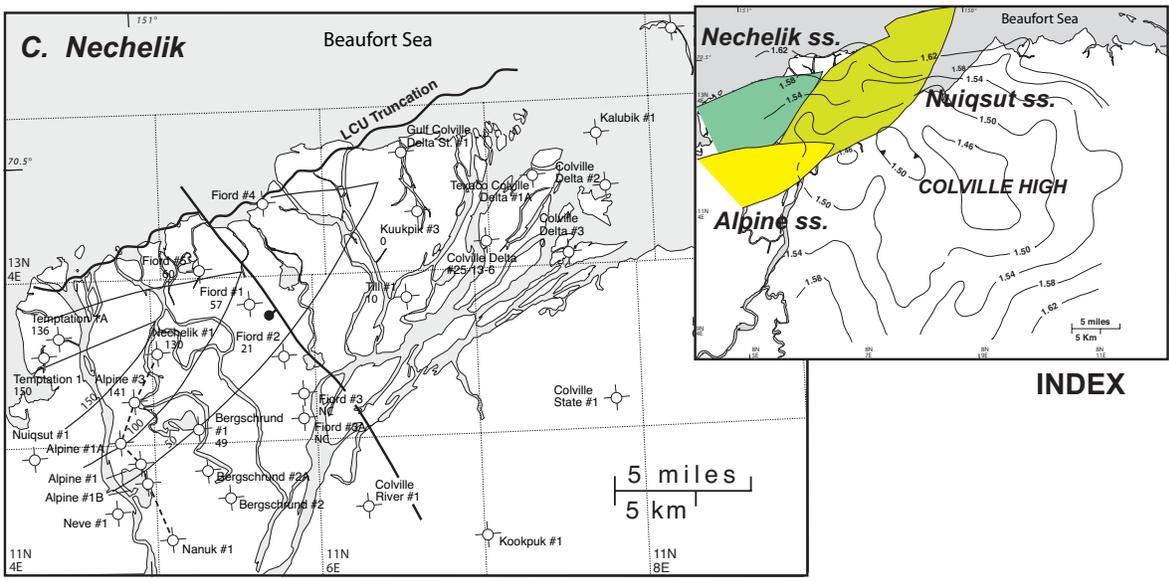
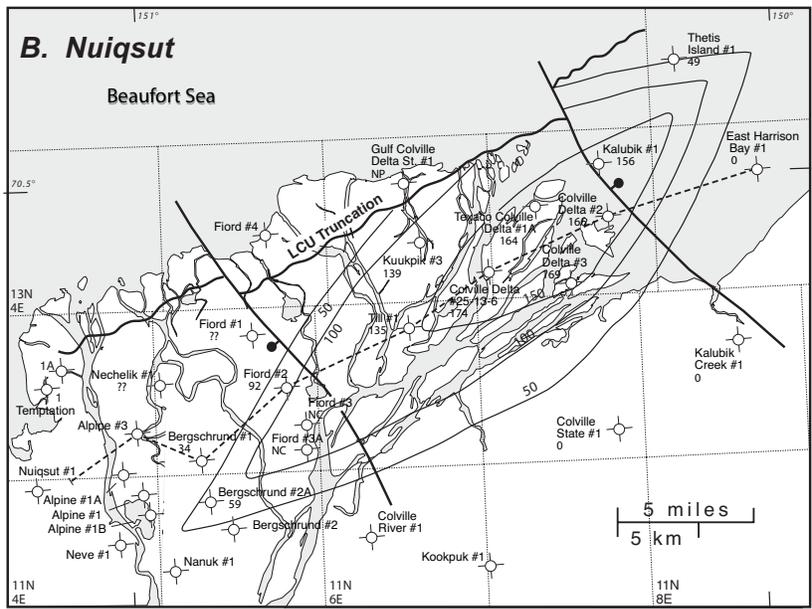
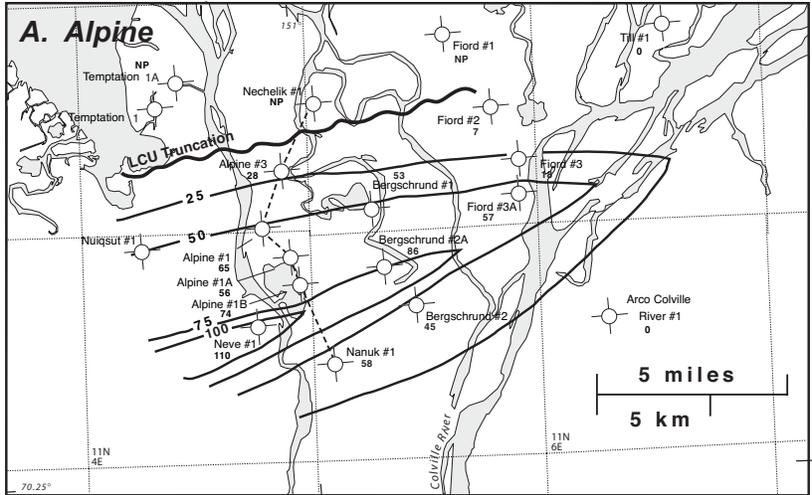
