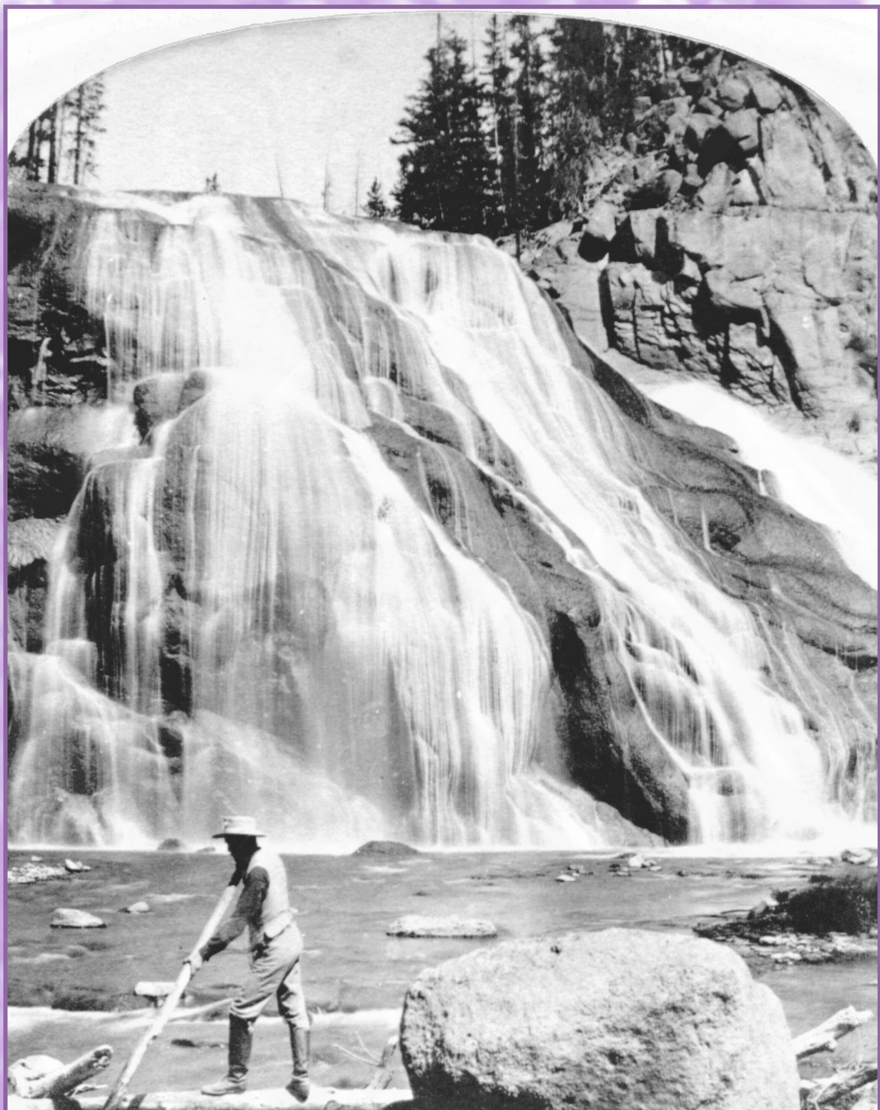
Wyoming Geo-notes
Number 69



In this issue:

Pyrophoricity of Powder River Basin coals–considerations for coalbed methane development

WYDOT's water well at Mule Creek Junction rest area, Niobrara County, Wyoming

Wyoming State Geological Survey
Lance Cook, State Geologist

Laramie, Wyoming
April, 2001

FEATURED ARTICLES

CONTENTS

WYOMING GEO-NOTES: This quarterly digest on the state's geology and mineral resources and activities of the Wyoming State Geological Survey is available by subscription (four issues for $15.00) or as single copies at $5.00 each. Two-year subscriptions are accepted.

People with disabilities who require an alternative form of communication in order to use this publication should contact the Editor, Wyoming State Geological Survey at (307) 766-2286. TTY Relay operator 1 (800) 877-9975.

Printed on recycled fiber paper. 750 copies printed by Pioneer Printing and Stationery Company, Cheyenne, Wyoming.

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Front cover: Half of stereo pair #1259 entitled "Falls of the Gibbon" by F. Jay Haynes, Photographer, circa 1885. Albumen print from F. Jay Haynes' studio in Fargo, Dakota Territory. From the personal collection of Lance Cook. The falls were discovered by William Henry Jackson and John Coulter during the 1872 Hayden Survey [of Yellowstone National Park]. The Gibbon River was named in honor of General John Gibbon, its first explorer. For more information on the falls, refer to Rubinstein, Whittlesey, and Stevens (2000), *The Guide to Yellowstone Waterfalls and Their Discovery*: Westcliff Publishers, Inc., Englewood, Colorado.

MINERALS UPDATE

OVERVIEW

Lance Cook
State Geologist-Wyoming State Geological Survey

We appreciate all the favorable responses to our new format *Wyoming Geo-notes* that debuted last issue. We will continue developing and improving this publication, so we do welcome reader response and suggestions. Very soon, *Wyoming Geo-notes* will also be available on the Survey's web site (http://wsgsweb.uwyo.edu), which will allow our readers an alternate to the printed version and ultimately provide a digital archive of previous issues.

We will continue to offer on our web site supplemental or more detailed information that could not be included in the printed *Wyoming Geo-notes*. For example, this issue contains an article on the spontaneous combustion of coal in the Powder River Basin (see **PYROPHORICITY (SPONTANEOUS COMBUSTION) OF POWDER RIVER BASIN COALS. . .**), but the interested reader can now access a more detailed version on our web site.

In each new *Wyoming Geo-notes*, we also plan to publish a short article or two on new or especially interesting aspects of Wyoming geology, usually written by an outside author. In this issue, Mark Falk of the Wyoming Department of Transportation (WYDOT) describes a project that originated as a water well for a WYDOT rest area but may have resulted in both an oil discovery and a heretofore unknown geothermal source. In the next issue we will publish a report on a new fossil bird species recently discovered in the Green River Formation. Wyoming has some of the world's most fascinating, unique geology and we want to make people more aware of what the state offers. We invite our readers to help this effort or even participate.

Coalbed methane (CBM) continues to be at the forefront of the state's mineral activity. The Survey is completing a revised version of our popular Information Pamphlet 7, *Coalbed methane in Wyoming*, that contains some new and some updated discussions (see **COALBED METHANE UPDATE**). Projected exploration activity and expected production increases from this fledgling industry are addressed in the revised publication, which will become available about the time this issue of *Wyoming Geo-notes* is released.

. . . to achieve the 900 BCF per year of gas production expected by 2010, the pipeline capacity must increase at least five-fold.

To assist with a number of issues that have arisen from the CBM activities in the Powder River Basin (PRB) four of the geology sections at the WSGS are participating in a $400,000 grant from the Wyoming State Legislature. The Survey, in cooperation with a number of state and federal agencies, will develop a geologic and hydrologic database for the northern PRB (see a description of this in the section entitled **INTERACTIVE GEOLOGIC, HYDROLOGIC, AND WATER QUALITY DATABASE FOR THE NORTHERN POWDER RIVER BASIN, WYOMING**).

For the coalbed methane play in the PRB, annual production which is presently about 180 billion cubic feet of gas (BCF) per year may rise to 900 BCF per year by 2010. Similarly, the total number of producing wells may increase from 4800 to 30,000 for the same time interval. Although industry has shown the ability to permit and drill about 5000 CBM wells per year, our forecast uses a rate of 2500 new wells per year to compensate for production decline rates attributed to older producing CBM wells.

Our forecast may be affected by some uncontrollable factors, however. Because federal lands (and the minerals beneath them) are subject to the National Environmental Policy Act

It is with sadness that we note the passing of Dr. Daniel N. Miller, on March 26, 2001. Dr. Miller was the 12th State Geologist of Wyoming, having served in that capacity from 1969 to 1981. "Dan" as he was known to everyone, was instrumental in the development and growth of the Wyoming State Geological Survey and was responsible for the Survey's new building which was completed in 1976. He remained a close friend of the Survey and the entire Wyoming geologic community even after his move to Chapel Hill, North Carolina. In the next issue of *Wyoming Geo-notes*, we will carry a full article on Dr. Miller's life and accomplishments.

(NEPA), this process can delay the pace of CBM development on federal lands, including the issuance of permits for drilling and other development activities. Much of the anticipated CBM growth in the basin will be from federal leases.

Issuance of water discharge permits (by the Wyoming Department of Environmental Quality) has been delaying production lately, and may be an ongoing source of delay due to the issues involved between operators, surface owners, and water quality standards. Negotiations between Wyoming and downstream states may result in some water discharge delays as well.

Technology may develop that will allow numerous thin coal zones to be simultaneously produced (multiple coal seam completion). This may influence our projections because a larger area of the basin will be economically prospective for CBM than for single coal beds.

Two other factors may also affect future CBM development: pipeline capacity and price stability. At present, the pipeline infrastructure for moving CBM out of the PRB is limited to about 500 million cubic feet (MMCF) per day, but to achieve the 900 BCF per year of gas production expected by 2010, the pipeline capacity must increase at least five-fold. Finally, as long as natural gas prices remain at $4.00 to $5.00 per MCF as they are now, then development activity will remain at present high levels. However, if prices revert to the $1.00 to $2.00 per MCF levels similar to those in 1998, then development will proceed at a much slower pace.

With the exception of coal and trona, Wyoming mineral production for 2000 has been slightly more than expected. . .

For now, there is no sign of energy fuel prices deteriorating significantly, as high demand for coal, oil, and natural gas is limiting the supplies and affecting the price. The **OIL AND GAS UPDATE** and **COAL UPDATE** that follow document this optimistic viewpoint. Even the price of PRB coal on the spot market (which in the past was rock-stable) has shown significant movement in early 2001. With the exception of coal and trona, Wyoming mineral production for 2000 has been slightly more than expected (**Table 1**) and our forecasts have been adjusted upward somewhat. We anticipate having to adjust our production and price forecasts for oil, natural gas, and coal throughout the year 2001 as the energy fuel markets fluctuate.

As was the case in the last issue of *Wyoming Geo-notes* (No. 68, December, 2000), the average prices for oil and methane have been further revised upward (**Table 2**), reflecting an overall increase in energy prices and a strengthening of the markets. Although the CREG forecast still shows a slight decrease for longer term coal prices, the recent behavior of Powder River Basin spot coal prices leads us to doubt the stability of earlier predictions.

