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Sheet 2 of 2

Potential Tight Gas Resources in a Frontier Province - Jurassic Through Tertiary Strata Beneath the Brooks Range Foothills, Arctic Alaska

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Explanation of Well Log Plots.

Lithology: shale, gray with black dashes; siltstone, green; sandstone, yellow.
Gamma ray: gamma-ray log in American Petroleum Institute (API) units.
Depth: measured depth in feet; TD, total depth of well.
http://www.google.com/intl/en_us/mapfiles/lmc.pngResistivity or Induction Log Deep or Laterolog: electrical resistivity in ohm-meters.
Mud weight: mud weight in pounds per gallon.
Sonic: sonic travel time in microseconds per foot.
Depth: measured depth in feet, drillstem test in green bars, and cored intervals in reddish brown bars. GTS, gas to surface; TSTM, too small to measure; WTS, water to surface; LCU, Lower Cretaceous unconformity; PBBL, Pebble shale unit; 0.67 pressure-depth ratio in pounds per square inch per foot, based upon maximum of initial or final shut-in pressure.
TVDSS: true vertical depth subsea in feet.
General Eng.: casing shoe, black triangles.
TOC: total organic carbon in weight percent.
SGasDST: gas recovered from drillstem test, red flag to 0.8.
SC1gas: methane recovered in drilling mud, red flag to 0.6.
SC2gas: ethane and heavier gases in drilling mud, red flag to 0.4.
Sstain: oil stain, green flag to 0.65.
Soilshow: oil show, green flag to 0.45.
Sdeadoil: dead oil in core or cuttings, green flag to 0.25.
Sfluor: fluorescene in core or cuttings, green flag to 0.05.
Vitrinite Reflectance: values in percent: measurements, red triangles; least-squares fit, solid red line.

Summaries of drilling histories, drillstem tests, fluid recoveries, and pressures for the Awuna, East Kurupa, Itkillik River Unit 1, Kugrua, Seabee, Tulugak,and Tunalik wells are taken without modifications from drilling and geologic reports by Husky Oil NPR Operations Inc. (1983) and are available at http://nerslweb.cr.usgs.gov.

Awuna well

Core no. 3 was cut from 6,010' to 6,040' with full recovery. Higher than

normal formation pressures were encountered throughout the interval. At 6,344' the well started to flow on connections, ..., the mud weight was brought up to 11.2 ppg from 10.4 ppg to control the well. The mud weight was gradually brought up to 12.5 ppg while drilling to 7,048' where the mud was gas cut to 12.0 ppg. The mud was brought up to 14.5 ppg and drilling continued. The mud weight was increased with depth to 16.3 ppg at 8,303', the planned casing depth.

The 9-5/8" casing was run to 8,297' and cemented. ... The shoe was drilled out to 8,314' and the formation tested to a 0.962 psi/ft. equivalent gradient with no leakoff. ... Increased mud weight to 16.8 ppg and drilled to 8,412'. Ran drill-stem test 1 with no water cushion. Opened tool with fair blow increasing to strong blow; mud to surface in 56 minutes; water to surface in 65 minutes. Well flowed water at rate of 2,057 barrels per day, with 6,800 ppm chlorides. Flowed for three hours, with initial flow pressure of 2,948 psi and final flowing pressure of 3,848 psi. Shut-in for six hours with a final shut-in pressure of 7,132 psi.

Resumed drilling 8-1/2" hole to 8,573', with 16.8 ppg mud weight. At 8,573', gas-cut mud was encountered, and ... mud weight was increased to 18.0 ppg to control the well.

Note: From this depth to 10,123' circulation was lost several times and the well was squeeze-cemented prior to running a 7-5/8" liner, after which the well was drilled to TD using mud weights of approximately 15.6 ppg.

East Kurupa Well

DST 1. 12,112-12,132, 12,148-12,168 ft. 6 hr 4 min test. Flowed gas at rates from faint to 400 MCFPD. Backscuttled 47 barrels of muddy water.

DST 2. 10,749-10,769, 10,782-10,802 ft. No fluid or gas recovered during 4 hr 5 min test. Backscuttled out 40 barrels water cushion.

DST 3. 10,749-10,769, 10,770-10,780, 10,782-10,810 ft. 3 hr 23 min test. Medium blow decreasing to very faint blow. Backscuttled out 40 barrels water cushion.

DST 4. 8,930-8,960, 8,995-9,015, 9,095-9,115, 9,360-9,410 ft. 6 hr 12 min test. Gas to surface in 11 min. Flowed at 1300 MCFPD rate through 20/64" choke. Backscuttled out 1 barrel water cushion.