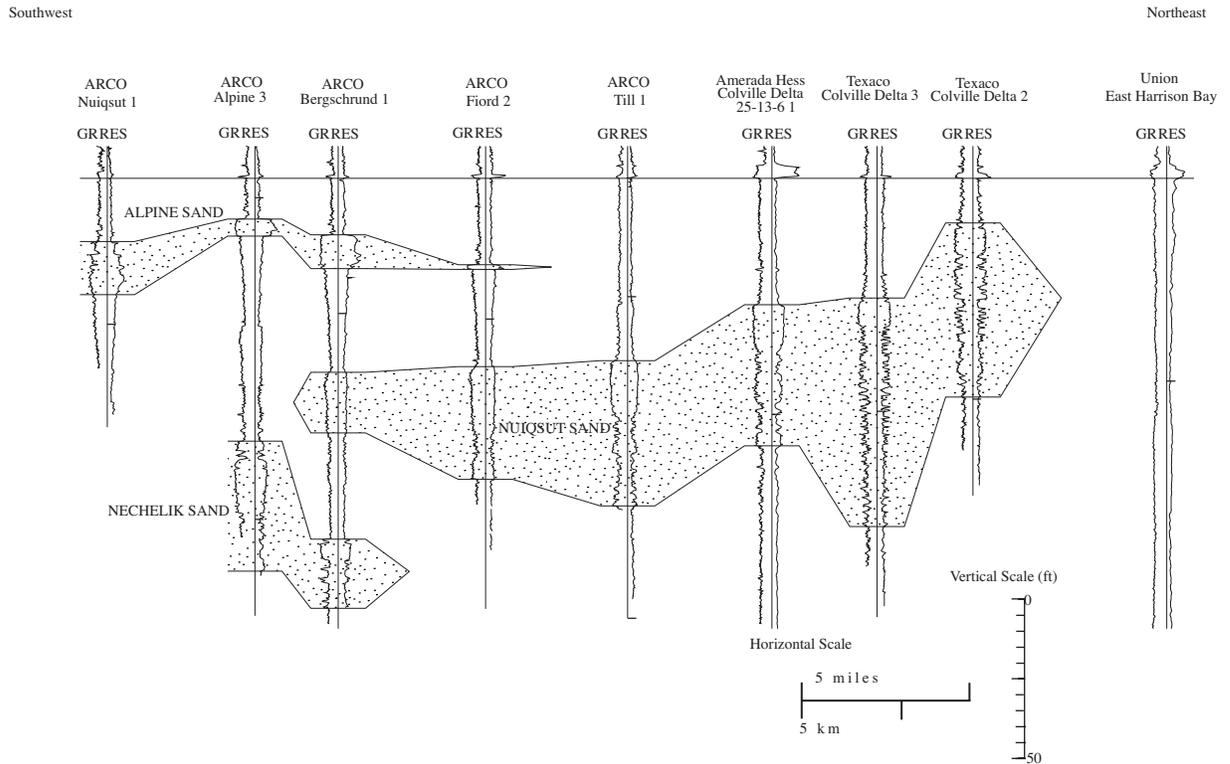
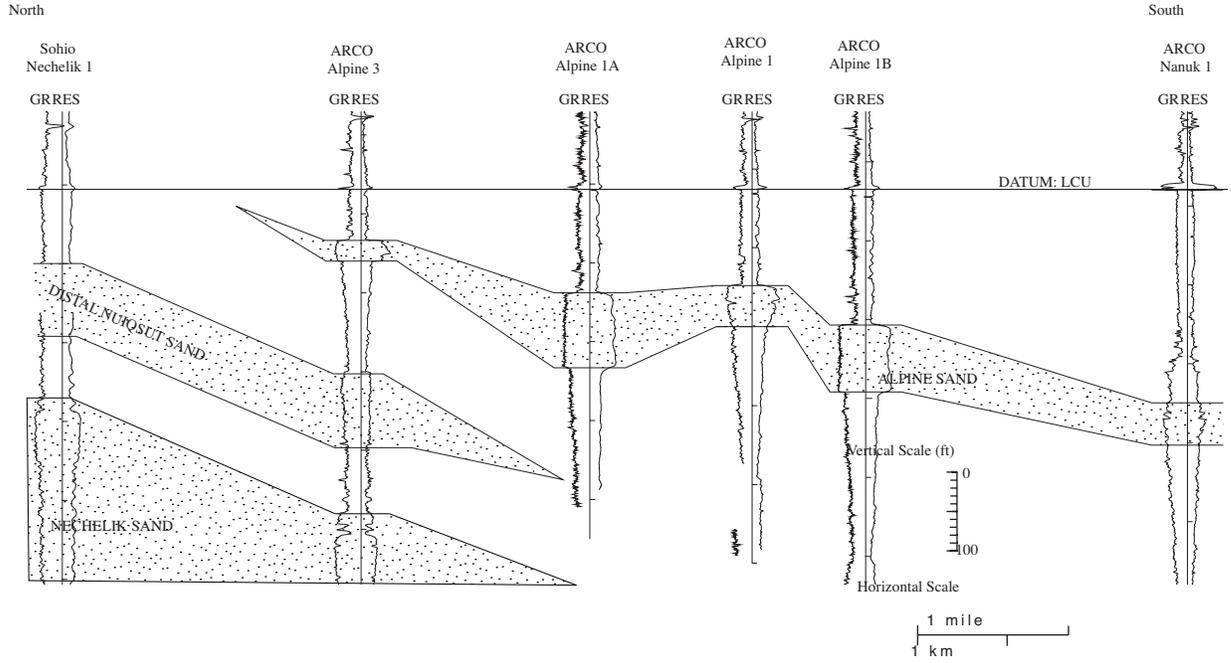