Table 2. Average prices paid for Wyoming oil, methane, coal, and trona (1985 through 1999) with forecasts to 2006[1].

Calendar Year	Oil[2]	Methane[3]	Coal[4]	Trona[5]
1985	24.67	3.03	11.36	35.18
1986	12.94	2.33	10.85	34.80
1987	16.42	1.78	9.80	36.56
1988	13.43	1.43	9.16	36.88
1989	16.71	1.58	8.63	40.76
1990	21.08	1.59	8.43	43.70
1991	17.33	1.46	8.06	44.18
1992	16.38	1.49	8.13	43.81
1993	14.50	1.81	7.12	40.08
1994	13.67	1.63	6.62	38.96
1995	15.50	1.13	6.38	40.93
1996	19.56	1.46	6.15	45.86
1997	17.41	1.94	5.68	42.29
1998	10.67	1.81	5.41	41.29
1999	16.44	2.06	5.19	38.49
2000	27.00	3.42	5.13	37.90
2001	20.00	4.50	5.07	37.75
2002	18.00	3.00	5.07	37.75
2003	18.00	2.25	5.07	37.75
2004	18.00	2.25	5.07	37.75
2005	18.00	2.25	5.07	37.75
2006	18.00	2.25	5.07	37.70

[1]From CREG's Wyoming State Government Revenue Forecast, October, 2000; [2]First purchase price in dollars per barrel (weighted average price for sweet, sour, heavy, stripper, and tertiary oil). Source: Energy Information Administration, 1985-1999; [3]Wellhead price in dollars per thousand cubic feet (MCF), includes coalbed methane. Source: Wyoming Office of State Lands and Investments, 1989-1999 (derived from State royalty payments); Minerals Management Service, 1985-1988 (derived from Federal royalty payments); [4]Dollars per short ton (weighted average price for coal mined by surface and underground methods). Source: Energy Information Administration, 1985-1990 and derived from Department of Revenue, 1991-1999; [5]Dollars per ton of trona, not soda ash. Source: Wyoming Department of Revenue, 1985-1999.

Table 1. Wyoming mineral production (1985 through 1999) with forecasts to 2006[1].

	Calendar Year	Oil[2,3]	Methane[3,4]	Carbon Dioxide[3,4]	Helium[4,5]	Coal[6]	Trona[7]	*In situ* Uranium[8]	Sulfur[3,9]
ACTUAL	1985	131.0	597.9	140.4	10.8	N/A	0.80	N/A	N/A
	1986	122.4	563.2	23.8	0.15	135.4	11.9	0.05	0.76
	1987	115.9	628.2	114.2	0.86	146.5	12.4	0.00	1.19
	1988	114.3	700.8	110.0	0.83	163.6	15.1	0.09	1.06
	1989	109.1	739.0	126.1	0.94	171.1	16.2	1.1	1.17
	1990	104.0	777.2	119.9	0.90	184.0	16.2	1.0	1.04
	1991	99.8	820.0	140.3	1.05	193.9	16.2	1.0	1.18
	1992	97.0	871.5	139.2	1.05	189.5	16.4	1.2	1.20
	1993	89.0	912.8	140.8	1.06	209.9	16.0	1.2	1.14
	1994	80.2	959.2	142.6	1.07	236.9	16.1	1.2	1.10
	1995	75.6	987.5	148.8	1.11	263.9	18.4	1.3	1.20
	1996	73.9	1023.4	149.0	1.10	278.4	18.6	1.9	1.22
	1997	70.2	1040.7	151.0	1.10	281.5	19.4	2.2	1.23
	1998	65.7	1072.6	151.0	1.10	315.0	18.6	2.3	1.20
	1999	61.3	1133.1	161.0	1.10	336.5	17.8	2.8	1.20
FORECAST	2000	61.0	1287.9	161.0	1.10	338.9	18.0	2.5	1.20
	2001	59.8	1370.9	161.0	1.10	352.3	20.0	2.0	1.20
	2002	58.0	1460.9	161.0	1.10	355.8	20.0	2.0	1.20
	2003	55.1	1541.9	161.0	1.10	359.4	21.0	2.0	1.20
	2004	52.4	1625.9	161.0	1.10	363.0	21.0	2.0	1.20
	2005	49.8	1710.9	161.0	1.10	365.6	21.0	2.0	1.20
	2006	47.3	1796.9	161.0	1.10	370.3	21.0	2.0	1.20

[1]From CREG's Wyoming State Government Revenue Forecast, October, 2000; [2]Millions of barrels; [3]Wyoming Oil & Gas Conservation Commission, 1985-1999; [4]Billions of cubic feet, includes coalbed methane; [5]Based on Exxon's estimate that the average helium content in the gas processed at Shute Creek is 0.5%; [6]Millions of short tons (Wyoming State Inspector of Mines, 1985-2000); [7]Millions of short tons (Wyoming Department of Revenue, 1985-1999); [8]Millions of pounds of yellowcake (Wyoming Department of Revenue, 1986-1999) (not available [N/A] for 1985 and previous years because it was only reported as taxable value); [9]Millions of short tons.

OIL AND GAS UPDATE

Rodney H. De Bruin
Staff Geologist-Oil and Gas, Wyoming State Geological Survey

Wyoming's oil and gas production for 2000 is expected to be even higher than predicted, although final numbers are not yet in. Oil production will be about 61 million barrels and natural gas (including coalbed methane, carbon dioxide, and helium) will be about 1.45 trillion cubic feet (TCF). Coalbed methane production will probably account for over 10% of the total methane produced, or about 150 billion cubic feet (BCF). Natural gas prices in 2000 were up about $1.36 per thousand cubic feet (MCF) over 1999, and will be even higher in 2001 as demand continues to increase. Crude oil prices for 2000 were substantially higher than in 1999, but this will probably be a short-lived increase. Like the previous three quarters of 2000, the fourth quarter also saw increased revenues to the State of Wyoming from federal production and state and federal lease sales. Drilling permits, geophysical activity, and drill rig counts also increased.

Production and prices

We have further refined our forecasts of oil and gas production and prices made earlier (see *Wyoming Geo-notes No. 68*, December, 2000). Although final production figures for 2000 are not yet available, we now believe that oil production in the next seven years will be about 0.5 million barrels per year higher than predicted earlier (**Table 1** and **Figure 1**), but still with a yearly decrease as production in older fields continues to decline. Gas production in the next seven years will be about 50 BCF per year higher than predicted (**Table 1** and **Figure 2**) as the state's gas industry continues to grow.

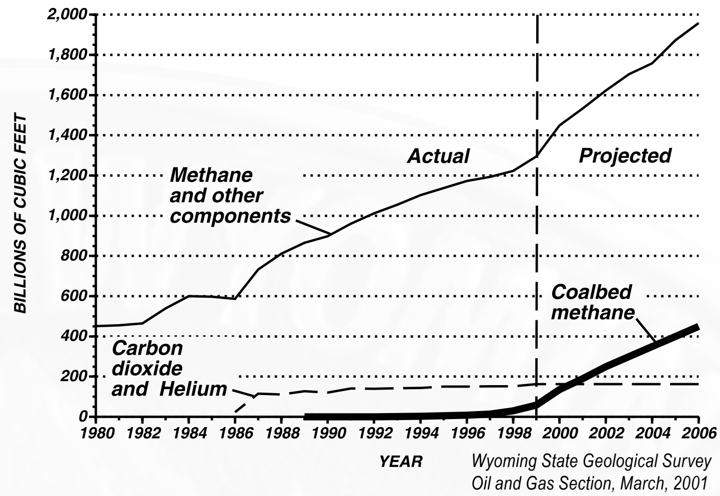

Figure 2. Annual natural gas production from Wyoming (1980 through 1999) with forecasts to 2006.

The average price for Wyoming crude oil for 2000 will be $1.00 per barrel higher than predicted earlier, followed by a drop of $7.00 per barrel in 2001 and then stabilizing at $18.00 per barrel in the out years (**Table 2** and **Figure 3**). The average price of natural gas at the wellhead was an actual $3.42 per MCF in 2000, $0.57 more than our earlier forecast. In 2001 the price per MCF will improve even more before stabilizing at $2.25 per MCF in the out years (**Table 2** and **Figure 4**).

Prices paid to Wyoming oil producers during the fourth quarter of 2000 averaged $27.29 per barrel. The average price for that quarter is $5.48 higher than for the fourth

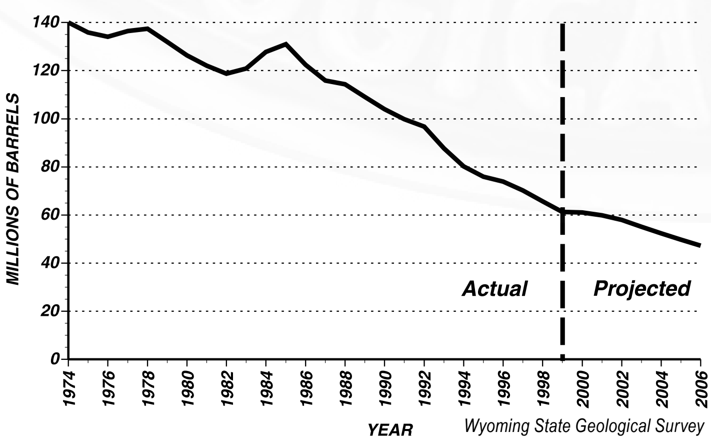

Figure 1. Annual crude oil production from Wyoming (1974 through 1999) with forecasts to 2006.

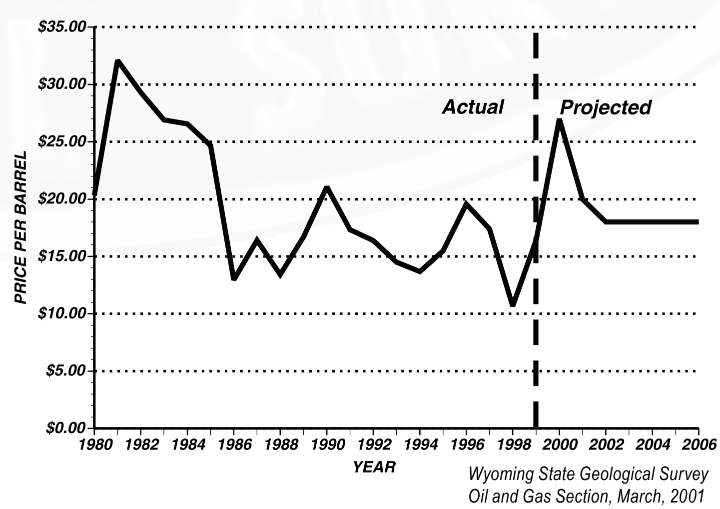

Figure 3. Average prices paid for Wyoming crude oil (1980 through 1999) with forecasts to 2006.