DST 5. 7,150-7,190 ft. 7 hr 57 min test. Gas to surface in 5 min. Flowed at 3500 MCFPD rate on 3/8" choke, 2700 MCFPD on 7/16" choke and 3800 MCFPD on 54/64" choke. Backscuttled out 1 barrel water cushion.

DST 6. 7,050-7,090, 7,100-7,120, 7,130-7,230 ft. 13 hr 42 min test. Gas to surface in 16 min. Flowed gas at rate of 1800 MCFPD on 11/64" choke, 3000 MCFPD on 28/64" choke, and 2660 MCFPD on 36/64" choke. Backscuttled out 2 barrels of muddy water.

Seabee well

Drillstem test 4, 2,652-2,664 ft test interval

Initial flow period: Immediate strong blow, continued throughout; gas to surface too small to measure in 9 min; max 50 psi at Halliburton manifold on rig floor. Final flow period: Tool opened with 100 psi, decreased gradually to 3 psi at 105 min; increased to 12 psi, then decreased to 5 psi for remainder of test at 180 min; no fluid to surface.

Drillstem test 3, 5,366-5,394 ft test interval

Gas to surface in 4 minutes. Ran five flow tests with choke sizes ranging from 6/64 to 17/64 inches, measuring flow rates ranging from 0.5 to 6.2 mmcfd, with surface flowing pressures ranging from 2100 to 2850 psi. Shut-in times ranged from 5 to 16 hours, with pressure measured on four downhole gauges at 5,323-5,379 ft. Average shut-in pressure for all gauges and all shut-in periods was 3617 psi. Pressure-depth ratio is equal to 0.67 psi/ft.

Tunalik well

Drilling halted for 65 days at 12,557 ft as mud losses alternated with gas in mud returns at surface. Mud weight varied from 15.1 to 16.0 ppg. At one point, after six hours circulation, had 16 ppg in and 14.7 ppg out with 1,900 units of gas. Finally were able to drill ahead after casing and cementing. Similar problems were encountered at 14,664 ft; mud weight was increased to 18.2 ppg at 14,726 ft. Drilling halted for 27 days at 14,726 ft until a liner was installed. Drilled ahead to 16,107 ft with 18 ppg mud, then drilled to TD at 20,355 ft with reduced mud weights.

Kugrua well

The Kingak Shale is geopressured throught the interval from 7650 ft to 8610 ft, and the inherent drilling problems associated with overpressuring occurred. Pore pressure did not reach the postulated 15.4 ppg derived from seismic interpretation, but it would have been impossible to have increased the mud weight beyond the 12.1 ppg which was used because of lost-circulation problems previously encountered.

A thick, somewhat porous sandstone unit occurs from 8713 ft to 8830 ft and was probably deposited as a barrier bar-beach complex formed during a southward progradation of the shoreline. Three thousand two hundred barrels of mud were lost in the top of this sandstone. Because of the overpressured conditions and attendant problems encountered in the overlying shale, the decision was made to set intermediate casing through this troublesome interval.

From 8897 ft and continuing to 9334 ft, deeper marine black shale deposits occur. This shale is overpressured at the top and is subject to sloughing.

At the top of Kingak, pore pressures increased slightly to 11.0 ppg and mud weight was raised to 11.3 ppg. After drilling and reaming, no problems were encountered in the interval. The Kingak Shale ... had increasing pore pressure from 11.0 ppg at 7304 ft to 11.3 ppg at 8712 ft. Severe sloughing shale problems were encountered throughout the interval.

Itkillik River Unit1

Opened tool for 2 hour test. Weak blow for 2 hours. 2 hour shut in. Recovered 120' of slight gas-cut rat-hole mud. FSIP 1485 psi.

Summary

Ample evidence exists for the presence of tight gas accumulations within Brookian and Beaufortian strata in the foothills of the Brooks Range. The evidence consists of numerous gas shows, stratigraphically dispersed source rocks, consolidated low-permeability reservoirs, and indications of overpressure in well log signatures and pressure measurements.

Maximum burial depths have been sufficient to produce gas, as shown by vitrinite reflectance values that commonly exceed 0.8%. Residual total organic carbon values are greatest in the basal Brookian units, less in the Kingak Shale, and least in the Torok Formation, as shown below.

Average values of vitrinite reflectance (Ro) and total organic content (TOC).