Figure 8. (a, b, and c) Maps showing gross sand thicknesses in the Nechelik, Nuiqsut, and Alpine oil accumulations and the location of corresponding well log sections (d).

Figure 8(d)



The Upper Jurassic Nuiqsut interval is a complex, coarsening and thickening upward sequence, marked by many internal mudstone breaks (fig. 8). The sandstones prograde from north to south and are truncated to the north by the LCU. They are very fine to fine grained, quartzose, well sorted, and highly bioturbated. The porosity of these sandstones ranges from 9 to 15 percent and averages 13 percent; permeability ranges from 2 to 14 md. The gross sand thicknesses can be very high, up to 174 feet, and cover large areas (fig. 8). The Nuiqsut oil-in-place is at least a few billion barrels but the poor permeability of the reservoir is a major challenge to its development; it remains subeconomic.

Nechelik

The Nechelik oil accumulation is in Upper Jurassic sandstone on the northwest flank of the Colville High (fig.8). It was first encountered and cored in the Sohio Nechelik 1 well. This core shows the Nechelik sandstone to be very fine to fine grained, quartzose, and contain a trace to 15 percent glauconite; asymmetric ripple lamination, wavy and lenticular bedding, interlaminated mudstone, and abundant burrowing and bioturbation is present (Kornbrath and others, 1997, p. 21). The Nechelik oil accumulation was next encountered in the ARCO Fiord 1 well where it was tested and flowed 180 BOPD of 29 degree API gravity oil after fracturing. This interval was subsequently encountered in several other western Colville High wells (fig. 8). In Fiord 5, a delineation well to the northwest of Fiord 1, 60 feet of Jurassic (Nechelik) sandstone flowed 1,400 BOPD of 29 degree gravity oil with a GOR of 464 SCF/STB (Petroleum News—Alaska, 1999). The reservoir quality of the Nechelik sandstone is generally poor; porosity is about 12 percent and permeability only 1.5 md or less in some wells (Kornbrath and others, 1997, p. 20). However, the greater producibility of the Jurassic sandstone in Fiord 5 suggests that better reservoir quality can be present in this system. In the Fiord 5 area, the Nechelik sandstone has an average porosity of 16 percent and an average permeability of about 8 md; it will be co-produced with the positionally adjacent and overlying Kuparuk (Fiord) reservoir (AOGCC online Fiord Oil Pool Rules). The controls on the distribution and reservoir quality of the Nechelik sandstone are not entirely clear. It appears that this sandstone can maintain thickness and continuity west of the Colville High (fig. 8). Future drilling of the Nechelik in the Fiord satellite development will provide additional information about this play.

Summary

The shelf sand systems in the Upper Kingak Shale contain very large oil accumulations; the Lower Kuparuk Formation in the Kuparuk River field will probably produce more than 1 billion barrels, the Alpine field will produce at least 439 million barrels, and the Nuiqsut and Nechelik sandstones probably contain several billion barrels of oil-in-place. Reservoir quality and producibility are variably and poorly developed in many places. They are primarily controlled by lithofacies and muddy, shallow shelf depositional environments where extensive bioturbation has significantly diminished reservoir quality in the Nechelik and Nuiqsut systems.

Alpine demonstrates that these sand systems can be stratigraphically trapped. Although technical details are not available, it is clear that 3D seismic data and amplitude-versus-offset (AVO) analysis have been important to the successful exploration of the Alpine sandstone, and acquisition of 3D seismic data has become a standard predrill part of western Colville High and NPRA exploration (see below; Gingrich and others, 2000). The high 1999 bid levels by AAI/APC and subsequently announced discoveries at NPRA prospects that are not located on obvious structures is an indication of the viability of stratigraphic plays west of the Colville High.

The location of sand sources shifted during Late Jurassic and Early Cretaceous evolution of the Colville High. Where northerly sand sources existed in other parts of the Kingak Shale, similar shelf sand systems could have developed. The Miluveach interval between Alpine and the Lower Kuparuk Formation on the Colville High and other parts of the Kingak Shale west of the Colville High are parts of this play. The Simpson and Barrow sandstones (Middle and Lower Jurassic, respectively) may be examples of similar shelf sand systems developed in older parts of the Kingak Shale west of the Colville High in NPRA.

EXPLORATION EXPERIENCES

Reviewing lease sale and drilling history can provide important insights into play concepts and prospects. However, how these play concepts and prospects evolved and how other factors may have influenced exploration decisions is not readily apparent from such a review. The exploration history of the Colville High since 1982 is one that saw many changes in the participants and their positions. For example:

- ARCO was a major leaseholder on the Colville High since its acquisition of Sinclair in 1969 but it did not become a leading explorer of the western Colville High until 1989.

- Texaco combined with AH, UTP and others to drill four wells and a sidetrack in the Colville River Delta area in the 1980s but only Amerada Hess and UTP continued exploration activities by themselves and with others through the 1980s and into the 1990s. UTP was involved in almost all western Colville High lease sales and exploration drilling from 1983 until its acquisition by ARCO in 1998.
- Other western Colville High lease holders included Chevron, Amoco, and Unocal in some areas. All were traded out of their land positions or otherwise removed from active exploration roles by ARCO. AH eventually shared this outcome as it participated in lease sales but not exploration drilling after 1986.
- BP, an original holder of many conditional-status leases on the western Colville High, became restricted to the Tarn prospect but APC was able to enter late (1994) and participate in the Alpine and Fiord successes.
- An AAI/UTP/APC partnership (AAI/APC partnership after acquisition of UTP by ARCO in 1998) eventually controlled all the western Colville High exploration opportunities.

Explorationists from the key companies that were involved (Texaco, UTP, APC, AAI, and APC) were interviewed to obtain information about their experiences in exploring the western Colville High. These interviews focused on identifying the key events, issues, and technical or business considerations that influenced exploration decisions in the area. The interviews indicate that technical advances and evolving play concepts were the biggest driver of exploration activities but that business and exploration strategies were also important to eventual success. The results of the interviews are summarized separately below for the principal companies that were involved.

TEXACO (1980s)

The first play concept tested by Texaco and its partners with Texaco Colville Delta 1 was structural closure at the Sadlerochit stratigraphic level (fig. 3). The earlier lack of success at the Mukluk prospect in the Beaufort Sea in 1983 led them to reevaluation of exploration potential to the south on the Colville High. The Texaco team was confident that they could test a closure at a structural level above that tested in Gulf Colville Delta 1. Serendipitously, Texaco Colville Delta 1 encountered the oil-bearing Upper Jurassic Nuiqsut sandstone (fig. 8) on its way to the original deeper target. The deeper targets in Texaco Colville Delta 1 were wet.

Three more wells and a sidetrack were drilled by the Texaco group to evaluate the Nuiqsut oil accumulation. Considerable efforts were made to understand how to satisfactorily complete and test these wells with mixed results. The generally poor reservoir properties of the Nuiqsut sandstone precluded achieving high flow rates. The low productivity of Nuiqsut wells combined with the lack of infrastructure ownership near to the discovery, led Texaco to eventually conclude that the Nuiqsut oil accumulation was sub-economic and that further exploration expenditures in the area were not justified. Texaco and other partners in the Texaco Group (Diamond Shamrock and the Hunt Companies) were not as bullish as AH and UTP in lease State Sale 54 (January 26, 1988) and subsequently farmed out their Colville High leasehold to AAI in 1990.