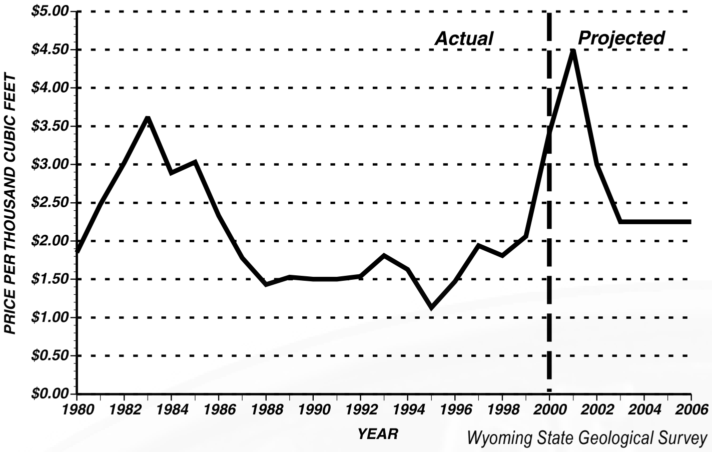

Figure 4. Average prices paid for Wyoming methane (1980 through 2000) with forecasts to 2006.

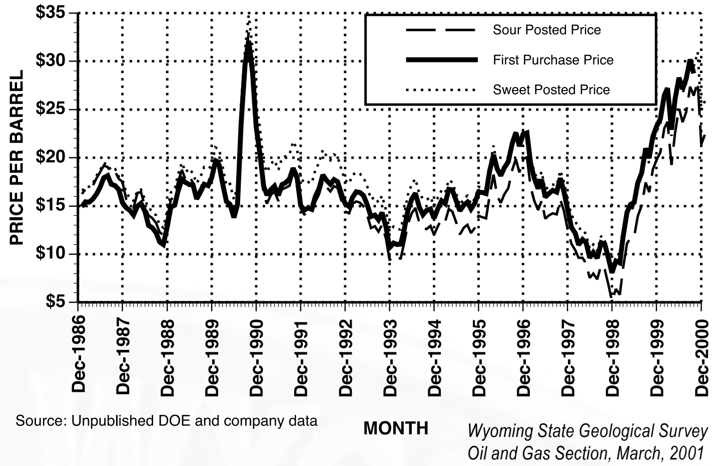

Figure 5. Wyoming posted sweet and sour crude oil prices and first purchase prices, averaged by month (January, 1987 through January, 2001).

quarter of 1999 but $1.22 less than the third quarter of 2000. The average price of $26.87 per barrel for 2000 is $10.43 higher than the average price per barrel in 1999 (**Table 3**). The posted sweet and sour crude prices and first purchase prices for Wyoming oil averaged by month (**Figure 5**) show the continued improvement in oil prices that began in early 1999.

Due to computer problems, the Wyoming Oil and Gas Conservation Commission (WOGCC) reported oil and gas production only through August, 2000. Oil production in Wyoming for the first eight months of 2000 was about 40.5 million barrels (**Table 4**). This production is a drop of only 1.2% from the first eight months of 1999. The decline in production has moderated over the last year because of higher prices for Wyoming oil.

Spot prices for natural gas at Opal, Wyoming averaged $4.88 per MCF during the fourth quarter of 2000. This is $2.43 per MCF higher than the average price for the fourth quarter of 1999 (**Table 5** and **Figure 6**). The average price in 2000 was $3.42 per MCF, compared to an average price in 1999 of $2.06. In January, 2001, as natural gas demand in the U.S. reached its peak, the average price soared to $8.75 per MCF.

Natural gas production in Wyoming for the first eight months of 2000 was 951.3 BCF, according to production figures from WOGCC. This production is 13.5% greater than the first eight

Table 3. Monthly average price of a barrel of oil produced in Wyoming (1997 through December, 2000).

	1997		1998		1999		2000	
	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative
JAN	$22.56	$22.56	$12.79	$12.79	$9.30	$9.30	$24.01	$24.01
FEB	$19.45	$21.01	$12.16	$12.48	$9.09	$9.20	$26.48	$25.25
MAR	$17.99	$20.00	$10.97	$11.97	$11.77	$10.05	$27.24	$25.91
APR	$16.81	$19.20	$11.54	$11.87	$14.34	$11.13	$22.92	$25.16
MAY	$17.74	$18.91	$11.19	$11.73	$15.16	$11.93	$26.06	$25.34
JUN	$15.90	$18.41	$9.63	$11.38	$15.36	$12.50	$28.31	$25.84
JUL	$16.29	$18.11	$10.20	$11.21	$17.39	$13.20	$27.12	$26.02
AUG	$16.61	$17.92	$9.58	$11.01	$18.43	$13.86	$28.18	$26.29
SEP	$16.42	$17.75	$11.19	$11.03	$20.97	$14.65	$30.22	$26.73
OCT	$17.89	$17.77	$11.04	$11.03	$20.01	$15.18	$28.75	$26.93
NOV	$16.51	$17.65	$9.64	$10.90	$22.20	$15.82	$29.56	$27.17
DEC	$14.72	$17.41	$8.05	$10.67	$23.22	$16.44	$23.57	$26.87
Average yearly price		**$17.41**		**$10.67**		**$16.44**		**$26.87**

All averages are derived from published monthly reports by the Energy Information Administration. *Wyoming State Geological Survey, Oil and Gas Section, February, 2001.*

Table 4. Monthly oil production from Wyoming in barrels (1996 through August, 2000).

	1996		1997		1998		1999		2000	
	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative
January	6,153,037	6,153,037	5,964,848	5,964,848	5,846,364	5,846,364	5,333,257	5,333,257	5,178,896	5,178,896
February	5,693,084	11,846,121	5,459,518	11,424,366	5,233,502	11,079,866	4,744,527	10,077,784	4,864,960	10,043,856
March	6,176,805	18,022,926	6,014,780	17,439,146	5,759,176	16,839,042	5,297,674	15,375,458	5,197,775	15,241,631
April	5,977,362	24,000,288	5,729,869	23,169,015	5,534,568	22,373,610	5,065,591	20,441,049	4,995,350	20,236,981
May	6,035,505	30,035,793	6,050,971	29,219,986	5,626,125	27,999,735	5,200,031	25,641,080	5,192,157	25,429,138
June	5,916,019	35,951,812	5,761,549	34,981,535	5,335,463	33,335,198	5,000,039	30,641,119	4,968,725	30,397,863
July	6,076,992	42,028,804	5,964,005	40,945,540	5,464,514	38,799,712	5,164,705	35,805,824	5,058,827	35,456,690
August	6,414,850	48,443,654	5,868,789	46,814,329	5,287,415	44,087,127	5,190,052	40,995,876	5,041,861	40,498,551
September	6,180,180	54,623,834	5,710,557	52,524,886	5,109,053	49,196,180	5,081,384	46,077,260		
October	6,186,019	60,809,853	5,949,974	58,474,860	5,274,269	54,470,449	5,163,165	51,240,425		
November	6,221,912	67,031,765	5,800,811	64,275,671	5,232,287	59,702,736	5,010,985	56,251,410		
December	6,330,701	73,362,466	5,900,791	70,176,462	5,078,909	64,781,645	5,090,959	61,342,369		
Total barrels reported[1]		**73,362,466**		**70,176,462**		**64,781,645**		**61,342,369**		
Total barrels not reported[2]		**525,957**		**52,364**		**897,131**				
Total barrels produced[3]		**73,888,423**		**70,228,826**		**65,678,776**				

[1]Monthly production reports from Petroleum Information/Dwights LLC. except for 1999 and 2000 which is from Wyoming Oil and Gas Conservation Commission; [2](Total barrels produced) minus (total barrels reported by Petroleum Information/Dwights LLC.); [3]Wyoming Oil and Gas Conservation Commission. *Wyoming State Geological Survey, Oil and Gas Section, February, 2001.*

Table 5. Monthly average spot sale price for a thousand cubic feet (MCF) of natural gas at Opal, Wyoming (1997 through February, 2001).

	1997		1998		1999		2000		2001	
	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative
January	$3.90	$3.90	$2.05	$2.05	$1.80	$1.80	$2.20	$2.20	$8.75	$8.75
February	$2.50	$3.20	$1.70	$1.88	$1.65	$1.73	$2.40	$2.30	$6.60	$7.68
March	$1.40	$2.60	$1.90	$1.88	$1.50	$1.65	$2.35	$2.32		
April	$1.45	$2.31	$1.90	$1.89	$1.60	$1.64	$2.70	$2.41		
May	$1.60	$2.17	$1.95	$1.90	$2.00	$1.71	$2.70	$2.47		
June	$1.35	$2.03	$1.65	$1.86	$2.00	$1.76	$3.65	$2.67		
July	$1.45	$1.95	$1.60	$1.82	$2.00	$1.79	$3.90	$2.84		
August	$1.40	$1.88	$1.75	$1.81	$2.20	$1.84	$3.10	$2.88		
September	$1.50	$1.84	$1.60	$1.79	$2.60	$1.93	$3.40	$2.93		
October	$2.05	$1.86	$1.65	$1.78	$2.40	$1.98	$4.30	$3.07		
November	$3.00	$1.96	$2.00	$1.80	$2.85	$2.05	$4.35	$3.19		
December	$1.95	$1.96	$2.00	$1.81	$2.10	$2.06	$6.00	$3.42		
Average yearly price		**$1.96**		**$1.81**		**$2.06**		**$3.42**		

Source: American Gas Association's monthly reports. *Wyoming State Geological Survey, Oil and Gas Section, February, 2001.*

months of 1999 (**Table 6**). Increased coalbed methane production from the Powder River Basin accounted for 89.3 BCF of the 113.4 BCF increase and 9.4% of Wyoming's natural gas production in the first eight months of 2000.

Projects, reports, and transactions

The U.S. Department of the Interior's Minerals Management Service (MMS) distributed more than $575.9 million in revenues from mineral production and lease sales to 34 states during the first nine months of 2000. This is an increase of almost $184 million from last year's nine-month total of $392 million. Wyoming received more than $250 million in the first nine months of 2000, which was over 43% of the amount distributed nationally.