Well Name	Torok Formation		Hue Shale and Pebble shale unit		Kingak Shale	
	Ro	TOC	Ro	TOC	Ro	TOC
North Inigok	0.50	1.00	0.54	3.68	0.70	1.59
Ikpikpuk	0.56	0.90	0.70	2.08	0.74	1.86
Kugrua	0.65	1.21	0.91	1.76	0.93	1.38
Inigok	0.59	1.49	1.01	2.76	1.12	1.82
South Meade	0.69	1.00	0.91	1.39	1.20	1.07
Seabee	0.93	1.30	1.73	1.83	2.24	3.03
Tunalik	1.01	1.24	1.85	2.83	2.29	1.30
Tulugak	1.28	1.12	2.56	1.62	--	--
average	0.78	1.16	1.28	2.24	1.32	1.72

The basal condensed sections, which occur in both the Torok Formation and the Kingak Shale, commonly exhibit indications that pore fluids are overpressured, including low sonic velocity, low resistivity, and high mud weights.

Data from Brookian rocks show that average porosity is around 10 percent and permeability is commonly less than 0.1 millidarcy. Descriptions of samples from these same intervals indicate that sandstones are well consolidated and very fine to fine grained. Reservoirs are likely to consist of low-permeability sandstones.

Reductions in resistivity and increases in sonic transit time, both causing leftward deflections on the well logs, are evidence of overpressuring. These deflections occur over vertical intervals of thousands of feet in most of the wells penetrating the Kingak Shale and in a few penetrations of the Torok Formation. Examples are the 11,500- to 14,300-ft interval within the Kingak Shale in the Tunalik well and the 9,500- to 12,600-ft interval within the Torok Formation in the East Kurupa well.

In three wells (Tunalik, Seabee, and Lupine), the mud weights required to drill the Kingak Shale exceeded 16 ppg, commencing at depths ranging from 11,800 to 13,200 ft. These three wells, located in areas that have undergone significant uplift and erosion, are distributed widely from west to east along the northern edge of the foothills belt. No other wells have penetrated the Kingak Shale south of this line of three wells. It is apparent that "hard overpressures" can be expected when drilling the Kingak Shale within the foothills belt.

We hypothesize that overpressure was initially generated by compactional disequilibrium caused by rapid accumulation of Cretaceous depositional sequences containing a large proportion of mudstone, particularly in the deeper part of the Colville Basin. Before this initial overpressure could dissipate through fluid escape, oil and gas generation during the Late Cretaceous to Tertiary and contractional structural deformation during the early Tertiary contributed to the spatial and temporal maintenance of overpressure. It is possible that gas generated during deep stratigraphic and structural burial during the late Cretaceous to early Tertiary displaced water from overpressured - and therefore undercompacted - pore networks, resulting in the undercompacted and gas-charged system that is observed in many exploration wells drilled in the foothills. In addition, significant uplift and unroofing during Tertiary structural deformation (Burns and others,

2006), combined with apparently effective seals associated with the predominantly mudstone strata of the Torok and Formation, may contribute to "relic overpressure" that has not equilibrated with current depth of burial.

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References

Burns, W. M., Hayba, D., O., Houseknecht, D. W., and Rowan, E. L., 2006, Estimation of the amount of eroded section in the partially exhumed Colville Basin of the Alaska North Slope using geophysical logs, in Haeussler, P., and Galloway, J., eds., Studies by the U.S. Geological Survey in Alaska, 2006: U.S. Geological Survey Professional Paper, in press.

Deming, D., J.H. Sass, A.H. Lachenbruch, and R.F. DeRito, 1992, Heat flow and subsurface temperature as evidence for basin-scale ground-water flow, North Slope of Alaska, Geological Society of America Bulletin, v. 104, p. 528-542.

Martinsen, R. S., 1994, Summary of published literature on anomalous pressures: implications for the study of pressure compartments: Chapter 2 in Ortoleva,P.J. ed., Basin compartments and seals, American Association of Petroleum Geologists Memoir 61, p. 27-38.

Moore, T.E., and Potter, C.J., 2000, Torok-Fortress Mountain duplex, north-central Brooks Range foothills, Alaska [abs.]: Geological Society of America Abstracts with Programs, v. 32, p. A-32.

Potter, C.J., and Moore, T.E., 2005, Brooks Range foothills structural plays: applicability of Canadian Rockies foothills play types framework [abs.]: 2005 AAPG Annual Convention, Abstracts Volume, v. 14, p. A112.

O'Sullivan, P.B., 1999, Thermochronology, denudation and variations in paleosurface temperature; a case study from the North Slope foreland basin, Alaska: Basin Research, v. 11, no. 3, p. 191-204.

Abbreviations Used in Drilling Reports and Drillstem Test (DST) Results

FSIP - final shut-in pressure
ISIP - initial shut-in pressure
MCFD, mcfd, MCFPD - thousand cubic feet per day.
MCFG - thousand cubic feet of gas.
mmcfd - million cubic feet of gas per day.
ppg - pounds per gallon.
ppm - parts per million.
psi - pounds per square inch.