AMERADA HESS (1980S–1990s)

AH was one of the partners in the Texaco group and operated one of their four exploration wells, the Amerada Hess Colville Delta 25-13-06 1. AH's conclusion after these tests of the Jurassic Nuiqsut oil accumulation was that continued exploration was warranted. The presence of oil-charged Jurassic sands in the Sohio Nechelik 1 well to the west led them and their partner UTP to participate aggressively in State Sale 54 (January 26, 1988) and bid successfully on nine tracts in the central Colville River delta area. Texaco and other partners were reluctant to be as aggressive as Amerada or UTP and only participated in a minor way in this sale. This signaled the impending breakup of the Texaco Group. Subsequently, attempts were made to replace Texaco by farming out Texaco's leasehold to another major operator on the North Slope. At the time, Conoco, BP, and AAI were considered possible candidates for farming in to Texaco's holdings.

AH worked diligently to secure a farm-in, eventually by AAI, and continue Colville High exploration. In the coming years they continued to participate in lease sales but Amerada Hess Colville Delta 25-13-06 1 was to be the last exploration well they participated in on the Colville High. This interesting outcome was not because of lack of enthusiasm for exploration opportunities but the impact of an unrelated business situation that developed in the company. At about this time, executive management at AH became involved in discussions with the governor of Alaska over royalty levels at their North Star prospect in the Beaufort Sea. These sometimes acrimonious discussions were not successful and the prevailing atmosphere within AH for new Alaska projects was less than supportive. As a consequence, the economic bar for Alaska projects was set high and new exploration projects, such as participation in Colville High wildcats, were unable to overcome the internal economic hurdles. The end result

was that AH became diluted or otherwise traded out of their Colville High holdings and they did not participate in the eventual successes here.

UNION TEXAS PETROLEUM (1983–1998)

UTP was a participant in most of the wells and all the lease sales on the western Colville High from 1984 to their purchase by ARCO in 1998. UTP's exceptional perseverance is traceable to a combination of both business and technical strategies. From the business strategy perspective, Alaska projects offered exposure to large, high stakes plays that could balance the company's portfolio of many smaller, lower risk opportunities. After becoming a publicly traded company in 1987 and subsequent to divestiture of domestic exploration assets in 1990, UTP's Alaska program became a source of upside potential in valuing the company. In addition, executive management at UTP became comfortable with the quality of their Alaska projects, their technical team, and the general environment for new oil field developments on the North Slope. This translated into a proactive willingness to participate in new ventures albeit mostly at low levels.

However, the fundamental foundation for UTP's commitment to Alaska projects in the 1980s and 1990s was the technical merits of the play concepts and prospects that they developed. This technical work was grounded in a regional analysis originally done by Allen Huckabay, the lead geologist on the UTP team. On the Colville High, UTP became the technical leader in pursuing stratigraphic concepts in the Upper Jurassic Kingak Shale and worked hard to ensure that all exploration wells they participated in reached at least this stratigraphic level.

The UTP commitment to the Upper Jurassic increased when geophysicist Dan Hughes joined the UTP team in 1992. Hughes was the leader in applying seismic amplitude analysis in the Upper Jurassic. For example, the first encounter of the Alpine oil field was six feet of oil-bearing sandstone in Fiord 2, a stepout to the Upper Kuparuk River Formation discovery in Fiord 1. Within two days of receiving the Fiord 2 well data, Hughes made a map of the potential Alpine sand distribution based on the amplitude of the migrated stack. This map turned out to be consistent with the depositional systems interpretations of geologist Bob Sperandio and the UTP team became convinced that the Bergschrund 1 well, to be spud about 30 days later, was going to test the Alpine sandstone (fig. 9). When some of AAI's interest in this well became available, it was the Alpine sandstone potential that justified UTP's increase to a 22 percent level. Because the other partners (AAI and APC) in Bergschrund 1 had primary targets at shallower stratigraphic levels (see below), UTP's commitment to an Upper Jurassic Alpine test in Bergschrund 1 was very important to continuing the well to this stratigraphic level.

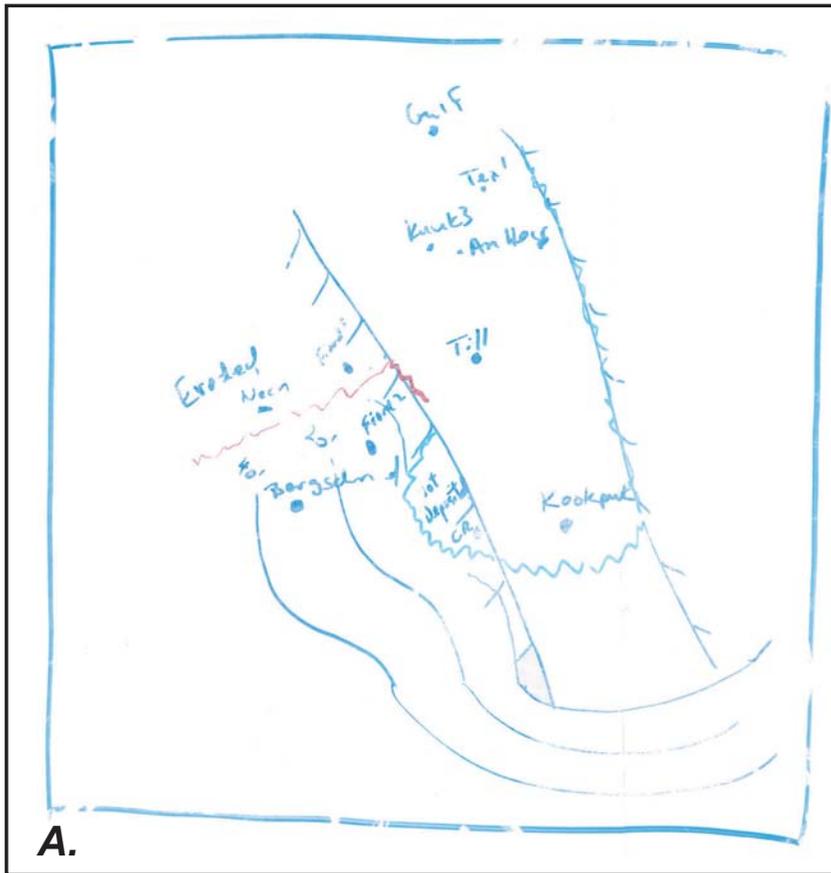
Hughes teamed with log analyst Roger Young and evolved the UTP geophysical work to full-fledged AVO analysis, the first known successful application of AVO technology on the North Slope. It has been an important part of ongoing exploration of the western Colville High and NPRA by UTP (until its purchase by ARCO in 1998) and its partners AAI and APC since the drilling of Bergschrund 1 in 1994.