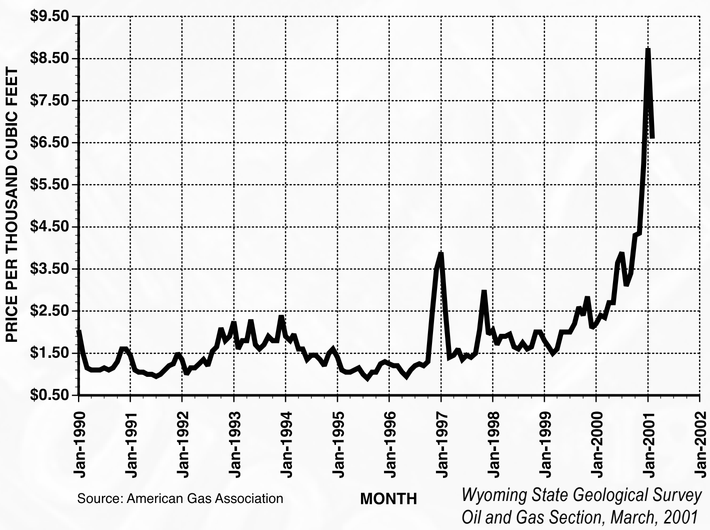

Figure 6. Spot sale prices for methane at Opal, Wyoming, averaged by month (January, 1990 through February, 2001).

A U.S. Department of Energy-sponsored project in New Mexico shows that mixing the fluids used to fracture a natural-gas-producing formation at the bottom of the well (downhole) could lead to a better, safer, and lower-cost way to produce additional gas out of tight gas sands. Conventional fracturing techniques mix the fracture fluids on the surface, but the method used by RealTimeZone allows the fluid to be changed right at (in) the formation and gives the operator more control over the fracturing process. Some of Wyoming's newest gas reservoirs are in tight gas sands, which would also be candidates for this process.

Alberta Energy Co. Ltd. (AEC) has entered into an agreement with TransCanada PipeLines to purchase the remaining 50% of the Express Pipeline that AEC does not already own. The Express system includes a 1700-mile-long North American crude oil pipeline that is made up of Express Pipeline and Platte Pipeline, and connects Canadian and U.S. producers' refineries in the Rocky Mountain and Midwest regions of the U.S. Express and Platte pipelines are operated in northern, central, and eastern Wyoming.

Burlington Resources began drilling a proposed 24,500-foot-deep Madison Limestone test at Madden Field in the Wind

Table 6. Monthly natural gas production from Wyoming in thousands of cubic feet (MCF) (1996 through August, 2000).

	1996		1997		1998		1999		2000	
	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative
January	101,359,648	101,359,648	99,579,818	99,579,818	103,640,214	103,640,214	108,524,793	108,524,793	121,821,179	121,821,179
February	96,303,300	197,662,948	91,766,159	191,345,977	94,501,819	198,142,033	94,288,888	202,813,681	113,267,361	235,088,540
March	103,541,127	301,204,075	104,157,578	295,503,555	103,906,999	302,049,032	111,012,987	313,826,668	120,756,362	355,844,902
April	99,479,609	400,683,684	99,459,039	394,962,594	98,201,007	400,250,039	102,363,550	416,190,218	118,278,867	474,123,769
May	97,900,863	498,584,547	101,070,371	496,032,965	96,741,237	496,991,276	104,746,697	520,936,915	117,793,578	591,917,347
June	87,069,612	585,654,159	91,905,308	587,938,273	98,413,520	595,404,796	102,717,295	623,654,210	116,207,220	708,124,567
July	100,219,275	685,873,434	100,129,497	688,067,770	102,055,968	697,460,764	106,733,493	730,387,703	120,844,678	828,969,245
August	99,874,019	785,747,453	97,673,622	785,741,392	105,378,334	802,839,098	107,536,099	837,923,802	122,334,512	951,303,757
September	93,510,551	879,258,004	100,028,888	885,770,280	98,474,782	901,313,880	108,200,542	946,124,344		
October	95,441,022	974,699,026	102,206,875	987,977,155	96,470,624	997,784,504	118,545,893	1,064,670,237		
November	94,015,007	1,068,714,033	100,752,128	1,088,729,283	103,445,859	1,101,230,363	110,904,046	1,175,574,283		
December	99,141,298	1,167,855,331	103,415,430	1,192,144,713	99,339,043	1,200,569,406	119,648,215	1,295,222,498		
Total MCF reported[1]		**1,167,855,331**		**1,192,144,713**		**1,200,569,406**		**1,295,222,498**		
Total MCF not reported[2]		**5,663,874**		**683,432**		**22,955,142**				
Total MCF produced[3]		**1,173,519,205**		**1,192,828,145**		**1,223,524,548**				

[1]Monthly production reports from Petroleum Information/Dwights LLC. except for 1999 and 2000 which is from Wyoming Oil and Gas Conservation Commission; [2](Total MCF produced) minus (total MCF reported by Petroleum Information/Dwights LLC.); [3]Wyoming Oil and Gas Conservation Commission. *Wyoming State Geological Survey, il and Gas Section, February, 2001.*

River Basin. The 7-34 Bighorn in NW SW section 34, T39N, R91W, is being drilled by Unit Drilling's Rig #201. This well will be the sixth ultra-deep Madison well drilled in Madden Field. In a related item, Grey Wolf signed a two-year contract with Burlington Resources for Unit Drilling's ultra-deep drilling rig #558 to drill additional wells in Madden Field.

Lease sales

Leasing activity at the Wyoming Office of State Lands and Investments (State Lands) October sale was concentrated in the Powder River Basin and southwestern Wyoming (**Figure 7**). The sale's top per-acre bid of $268 was made by Miller and Tack, LLC. for a 99.15-acre tract that covers parts of section 6, T47N, R77W (**location A, Figure 7**). The lease is 2 to 3 miles southwest of Fort Union coalbed methane production. The sale's second highest bid of $250 per acre was made by Questar Exploration & Production for a 640-acre tract that covers all of section 16, T17N, R94W (**location B, Figure 7**). The lease is in the Wild Rose Field area and contains an inactive Almond Formation gas producer. There were 21 tracts at this sale that sold for $50 or more per acre and almost 81,000 acres were leased. The sale generated revenue of over $1.6 million; the average price per acre was $20.35 (**Table 7**).

Leasing activity at the October Bureau of Land Management (BLM) sale was also concentrated in the Powder River Basin and southwestern Wyoming (**Figure 8**). Marathon Oil Co. made the highest per-acre bid of $510 for a 1253-acre lease that covers parts of section 31 and all of section 32, T16N, R94W (**location A, Figure 8**). The lease is just south of Mulligan Draw Field. Marathon also made the sale's second highest per-acre bid of $430 for a 610.52-acre tract that covers parts of section 30, T16N, R94W (**location A, Figure 8**). Yates Petroleum made the sale's third highest per-acre bid of $380 for a 161.1-acre lease that covers parts of section 33, T47N, R76W (**location B, Figure 8**). The lease is in an area of coalbed methane development in the Fort

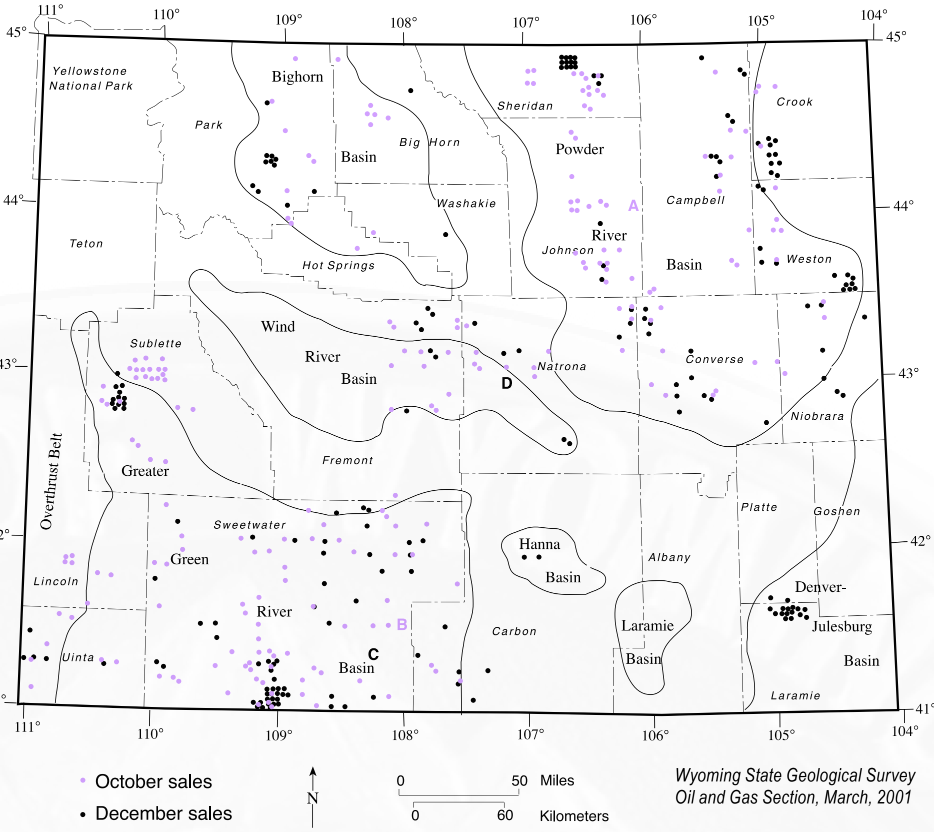

Figure 7. Locations of state oil and gas tracts leased by the Wyoming Office of State Lands and Investments at its October, 2000 and December, 2000 sales.