An aspect of the UTP history in the 1990s that comes up in all discussions with the participants is the importance of team efforts on their eventual success. This team included a petrophysicist, geophysicist, geologists, landpersons, engineer, and supportive management. They voluntarily migrated from their individual offices to a project workroom where work stations and complete digital files made timely evaluation of new data and interpretations possible. A spirit of cooperation and mutual support seems to have been very well developed in this group. In many ways, these attitudes spilled over to their relationships with partners.

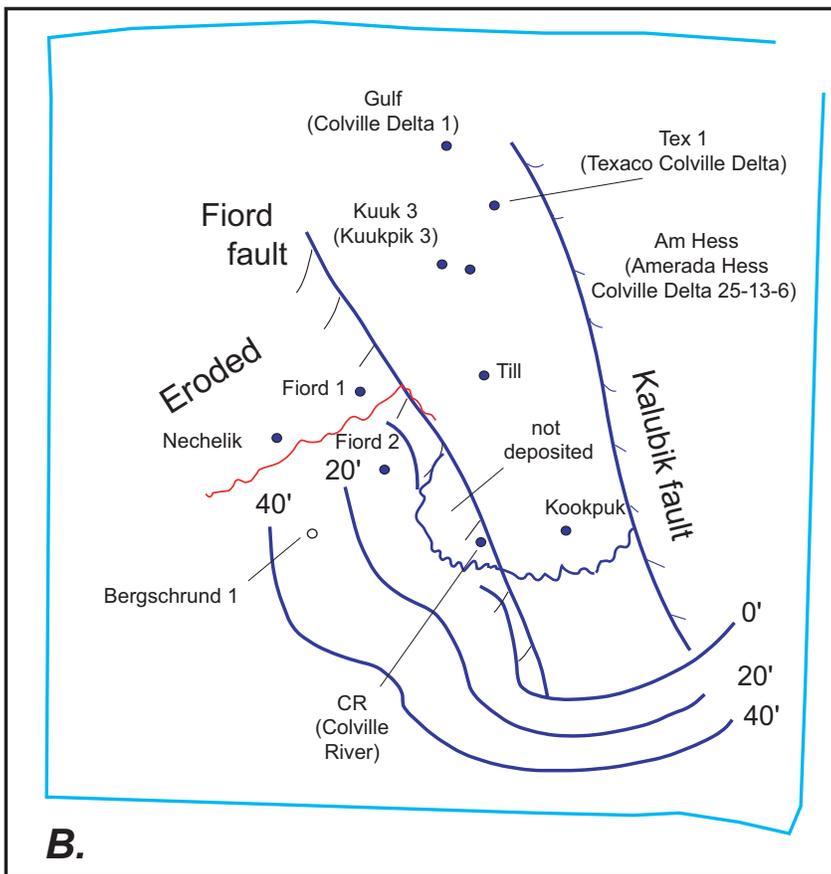
ARCO ALASKA INC. (1980s TO 1999)

The AAI exploration program encountered tough sledding in the late 1980s when various reorganizations affected it in many ways. At one point, the entire exploration group was transferred to Texas to be part of a new ARCO company. After a brief time there, most of these explorationists were transferred back to Alaska and a recommitment to Alaska exploration began to develop. This recommitment culminated with the assignment of Jerry Dees to be AAI vice president of exploration in 1989. He continued in this role until 1991.

The 1980s saw AAI exploration activities on the Colville High mostly limited to lease sale evaluations. However, the exploration potential of the western Colville High, and the advantages of this area due to its proximity to the AAI-operated Kuparuk River field, were well appreciated by many AAI explorationists. When the possibility of farming into Texaco's leasehold in the Colville River delta area came up in 1989, a much-interested AAI team journeyed to Houston to examine the proprietary data from the Texaco group's Colville River delta wells. The farm-in presentation by Texaco, UTP, and AH staff emphasized their encounter with the Nuiqsut sandstone and its supposed potential. However, as the AAI group toured around the data room looking at the well logs for the first time, it was an observation about the Amerada Hess Colville Delta 25-13-06 1 well that raised their interest the most.



A.



B.

Figure 9. (a) Photograph showing the Alpine prospect as sketched on UTP workroom wall 2 days after receiving well data from Fiord 2 and about 30 days before Bergschrund 1 was spud. (b) Guide to the locations and features shown on (a). Photograph courtesy of Dan Hughes.

Geologist Jim Sallee was the first to notice that 21 feet of oil-bearing Upper Kuparuk Formation sandstone was present in the Amerada Hess Colville Delta 25-13-06 1 well (fig. 7). This was the first indication for AAI that this sand was developed west of the Kuparuk River Unit and it became the key information that led to AAI's farming into the Texaco group leasehold and the subsequent round of exploration drilling on the Colville High. Upon returning to Anchorage, Sallee quickly made a map the old-fashioned way. He included information from a seismic fault throw study by geophysicist Dean Gingrich and initially delineated several Upper Kuparuk Formation prospects including Fiord, Bergschlund, Kuukpik, and Kalubik. Targeting the Upper Kuparuk Formation was important because AAI basically agreed with Texaco that the Upper Jurassic Nuiqsut accumulation was sub-economic. At the time, it was concluded that the Upper Kuparuk prospects represented the best chance for finding good reservoir properties on the western Colville High. Recommendations for farming into the Texaco acreage were readily accepted by Exploration VP Dees and the next round of exploration on the western Colville High began.

AAI's new effort included a full range of exploration activities including seismic acquisition, aggressive lease sale participation, and exploration drilling. However, upon completing the Texaco farm-in, a business strategy was developed that eventually proved to be very important to AAI's success in discovering the Alpine field. Gerry Arnold, AAI's exploration land department manager, vigorously proposed and supported the need for AAI to acquire a dominating land position, a reduced number of partners, and both the control and flexibility provided by large exploration units. Arnold was comfortable in tying up the leasehold even if high-quality prospects were yet to be identified; he had a healthy respect for the uncertainty in exploration interpretations. Land persons Jim Rudd, Mark Landt, and Brad Dowdell were instrumental in developing AAI's dominating land position. Landt in particular did much of the heavy lifting in the early 1990s when partner dilution, aggressive lease sale participation, and various trades effectively reduced AAI's partners to UTP by 1994. Texaco, Amerada Hess, Chevron, BP, Unocal, and some smaller groups no longer presented lease ownership obstacles to AAI's program after these efforts. Significant challenges remained, particularly related to Native land holdings, but the dominating land position that was in place by 1994 became an important key to AAI's eventual success in the area.

The first well in the new program, KRU (Bermuda) 36-10-7 was a 100 percent AAI well that was drilled inside the Kuparuk River Unit but just offsetting and only a few days prior to State Sale 70A (January 29, 1991). Dees sponsored the Bermuda well for data gathering prior to the lease sale. Although drilled to gather information about the Kuparuk Formation, this well discovered what has become the Tarn oil field in younger Cretaceous turbidites. The Tarn interval in the Bermuda well represents a moderately distal facies, which was not tested due to a combination of time restraints and internal complications related to management of the Kuparuk River Unit. It would not be known for several more years that the challenging reservoir character of the Tarn sandstone (abundant ductile lithic grains) would be compensated for by the presence of secondary porosity, high gravity oil, and thicker reservoir sandstone in more proximal locations.

The Upper Kuparuk Formation prospects on the western Colville High were refined by Sallee and Gingrich based on many years of company experience with this formation in the Kuparuk River Unit. The key technical approach at this time was the mapping of faults thought to have been active at the time of Upper Kuparuk deposition. Seismic amplitude anomalies on the downthrown side of these faults were interpreted to indicate sandstone presence (Masterson and Eggert, 1992). Two of these fault-controlled prospects were drilled in 1992, Fiord and Kalubik, and both were discoveries (see above); the AAI team was very encouraged about its western Colville High prospects. In addition to fault controls, another Upper Kuparuk play concept was developed. This play mapped out subtle increased sediment thicknesses associated with higher seismic amplitudes on the LCU, a relationship thought to be indicative of Upper Kuparuk River sandstone deposition. The Till prospect was an example of this play concept.

Optimism was high as the 1993 exploration drilling season approached. Drilling of well stepouts was planned on two fault-controlled discoveries (Kalubik and Kuukpik—the name given the original Upper Kuparuk discovery in the Amerada Hess Colville Delta 25-13-06 1); the Till prospect also was to be drilled. However, 1993 was singularly disappointing, not just for AAI's Colville High program but for its Alaska program in general; stepouts on the Kuvlum prospect in the Beaufort Sea, the Sunfish prospect in Cook Inlet, and the Kalubik and Kuukpik prospects on the Colville High were less than successful and the Upper Kuparuk play concept at Till simply didn't work. The fault-controlled Upper Kuparuk prospects on the Colville High did contain oil-bearing sandstone where drilled but the reservoir was either thin, highly cemented, or both in the 1993 wells. The offshore Beaufort Sea and Cook Inlet drilling in AAI's 1993 exploration program combined with aggressive pursuit of new leases in Cook Inlet made this year a very expensive failure for AAI exploration. This resulted in an episode of close scrutiny of the AAI program by Atlantic Richfield executive management. Although the Colville High program was an inex-

pensive part of the overall Alaska effort (dry hole costs were commonly in the \$3 to \$5 million dollar range) and two oil accumulations had been discovered that later became economic (Fiord and Tarn), the review of AAI exploration by Atlantic Richfield executive management placed continued exploration on the Colville High in serious jeopardy. The low prospect values indicated by low AAI bid levels in State Sale 75A reflect the influence of Atlantic Richfield executive management oversight of the Colville High exploration program.

The role of serendipity in Colville High drilling was well appreciated by the AAI team and they worked hard to understand how new wildcats could be positioned to test multiple prospect horizons. However, because of the poor reservoir quality of the Upper Jurassic Nuiqsut and Nechelik sandstones, most AAI work on defining new non-Kuparuk Formation prospects was in the Brookian section above the Kuparuk Formation. These prospects became especially important after the 1993 drilling season showed that Upper Kuparuk sandstone had a much more limited distribution than originally hoped. The technical work on the Brookian section included development of prospects in the topsets of the prograding Cretaceous clinofolds, but more importantly, a focus was developed on turbidite systems in base-of-slope settings. The ability of these turbidite systems to trap oil had been demonstrated at the Tarn and Moraine prospects (see above). The general distribution of the turbidite-bearing packages could be mapped with the available 2D seismic data and one turbidite prospect on the west flank of the Colville High, the Neve prospect, was very large. Parts of the Neve prospect that were encountered in some distal wells showed sand development although the sandstones appeared to be wet. However, the Neve prospect was large enough that much room existed updip for an oil accumulation; this prospect was to become AAI's primary objective in the Bergschrund 1 well.