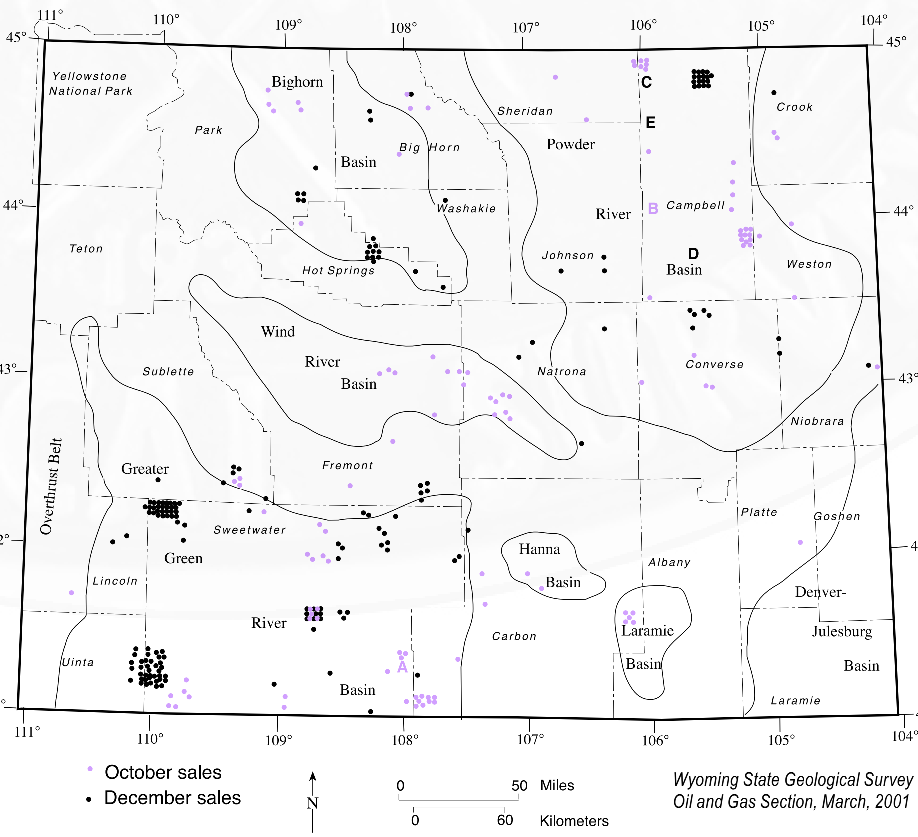

Figure 8. Locations of federal oil and gas tracts leased by the U.S. Bureau of Land Management at its October, 2000 and December, 2000 sales.

Table 7. Federal and state competitive oil and gas lease sales in Wyoming (1996 through December, 2000).

FEDERAL SALES (BUREAU OF LAND MANAGEMENT)

Month	Total Revenue	Number of parcels offered	Number of parcels leased	Total acres	Acres leased	Average price per acre leased	High price per acre
			1996				
TOTAL	$11,487,567	1828	1125	1,403,444	739,505	$15.53	$1,450.00
			1997				
TOTAL	$31,976,603	1787	1485	1,578,938	1,206,642	$26.50	$600.00
			1998				
FEB	$5,262,908	369	285	366,787	241,654	$21.78	$415.00
APR	$10,287,111	247	227	192,561	162,393	$63.35	$395.00
JUN	$14,737,117	463	367	498,339	368,816	$39.96	$430.00
AUG	$8,033,029	306	245	349,605	278,095	$28.89	$500.00
OCT	$10,251,074	455	308	421,900	293,141	$34.97	$430.00
DEC	$15,229,257	407	278	388,783	277,538	$54.87	$800.00
TOTAL	$63,800,496	2247	1710	2,217,975	1,621,637	$39.34	$800.00
			1999				
FEB	$2,734,442	170	138	157,779	124,880	$21.90	$325.00
APR	$2,121,220	124	116	129,358	121,421	$17.47	$280.00
JUN	$8,358,363	179	155	233,599	207,978	$40.19	$32,000.00
AUG	$3,294,339	206	197	215,631	208,777	$15.78	$290.00
OCT	$4,395,288	214	175	195,827	142,525	$30.84	$580.00
DEC	$5,598,020	176	164	128,480	124,093	$28.99	$410.00
TOTAL	$26,501,672	1069	945	1,060,674	929,674	$26.03	$32,000.00
			2000				
FEB	$5,497,834	192	180	130,289	120,219	$45.73	$525.00
APR	$3,057,278	189	161	160,712	128,063	$23.87	$440.00
JUN	$6,387,887	230	184	260,294	190,306	$33.57	$410.00
AUG	$5,213,595	240	222	174,040	154,920	$33.65	$475.00
OCT	$5,028,610	147	129	149,934	124,724	$40.32	$510.00
DEC	$6,352,525	185	179	182,935	180,380	$35.22	$725.00
TOTAL	$31,537,729	1183	1055	1,058,204	898,612	$35.09	$725.00

STATE SALES (OFFICE OF STATE LANDS AND INVESTMENTS)

Month	Total Revenue	Number of parcels offered	Number of parcels leased	Total acres	Acres leased	Average price per acre leased	High price per acre
			1996				
TOTAL	$2,325,497	1049	508	418,111	206,814	$11.24	$206.00
			1997				
TOTAL	$3,151,030	1198	704	438,296	263,230	$11.97	$340.00
			1998				
APR	$1,203,792	300	161	115,646	63,848	$18.85	$320.00
JUN	$1,660,438	300	148	108,654	52,501	$31.63	$600.00
OCT	$1,313,792	298	178	98,856	65,212	$20.14	$590.00
DEC	$1,045,447	300	187	121,551	77,852	$13.43	$215.00
TOTAL	$5,223,469	1198	674	444,707	259,413	$20.14	$600.00
			1999				
APR	$1,815,526	299	196	123,119	89,194	$20.35	$890.00
JUN	$1,002,039	300	190	108,310	69,858	$14.34	$400.00
OCT	$2,369,527	300	216	109,140	77,261	$30.67	$475.00
DEC	$956,113	291	129	115,502	51,674	$18.50	$500.00
TOTAL	$6,143,205	1190	731	456,071	287,987	$21.33	$890.00
			2000				
APR	$1,475,661	299	191	120,319	71,933	$19.54	$525.00
JUN	$2,119,198	300	197	127,798	79,743	$26.58	$775.00
OCT	$1,660,315	300	216	117,598	81,603	$20.35	$268.00
DEC	$1,240,442	300	192	109,375	62,636	$19.80	$210.00
TOTAL	$6,495,616	1199	796	475,090	295,915	$21.95	$775.00

Sources: Wyoming Office of State Lands and Investments, Petroleum Information/Dwights LLC. - Rocky Mountain Region Report, and U.S. Bureau of Land Management. *Wyoming State Geological Survey, Oil and Gas Section, February, 2001.*

Union Formation. There were a total of 45 parcels at this sale that received bids of $50 or more per acre. Almost 125,000 acres were leased and the sale generated revenue of over $5.0 million; the average per-acre bid was $40.32 (**Table 7**).

The highest concentration of leasing activity at the State Lands December sale was again in the Powder River Basin and southwestern Wyoming (**Figure 7**). The highest per-acre bid at the sale was $210 made by Questar Exploration & Production for a 640-acre lease that covers all of section 16, T16N, R96W (**location C, Figure 7**). The tract is about 5 miles west of the Willow Reservoir Field discovery in the Almond. The sale's second highest per-acre bids were made by Prima Oil & Gas for two adjoining tracts in the Wind River Basin. Prima paid $130 per acre for a 120-acre lease that covers N/2 NE and NE NW section 8, T35N, R86W, and also paid $130 per acre for a 40-acre lease that covers NW NW section 9, T35N, R86W (**location D, Figure 7**). The two leases are about 4 miles southeast of Waltman Field. There were a total of 12 leases at this sale that received bids of $50 or more per acre. The 192 parcels leased, covering over 109,000 acres, generated total revenue of over $1.2 million; the average price per acre was $19.80 (**Table 7**). For the year, about $6.5 million in total revenues came to the State of Wyoming from the their oil and gas lease sales.

For the year, about $31.5 million in total revenues were received by the federal government from these oil and gas lease sales.

Leasing activity at the December BLM sale was concentrated in southwestern Wyoming (**Figure 8**). Contex Energy made the sale's highest per-acre bid of $725 for a 120-acre lease that covers S/2 NE and SW NW section 14, T56N, R75W (**location C, Figure 8**). The lease is in an area that is currently being developed for coalbed methane. Yates Petroleum and Tab McGinley both made the second highest per-acre bids of $460. Yates paid $460 per acre for a 247.47-acre tract that covers parts of sections 1 and 32, T44N, R73W (**location D, Figure 8**). McGinley paid $460 per acre for a 120-acre lease that covers SE NE and E/2 SE section 4, T53N, R76W (**location E, Figure 8**). Both leases are in areas that are being developed for coalbed methane. This sale had a total of 57 leases that sold for $50 or more per acre. The 179 parcels leased, covering about 183,000 acres, generated total revenue of over $6.5 million; the average price per acre was $35.22 (**Table 7**). For the year, about $31.5 million in total revenues were received by the federal government from these oil and gas lease sales. The State of Wyoming receives half of these revenues.

Permitting and drilling

The WOGCC approved 1633 Applications for Permit to Drill (APDs) in the fourth quarter of 2000. The total of 8598 APDs approved in 2000 is more than the number of APDs approved in the last six years or more (**Table 8**). Campbell County again led with 57% of the total APDs that were approved in the fourth quarter. Sheridan and Johnson counties combined for about 23% of the total APDs that were approved in the fourth quarter. Nearly all of the approved APDs in these three counties were for coalbed methane tests.

The WOGCC permitted 11 seismic projects in the fourth quarter of 2000. The number of permits and miles permitted is up substantially from last year. The number of permitted conventional miles is higher than the total for 1998 and 1999; the number of permitted 3-D square miles surpassed the total for 1997 and 1999, and nearly equaled the total for 1998 (**Table 9**). Geophysical activity is a good indicator of future exploration and production drilling.

The average daily rig count for the fourth quarter of 2000 was 51, nine more than for the fourth quarter of 1999. The rig count does not include rigs drilling for coalbed methane, which is on the order of 75. **Figure 9** shows the Wyoming daily rig count averaged by month and averaged by year. The average rig count for 2000 was 41 compared to only 32 for 1999.

Table 8. Number of Applications for Permit to Drill (APDs) approved by the Wyoming Oil and Gas Conservation Commission (1995 through December, 2000).

County	1995 APDs	1996 APDs	1997 APDs	1998 APDs	1999 APDs	2000 APDs
Albany	1	1	0	0	0	0
Big Horn	16	53	59	13	6	11
Campbell	151	554	941	1586	4461	5580
Carbon	50	77	84	96	127	174
Converse	29	20	16	6	19	70
Crook	15	37	26	29	30	47
Fremont	30	26	58	76	67	136
Goshen	0	0	0	0	0	0
Hot Springs	13	24	42	1	8	6
Johnson	6	16	6	49	304	769
Laramie	10	2	3	2	0	2
Lincoln	64	55	122	105	51	70
Natrona	80	74	59	36	51	53
Niobrara	4	7	8	8	5	18
Park	20	30	25	11	12	18
Platte	0	0	0	0	0	0
Sheridan	0	0	2	35	416	891
Sublette	61	118	179	230	189	338
Sweetwater	153	136	210	181	124	335
Teton	0	0	0	0	0	0
Uinta	11	10	27	26	26	53
Washakie	31	30	36	9	0	7
Weston	10	10	5	6	4	20
Totals	755	1280	1908	2505	5900	8598

Source: All data are from the Wyoming Oil and Gas Conservation Commission. *Wyoming State Geological Survey, Oil and Gas Section, January, 2001.*

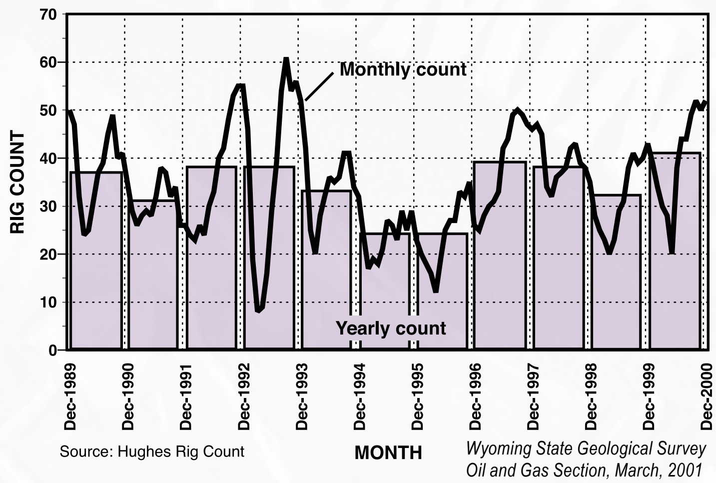

Figure 9. Wyoming daily rig count, exclusive of coalbed methane rigs, averaged by month (line graph) and year (bar graph) (December, 1989 through January, 2001).

Table 9. Number of seismic projects and miles permitted by the Wyoming Oil and Gas Conservation Commission (1997 through December, 2000).

County	1997 Permits	1997 Conventional Miles	1997 3-D Sq Miles	1998 Permits	1998 Conventional Miles	1998 3-D Sq Miles	1999 Permits	1999 Conventional Miles	1999 3-D Sq Miles	2000 Permits	2000 Conventional Miles	2000 3-D Sq Miles
Albany	0	0	0	0	0	0	0	0	0	0	0	0
Big Horn	2	0	45	1	0	16	0	0	0	1	387	0
Campbell	20	52	79	14	18	182	4	4	10	14	64	132
Carbon	3	7	190	4	0	318	5	77	57	0	0	0
Converse	1	5	0	4	12	239	1	0	50	1	15	0
Crook	7	8	18	2	2	4	1	0	10	7	16	22
Fremont	6	43	126	2	100	0	1	0	88	4	25	116
Goshen	2	227	0	0	0	0	0	0	0	0	0	0
Hot Springs	1	8	0	4	19	0	0	0	0	0	0	0
Johnson	2	7	17	1	4	0	0	0	0	4	35	0
Laramie	0	0	0	0	0	0	0	0	0	0	0	0
Lincoln	3	7	116	1	10	0	1	0	32	0	0	0
Natrona	5	14	101	6	12	214	2	0	230	5	36	135
Niobrara	0	0	0	0	0	0	5	16	31	1	0	25
Park	4	56	58	3	16	132	3	25	32	1	13	0
Platte	0	0	0	0	0	0	0	0	0	0	0	0
Sheridan	0	0	0	1	14	0	0	0	0	0	0	0
Sublette	1	0	61	2	1	115	3	0	308	4	77	44
Sweetwater	4	66	296	6	214	66	9	0	530	13	54	1004
Teton	0	0	0	0	0	0	0	0	0	0	0	0
Uinta	0	0	0	2	0	147	1	0	26	0	0	0
Washakie	3	36	0	4	41	35	1	0	8	0	0	0
Weston	1	0	17	1	0	35	1	40	0	0	0	0
Totals	65	536	1124	58	463	1503	38	162	1412	55	722	1478

Source: All data are from the Wyoming Oil and Gas Conservation Commission. *Wyoming State Geological Survey, Oil and Gas Section, January, 2001.*

Exploration and development

Company data, news releases, and information compiled and published by Petroleum Information/Dwights LLC. are used to track oil and gas exploration and development activity in Wyoming. **Table 10** reports the most significant activities exclusive of coalbed methane (see the **COALBED METHANE UPDATE** for development in this industry) during the fourth quarter of 2000. The numbers correspond to locations on **Figure 10**.

Table 10. Significant exploration and development wells in Wyoming during the fourth quarter of 2000. Number corresponds to location on Figure 10 and may indicate more than one well.

	Company name	Well name/number	Location	Formation tested	Depth(s) interval(s) tested	Tested production (per day)	Remarks
1	Amoco Production	1A Kewanee Federal	NW SE sec 24, T18N, R120W	Madison Ls.	13,000-16,155	24.2 MMCF	Directional redrill in Whitney Canyon-Carter Creek Field
2	Cabot Oil & Gas	40-3 Ballerina	C SE sec 3, T21N, R113W	Dakota Ss.	12,331-12,345 12,252-12,362	3.6 MMCF 26 BBL Cond	Southwestern flank of Cow Hollow Field
3	EOG Resources	140-14 “B”	SE NE sec 14, T29N, R113W	“transition zone”	3179-3246	175 BBL Oil 131 MCF	Big Piney Field area
	EOG Resources	59-16E North La Barge Shallow Unit	SE NW sec 16, T27N, R113W	Mesaverde Fm.	5 intervals 1833-1943	168 BBL Oil 149 MCF 125 BBL H_2O	La Barge North Field area
	EOG Resources	143-25 “B”	SW NE sec 25, T29N, R113W	“transition zone”	2 intervals 3539-3593 3653-3695	195 BBL Oil 263 MCF	Big Piney Field area
	EOG Resources	1-25H Osprey	SE NE sec 25, T29N, R113W	Frontier Fm.	true vertical depth 8075		Planned horizontal test of the Frontier Fm.
4	McMurry Oil	3-5 Jonah-Federal	NE NW sec 5, T28N, R108W	Lance Fm.	6 intervals 8707-10,408	6.0 MMCF 80 BBL Cond	Southern flank of Jonah Field
	Ultra Petroleum	6-23 Stud Horse Butte	SE NW sec 23, T29N, R108W	Lance Fm.	several intervals 8802-12,366	12.0 MMCF	Jonah Field
5	Tom Brown	11 Bravo Unit	NE SW sec 4, T23N, R99W	Lewis Sh.	6754-6790	3.5 MMCF 48 BBL Cond 12 BBL H_2O	Sinkhole Field
	Tom Brown	12 Bravo Unit	SW SW sec 3, T23N, R99W	Lewis Sh.	6730-6766	3.2 MMCF 51 BBL Cond 2 BBL H_2O	Sinkhole Field
6	Saurus Resources	2-5 SRI/UP	SE NW sec 5, T17N, R107W	Green River Fm.	1080-1528	70 MCF	New discovery in Green River Fm.
	Saurus Resources	3-5 SRI/UP	SW SW sec 5, T17N, R107W	Green River Fm.	840-1246	65 MCF	New discovery in Green River Fm.
7	Marathon Oil, Wexpro, Questar Exploration & Production		T12-14N, R99-101W				Environmental Assessment allows up to 56 additional wells in Vermillion Basin area
8	EOG Resources	3-19D Cepo Lewis Unit	NE NW sec 19, T14N, R95W	Fox Hills Ss.	12,174-12,194 12,208-12,221	633 MCF 2 BBL H_2O	Shallower pay discovery, offsets Lewis Sh. Discovery
9	Cabot Oil & Gas	40-8 Lookout Wash Unit	SW SE sec 8, T14N, R93W	Almond Fm.	10,783-10,803	4.1 MMCF 45 BBL Cond	Development well in Lookout Wash Field
10	Flying J Oil & Gas	2-32 Red Lakes	C NW sec 32, T19N, R94W	Almond Fm.	9758-9786 9832-10,016	3.7 MMCF 68 BBL Cond 43 BBL H_2O	Red Lakes Field area
11	Amoco Production	20-2 Two Rim Unit	NE NW sec 20, T20N, R94W	Almond Fm.	3 intervals 9753-10,177	2.2 MMCF	Wamsutter Field
12	Devon SFS Operating	12-30-21-93 Five Mile Ditch	NW SW sec 30, T21N, R93W	Lewis Sh. Almond Fm.	9104-9131 10,492-10,629	2.3 MMCF 32 BBL Cond 3 BBL H_2O	North offset to Five Mile Gulch Field
13	Snyder Oil	2-5 North Alkali Tribal	NW NE sec 5, T2S, R6E	Lakota Ss.	6862-6880	3.0 MMCF	Half a mile south of Alkali Butte North Field
14	Tom Brown	46 Graham Unit	NE SW sec 18, T37N, R89W	Fort Union Fm. Lance Fm.	various intervals 9275-11,520	2.4 MMCF 791 BBL H_2O	Western flank of Frenchie Draw Field
15	Burlington Resources	66 Madden Deep Unit	SW NE sec 10, T38N, R90W	Fort Union Fm.	5854-5888	3.7 MMCF 26 BBL H_2O	Madden Field
16	Tom Brown	19-14M Tribal-MR	SW SW sec 19, T4N, R3E	Lance Fm. Meeteetse Fm. Mesaverde Fm.	9334-9390 9628-10,524 11,762-12,321	5.1 MMCF 22 BBL Cond 68 BBL H_2O	Muddy Ridge Field
17	Ballard Petroleum	43-3 RPG-Federal	NE SE sec 3, T56N, R68W	Minnelusa Fm.	4742-4770	120 BBL Oil	Offsets new discovery
18	Duncan Oil	2-13 Record	NE SW sec 13, T50N, R71W	Minnelusa Fm.	9166-9182	354 BBL Oil	Extends FD Field to the northwest
19	Westport Oil & Gas	32-19 ST Reno Unit-Federal	SW NE sec 19, T45N, R79W	Minnelusa Fm.	15,478-15,552	98 BBL Oil 6 BBL H_2O	Directionally drilled in Reno Field
20	Ensign Operating	501I Quest Muddy Unit	irregular sec 1, T45N, R68W	Muddy Ss.	7458-7465	220 BBL Oil 220 MCF	Quest Field
21	Abraxas Petroleum	3H Sage Grouse	SE SW sec 15, T38N, R67W	Turner Ss.	8645-12,900	400 BBL Oil	Horizontal completion in Brooks Draw Field, reported pay behind casing in Niobrara
	Abraxas Petroleum	3H-10-38 Middleton	SW SW sec 10, T38N, R67W	Turner Ss.	8643-11,704	235 BBL Oil 193 MCF	Horizontal completion west of Brooks Draw Field, another well is testing and another well has been staked in the area