The Neve prospect was not well received by Atlantic Richfield executive management that came to oversee the AAI program. In general, stratigraphic traps were not in favor and valiant efforts to demonstrate the validity of the turbidite prospects, even existing oil accumulations like Tarn, were not successful. However, the 1994 drilling recommendations for the Colville High were rooted in the tested and verified fault-control of Upper Kuparuk sandstone. Fiord 2 was drilled by AAI and UTP as a stepout on the Upper Kuparuk discovery in Fiord 1; the target interval contained thin Upper Kuparuk sandstone but, very importantly, this well also encountered 6 feet of oil-charged Upper Jurassic Alpine sandstone. AAI's original Bergschrund prospect was a fault-controlled Upper Kuparuk prospect like Fiord but less robust. It could not alone justify the Bergschrund 1 well so the large size of the shallower Neve turbidite prospect became the primary target for AAI explorationists in this well. However, Atlantic Richfield executive management's opposition to the Neve prospect prevented AAI funding of Bergschrund 1. It was at this time that AAI's dominant land position came into play.

A rush effort was made to farm in another partner to fund the dry hole costs of Bergschrund 1. APC was successfully recruited and AAI's percentage went from about 90 percent to 56 percent as existing partner UTP matched APC's buy-in at a 22 percent level. It was for this reason that drilling of the Bergschrund 1 well went ahead in 1994. UTP quickly recognized the significance of the Alpine sand in Fiord 2 for the proposed Bergschrund 1 well location (see above) but APC's commitment to Bergschrund 1 came from their acceptance of the Neve turbidite prospect as a primary objective (see below).

AAI's technical work did not focus on the Upper Jurassic prior to the Alpine discovery in Bergschrund 1 with two exceptions. First, geophysicist Jerry Veldhuis demonstrated the separate distributions of the Nuiqsut and Nechelik sands in the Colville River delta area soon after farming in to the Texaco leasehold in 1990. Second, clastic sedimentologist Bill Morris defined the depositional systems setting for the Upper Jurassic sandstone systems and early on predicted the potential for sand in what was to become the Alpine interval. Morris's prediction came from the interpretation of regional well log sections and in particular a section he constructed upon receiving the Kalubik 1 well data in 1992 (fig. 7). Morris interpreted the truncated coarsening upward character of the Alpine interval in the central part of the Colville High to indicate a sand-prone character like that in the older Nuiqsut and Nechelik intervals. He mapped a regional trend on the northwest Colville High where he thought the Alpine interval could be sand-bearing (fig. 10). An early hand-drawn version of this map was used to evaluate the Bergschrund 1 location; Morris's Alpine trend passed through the Bergschrund 1 location and became the AAI Colville High team's reason for including the Jurassic in the planned depth of this well. Some opposition to this planned depth was always present in AAI as the unfavorable view of the Colville High prospects by Atlantic Richfield executive management and the accompanying stress on the drilling budget created a constant effort by senior management to lower costs and retreat from the program. Unknown to the exploration team at the time, AAI senior management started making plans to terminate western Colville High drilling after the Bergschrund 1 well. However, it was always understood within the AAI exploration team that UTP was likely to require drilling to the Jurassic in Bergschrund 1 and that internal battles to preserve this well depth could be passed on to UTP if necessary.

Fiord 2 and Bergschrund 1 did not change Atlantic Richfield executive management's pessimistic view of any of the western Colville High prospects; the Neve turbidite was wet, the Upper Kuparuk sandstones were thin, and the Alpine sand would "not go anywhere." As a consequence, continued pressure to retreat from the program existed and the AAI land position was again used to enable continued drilling. The 1995 Alpine delineation wells, Alpine 1, 1A, and 1B and Fiord 3 and 3A, were funded by continued dilution of AAI's land position to 56 percent and spreading of both UTP and APC at 22 percent levels through western Colville High acreage. The Alpine 1, 1A, and 1B wells were highly successful and as a result, widespread support for Colville High exploration was reestablished within ARCO.

The exploration that has continued after 1995 has been very aggressive. Most of the wells drilled between 1995 and 2000 were follow-ups to the Alpine discovery. Even Nanuk 1, drilled in 1996, had to be sold within AAI as an Alpine delineation well although the AAI exploration team (and the other well partners) considered the primary target to be Albian turbidites. But now stratigraphic traps are emphasized, the application of AVO analysis is common, and 3D seismic data are acquired at the predrill exploration stage. Alpine and Tarn are in production and Fiord, Nanuk (Nanuq), and the part of Nechelik connected to Fiord will be developed as satellites to Alpine. The success of Alpine led to new exploration in NPRA and essentially required a new round of federal leasing there. AAI, the most aggressive explorer on the western North Slope, purchased UTP in 1998 and was itself purchased by Phillips Petroleum in 2000 through a federally required spinoff resulting from the larger acquisition of ARCO by BP.

ANADARKO PETROLEUM (1994–1999)

The need for AAI to externally fund dry hole costs for the 1994 drilling season led them to APC's doorstep. APC was experiencing much exploration success in the Gulf of Mexico and overseas. Their exploration program was well supported, they were receptive to new opportunities, and they had just started their Alaska involvement by participating in Exxon's Thetis Island well.

Bergschrund 1 was a wildcat on new prospects but APC's evaluation of the Neve turbidite prospect here was similar to AAI's and the Neve prospect competed successfully against overseas prospects that were being considered at the time. AAI promoted APC into Bergschrund 1 and their participation earned them a 22 percent interest in a part of AAI's southwest Colville High leasehold. The discovery of the Alpine field in this well, combined with APC's acceptance of the UTP seismic amplitude studies, enabled them to continue to expand their Colville High interest. As ARCO management continued to doubt the merits of Alpine and UTP's seismic analysis, APC was able to expand their 22 percent interest by disproportionate spending in the 1995 delineation wells (Alpine 1, Fiord 3, and their sidetracks). These expenditures provided Anadarko a 22 percent interest in an expanded leasehold in the southwest Colville High including the Fiord oil accumulation.

The discovery of the Alpine field in Bergschrund 1, followed with the successful delineation wells in 1995, started an ongoing exploration effort that now finds APC part of the technical and leasehold leaders in both the western Colville High as well as the continuation of exploration westward to NPRA. This aggressive effort has seen the Alpine field become economic and the Fiord and Nanuk (Nanuq) accumulations to be developed as Alpine field satellites. Many new prospects were developed by the AAI/UTP/APC team. As the newest and third partner in this team, APC had an interesting role in exploration decision-making. In general, APC did not need to take the lead in sponsoring initiatives but more commonly reflected on situations, evaluated their partners' positions, and facilitated consensus building up to the time of ARCO's purchase of UTP in 1998.

SUMMARY

The success of western Colville High exploration efforts from the 1980s through the 1990s can be traced to a combination of business strategies, exploration strategies, and technical advances. Two business strategies were very important including:

- UTP's commitment to an active Alaska program to balance its investment portfolio and provide significant upside potential for its exploration expenditures.
- AAI's commitment to obtaining a dominating land position over the entire western Colville High, regardless of where exploration potential was perceived at any given time.

The exploration strategy that was important and used in various ways by all the wildcat drilling partners was:

- Stratigraphically stack objectives as much as possible; this has worked extremely well on the Colville High where the Ugnu, West Sak, Tabasco, Moraine, Tarn, Kuparuk River, Alpine, Nuiqsut, and Nechelik oil accumulations have all been discovered through serendipitous penetrations.

The technical advances that were important included:

- Recognition by AAI that Upper Kuparuk River potential existed west of the Kuparuk River field and the relationship of contemporaneous faulting to sand deposition. This led to discovery of the Fiord and Kalubik accumulations.
- Recognition by UTP that seismic amplitudes were important to understanding sandstone distribution in the Upper Jurassic. Successful AVO analysis on the North Slope was an outcome of this work.
- Depositional systems analysis by UTP and AAI that evaluated the regional Upper Jurassic to Lower Cretaceous (pre-LCU) geology and explained how shelf sand systems like the Nuiqsut, Nechelik, Alpine, and Lower Kuparuk could be developed and predicted.

The role of management in this period of Colville High exploration was mixed:

- ARCO's revitalization of Alaska exploration starting in 1989 and in full speed by the time of his transfer to VASTAR in 1991 was led by their exploration vice president, Jerry Dees.
- AAI's success at Alpine was accomplished in spite of Atlantic Richfield executive management opposition; the 1994 and 1995 drilling programs that discovered this field were possible because of marketable prospects and land positions, not management support.
- UTP's perseverance and effective team effort reflected strong, continued support from a management that was comfortable with both the business and technical merits of their Alaska exploration program.
- AH's inability to participate in Colville High wildcat drilling and the eventual exploration successes reflected at least indirect negative influences of executive management on Alaska projects.

CONCLUSION

The Colville High is an especially important structure on the North Slope of Alaska. It has more than 500,000 acres of closure at key stratigraphic levels and 14 oil accumulations are now known on or adjacent to it. Nine of these accumulations, all or in part, have become commercial; together they contain original reserves totaling at least 3 billion barrels (table 1). The known accumulations probably contain more than 30 billion barrels of oil-in-place. These accumulations have all been discovered since 1965, when the first wildcat was drilled on the structure. The original play concepts for the Colville High, structural closure at Paleozoic and Triassic stratigraphic levels, were not successful. What were successful were stratigraphic plays in Jurassic and Cretaceous sandstone-bearing clastic systems.

The development of stratigraphic play concepts and their successful pursuit has mostly been accomplished since about 1984. The compilation of lease sale history, exploration drilling history, exploration results, and exploration experiences for the Colville High since this time, defines an interesting and complex interplay of technical analysis and advances, business strategies, internal company challenges, and serendipity that ultimately led to the discovery of about 600 million barrels of new reserves in the 1990s. These successes are rooted in evolving play concepts that guided exploration expenditures. A total of \$37.5 million of high bonus bids was spent in lease sales and about 400,000 feet of exploration drilling was completed through 1999. This effort enabled the discovery and/or evaluation of nine oil accumulations on the western Colville High including Tarn (at least 50 mmbbls of reserves), Fiord (at least 50 mmbbls of reserves), and Alpine (at least 439 mmbbls of reserves). Some of the conclusions from this exploration history of the Colville High are:

- There are two stratigraphic plays and one combination structure/stratigraphic play that have been successfully pursued on the Colville High. From younger to older, these plays are (1) mid and Late Cretaceous (Brookian) turbidites, (2) normal-fault controlled, Hauterivian (Beaufortian) sandstone deposits on the LCU, and (3) large Upper Jurassic and Early Cretaceous (Beaufortian) mudstone-encased shelf sand systems.
- Important technical advances included: (1) Upper Kuparuk potential and its controls were recognized west of the Kuparuk River field (Fiord and Kalubik discoveries), (2) seismic amplitudes were recognized to be important to understanding oil-charged sandstone distribution in the Upper Jurassic, (3) depositional system analysis explained how shelf sand systems like the Nuiqsut, Nechelik, Alpine, and Lower Kuparuk could be developed and predicted, and (4) 3D seismic data became a predrill exploration tool.
- Exploration and business strategies that became important to success were: (1) the common location of wildcats to test multiple (stacked) prospects, (2) systematic development of a dominating land position over the entire western Colville High (AAI), and (3) a low-level but persevering participation in all possible exploration opportunities (UTP).

- Explorationists were able to overcome internal company hurdles in some cases (AAI) but not in others (AH). Management leadership and support was important to AAI's revitalization of exploration in 1989–1991, UTP's 15 years of persevering efforts, and APC's receptiveness to new Alaska opportunities.
- The role of serendipity has been especially important throughout the exploration history of the Colville High. Of the 14 oil accumulations on the Colville High, only three, the Upper Kuparuk accumulations at Fiord and Kalubik and the Torok Formation accumulation at Nanuk (Nanuq), were the operator's (or the operator's explorationists in the case of Nanuq) primary objective in wildcat wells.
- The exploration results on the Colville High are important to assessing the exploration potential of other North Slope areas. Colville High explorationists have already pursued prospect opportunity to the south along the Tarn trend (Meltwater discovery, see above) and to the west in NPRA where over \$104 million was spent on six priority prospect areas in the May 5, 1999, Federal lease sale. On May 21, 2001, Phillips and APC announced that six of their first seven exploration wells (including one sidetrack) in the NPRA were successful. The six successful wells targeted stratigraphic traps in the Jurassic Kingak Shale.

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