Abbreviations include: sec=section; MMCF=millions of cubic feet of natural gas; MCF=thousands of cubic feet of natural gas; BBL=barrels; Cond=condensate; H_2O=water. Ss.=Sandstone; Ls.=Limestone; Fm.=Formation;Sh.= shale. *Wyoming State Geological Survey, February, 2001.*

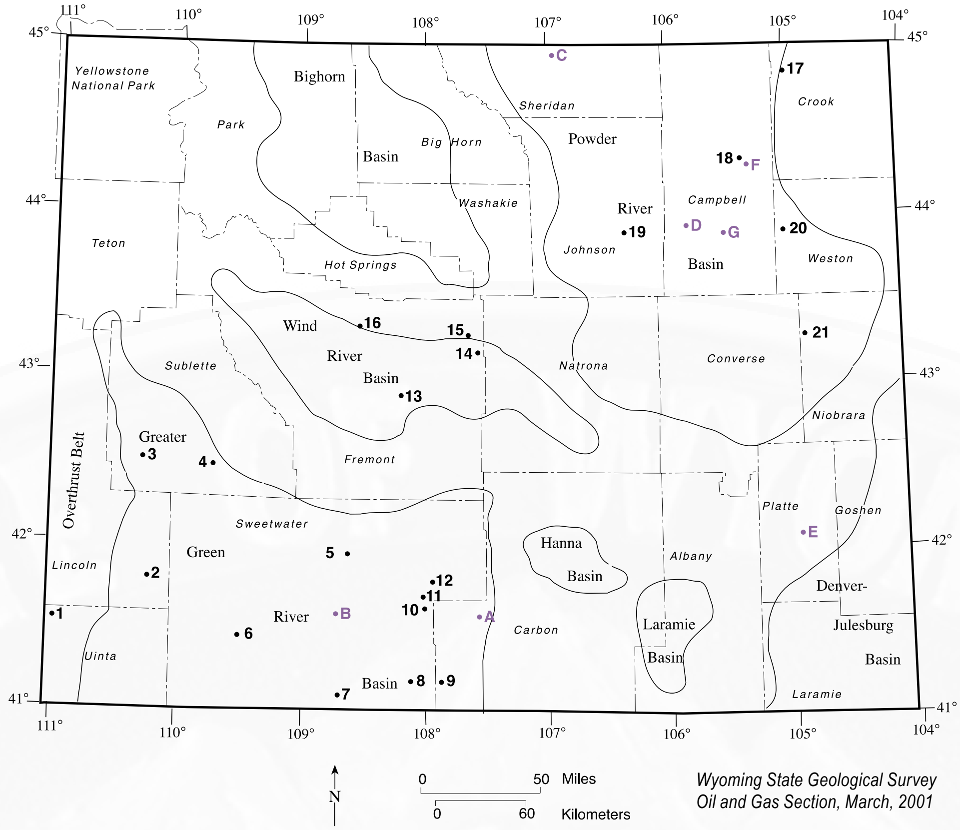

Figure 10. Oil and gas exploration and development activities (numbers) and coalbed methane activities (purple letters) in Wyoming during the second quarter of 2000. Locations are approximate and may represent more than one well location or project.

STAFF PROFILE–RODNEY H. DE BRUIN

Richard W. Jones
Editor/Geologist-Wyoming State Geological Survey

Rodney H. ("Rod") De Bruin (**Figure 11**) is head of the Oil and Gas Section at the Wyoming State Geological Survey (WSGS). Rod is responsible for oil- and gas-related activities at the WSGS, including documentation of Wyoming's oil and gas resources through maps and reports, projecting revenues to the State of Wyoming from development of these resources, promoting the oil and gas industry, and answering inquiries on oil and gas from industry, the public, and government. He utilizes subsurface information to characterize important fields and their reservoirs and to develop the stratigraphic framework of basins in Wyoming that produce oil and gas.

Rod serves on several important committees or groups, including the State's Consensus Revenue Estimating Group (CREG) and Wyoming's Oil and Gas Resource Assessment, a federal-state cooperative effort. He furnishes well data and information on oil and gas to the Wyoming Office of State Lands and Investments in support of their leasing activities and is active in the American Association of Petroleum Geologists' Visiting Speakers Program. He gives a number of talks and presentations on the state's oil and gas throughout the year to various groups and at professional and technical meetings.

Rod was born in Oskaloosa, Iowa and grew up in the small farming com-

Figure 11. Rodney H. De Bruin is the head of the Oil and Gas Section at the Wyoming State Geological Survey.

Staff profile, continued.

munity of Leighton, Iowa. He graduated from high school at nearby Pella, Iowa and continued his education at Iowa State University in Ames where he earned a B.S. in Geology with minors in mathematics and physics. His educational experience was interrupted by a draft notice, which landed him in the U.S. Army for 21 months and took him to exciting places like Fort Leonard Wood, Missouri, Madigan Hospital, Washington, and finally Bamberg, Germany. He was assigned to an infantry unit in Bamberg and spent many days and nights on alert near the Czechoslovakian border. He returned to graduate school at Iowa State after his military tour, earning an M.S. in Geology with a minor in statistics.

Rod's connection with Wyoming began after attending Iowa State's Geology Field Camp near Shell, Wyoming as an undergraduate. For his M.S. thesis, he mapped Precambrian geology of the Bruce Mountain area in the Bighorn Mountains. Rod is one of three Iowa State University graduates at the WSGS.

Rod began his career as a geophysicist with Conoco at Ponca City, Oklahoma for three years. At Conoco he also did well site work in the Gulf of Mexico out of the Lake Charles, Louisiana office; worked up prospects in Thailand, Libya, and Egypt; and provided geophysical support to Conoco's International Exploration Group and their Exploration Research Group. Although the Gulf Coast and the Midcontinent were warmer and more vegetated, he longed to see rock exposures again and the Wyoming mountains and plains beckoned.

Rod joined the WSGS, first as head of the Environmental Geology Section and then as head of the Stratigraphy Section. In 1986 he moved into his present position as head of the Oil and Gas Section. He has published over 200 maps, articles, and reports while at the WSGS and has been involved in a number of grants ranging from cataloging and mapping Wyoming's geologic hazards to research on tight gas sands in the Green River Basin and work on Wyoming's heavy oil and tar sand deposits. He was a major contributor to Wyoming's chapter in the *Atlas of major Rocky Mountain gas reservoirs*.

More recently, he was a principal investigator on a grant to develop a geologic and ground water computer database and interactive mapping/characterization program for the Little Snake River basin in southern Wyoming. A new but similar project now underway in the Powder River Basin coalbed methane area (see description in the **MAPPING AND HAZARDS UPDATE**) will utilize Rod's experience in geophysics, stratigraphy, and subsurface methods. He is also developing a database of important formation tops throughout Wyoming oil and gas basins as picked from geophysical logs. He is author of the *Oil and gas map of Wyoming*, the oil and gas maps of individual basins and areas of Wyoming, co-author for the Survey's new coalbed methane maps of the Powder River Basin, and co-author of the popular pamphlet on coalbed methane in Wyoming. A similar brochure is being prepared on Wyoming's carbon dioxide resources.

Rod is a long-time member of the American Association of Petroleum Geologists and the Wyoming Geological Association, as well as a Registered Professional Geologist (PG-3045) in Wyoming. He lists sports memorabilia, stamp and coin collecting, and fishing as his hobbies and he enjoys sports as both spectator and participant. He follows the University of Wyoming Cowboys sports teams and is a big fan of college basketball, especially when the Iowa State Cyclones are playing.

COAL UPDATE

Robert M. Lyman
Staff Geologist-Coal, Wyoming State Geological Survey

Production from Wyoming coal mines in 2000 showed a modest 0.7% increase from 1999 but some 8 million short tons less than that forecast. Production in Campbell County continues to increase as production from Carbon County dwindles with the closing of the state's only underground mine and depletion of minable reserves. Average prices for Wyoming coal continue to drop with both the loss of some of the high-priced coal in southern Wyoming and a decrease in the percentage of higher-priced coal from older contracts in the Powder River Basin (PRB). Relief from price doldrums for Powder River coal may be seen later this year, as spot coal prices rise dramatically in early 2001 and coal supplies at electric utilities reach all-time lows from heavy fuel usage and high power demands.

Production and prices

For the thirteenth year in a row, Wyoming led the nation in coal production in 2000 with a final total of 338,852,148 tons (Office of the Wyoming State Inspector of Mines, personal communication, 2001). Wyoming mines had another record-setting year, besting 1999's record production by about 2.4 million tons (**Table 1**). The 0.7% increase over 1999 production seems small compared to our earlier estimate of a 2.9% increase, yet, considering that 2000 was a year of many challenges for the Wyoming coal industry, it shows the vitality of Wyoming coal mining.

The National Mining Association (NMA) projects in their *2001 Forecast of coal markets* that coal use in the U.S. this year (2001) will reach an all-time high. Last year the U.S. consumed a record 1.064 billion short tons (tons) of coal. In 2001 the NMA predicts that the U.S. will use approximately 1.085 billion tons of coal. The increased coal use is being driven by one of the coldest winters on record, coupled with the current high price of natural gas. Adding the 65.3 million tons of exported coal, NMA predicts a total market for the nation's coal of about 1.15 billion tons. NMA also predicts that at this level of consumption, coal stockpiles at utilities across the nation by the end of 2001 will be lower than at any time since 1974, when consumption was less than half of current levels (Mining Week, 1/22/01).

Our estimates for coal production from 2001 through 2006 (**Tables 1** and **11**) are the same as in the last *Wyoming Geo-notes* (No. 68, December, 2000) but will change to reflect higher spot market prices reflected in the PRB going into the 1st and 2nd quarters of 2001. After a minor flattening of the production curves, such as occurred in 1986, 1992, and 1997 (**Figure 12**), coal production usually rebounds the next year, which is what we expect in 2001. Actual production from PRB mines was about 10 million tons less than expected, probably due to some of the production cutbacks earlier in the year (related to low spot prices). This was offset somewhat by about 2 million tons more production than expected in southern Wyoming, primarily in Sweetwater County.

Coal deliveries from Wyoming through October, 2000 trailed those for the same period in 1999 by 10.5% (**Table 12**). Apparently the Federal Energy Regulatory Commission (FERC) Form 423 is capturing only about 90% of this year's production. As more electric utilities are being impacted by deregulation (resulting in less public ownership), many merchant generating plants no longer have to report coal deliveries to FERC. Even with this shortcoming, monthly coal deliveries for 2000 are still somewhat below 1999 and 1998 levels and equal to or above 1997 levels (**Figure 13**). As noted in the last *Wyoming Geo-notes* (No. 68, December, 2000) deficits in deliveries of contract coal (**Figure 14a**), even with the 10% not reported, are being made up by increased spot coal sales (**Figure 14b**).

Our estimated prices for Wyoming coal (**Table 13**) have not changed since *Wyoming Geo-notes No. 68* (December, 2000), but the apparent strengthening of spot coal prices will affect our forecasts later in 2001. For the last two quarters of 2000 and the first two months of 2001, the Wyoming PRB spot market coal prices continued to strengthen. The discipline that the PRB coal producers applied to their 2000 production schedules, coupled with record cold

Table 11. Wyoming coal production by county[1,2] (in millions of short tons), 1995 through 2000 with forecasts to 2006.

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Powder River Basin												
Campbell County	232.4	245.3	246.3	274.1	294.3	299.5	309.3	312.8	314.4	323.0	325.6	330.3
Converse County	14.1	15.8	17.8	23.4	25.6	23.6	30.0	30.0	30.0	25.0	25.0	25.0
Sheridan County	M	M	M	M	0.1	M	M	M	M	M	M	M
Subtotal	246.5	261.1	264.1	297.5	320.0	323.1	339.3	342.8	344.4	348.0	350.6	355.3
Southern Wyoming												
Carbon County	3.8	4.7	5	3.5	2.7	2.0	M	M	2.0	2.0	2.0	2.0
Sweetwater County	9.1	8.2	7.8	9.2	9.4	10.0	8.0	8.0	8.0	8.0	8.0	8.0
Lincoln County	4.5	4.4	4.6	4.7	4.3	3.7	5.0	5.0	5.0	5.0	5.0	5.0
Subtotal	17.4	17.3	17.4	17.4	16.4	15.7	13.0	13.0	15.0	15.0	15.0	15.0
Total Wyoming[3]	**263.9**	**278.4**	**281.5**	**314.9**	**336.5**	**338.9**	**352.3**	**355.8**	**359.4**	**363.0**	**365.6**	**370.3**
Annual change	**11.4%**	**5.5%**	**1.1%**	**11.9%**	**6.9%**	**0.7%**	**3.9%**	**1.0%**	**1.0%**	**1.0%**	**1.0%**	**1.0%**
Higher-priced coal[4]	**26%**	**24%**	**22%**	**17%**	**13%**	**9%**	**6%**	**4%**	**4%**	**4%**	**4%**	**4%**

[1]Reported tonnage from the Wyoming State Inspector of Mines (1995 through 2000). [2]County estimates by the Wyoming State Geological Survey, Februay, 2001 for 2001 through 2006. Totals may not agree because of independent rounding. [3]Estimate modified from CREG's Wyoming State Government Revenue Forecast, October, 2000. [4]Estimated percentage of Powder River Basin coal production that is sold at prices above $5.00/ton (older long-term contracts that have not yet expired). M=minor tonnage (less than a million tons). *Wyoming State Geological Survey, Coal Section, February, 2001.*

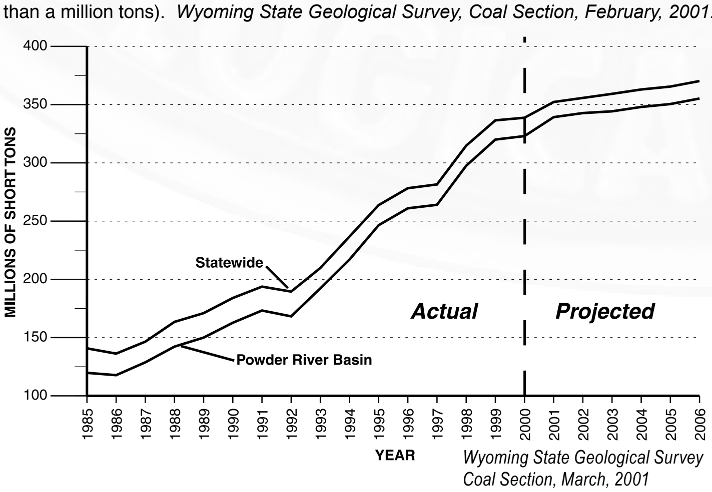

Figure 12. Annual coal production from Wyoming and the Powder River Basin (1985 through 2000) with forecasts to 2006. Sources: Wyoming State Inspector of Mines (1985 through 2000), CREG (2001 through 2006), and Wyoming State Geological Survey.

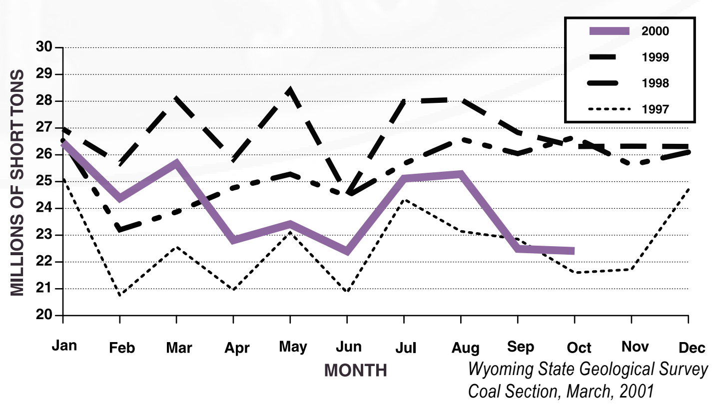

Figure 13. Reported monthly deliveries from Wyoming coal mines (1997 through October, 2000). From Form 423 of the Federal Energy Regulatory Commission (FERC).

Table 12. Monthly coal deliveries from Wyoming's mines in short tons (January, 1996 through October, 2000)

	1996		1997		1998		1999		2000	
	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative
January	21,793,387	21,793,387	25,165,405	25,165,405	26,536,217	26,536,217	26,970,936	26,970,936	26,451,057	26,451,057
February	20,374,055	42,167,442	20,743,224	45,908,629	23,196,152	49,732,369	25,675,015	52,645,951	24,375,342	50,826,399
March	22,507,800	64,675,242	22,566,012	68,474,641	23,861,472	73,593,841	28,082,331	80,728,282	25,693,360	76,519,759
April	22,579,959	87,255,201	20,961,008	89,435,649	24,768,989	98,362,830	25,836,684	106,564,966	22,811,642	99,331,401
May	22,216,016	109,471,217	23,102,867	112,538,516	25,278,960	123,641,790	28,414,354	134,979,320	23,412,960	122,744,361
June	20,698,814	130,170,031	20,862,610	133,401,126	24,450,835	148,092,625	24,508,742	159,488,062	22,397,782	145,142,143
July	24,842,971	155,013,002	24,074,929	157,476,055	25,663,577	173,756,202	27,986,592	187,474,654	25,114,663	170,256,806
August	24,421,537	179,434,539	23,002,254	180,478,309	26,591,950	200,348,152	28,066,096	215,540,750	25,282,865	195,539,671
September	23,339,792	202,774,331	22,452,566	202,930,875	26,041,099	226,389,251	26,836,683	242,377,433	22,491,643	218,031,314
October	22,615,721	225,390,052	21,623,057	224,553,932	26,659,121	253,048,372	26,311,074	268,688,507	22,408,148	240,439,462
November	21,421,085	246,811,137	21,695,072	246,249,004	25,620,216	278,668,588	26,316,687	295,005,194		
December	22,105,530	268,916,667	24,695,740	270,944,744	26,102,620	304,771,208	26,308,752	321,313,946		
Total tonnage reported[1]		**268,916,667**		**270,944,744**		**304,771,208**		**321,313,946**		
Total tonnage not reported[2]		**9,508,289**		**10,536,772**		**10,190,883**		**15,145,992**		
Total tonnage produced[3]		**278,424,956**		**281,481,516**		**314,962,091**		**336,459,938**		**338,852,148**

[1]From Federal Energy Regulatory Commission (FERC) Form 423 1996-2000. [2]Includes estimates of residential, industrial, and exported coal, plus tonnage not reported on FERC's Form 423. [3]Wyoming State Mine Inspector's Annual Reports. Wyoming State Geological Survey, Coal Section, February, 2001.

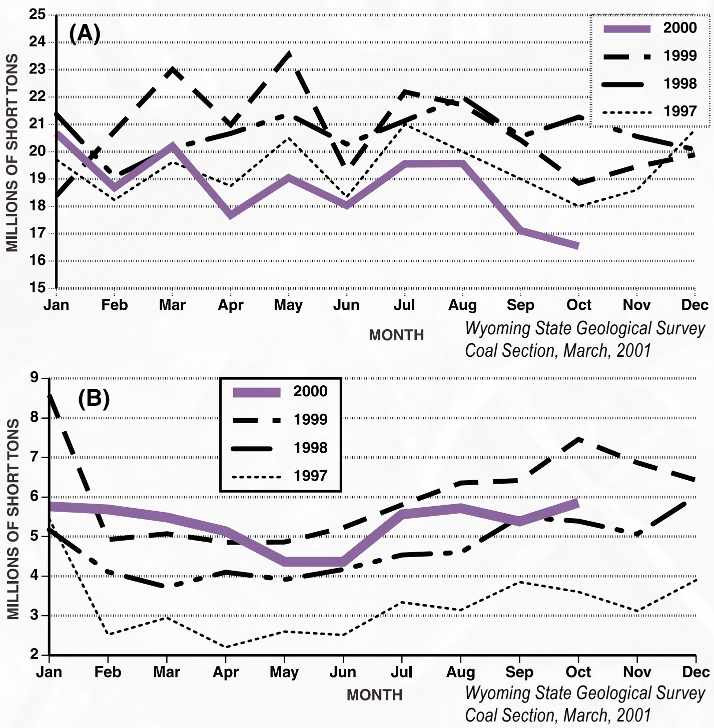

Figure 14. Monthly coal deliveries from Wyoming (1997 through October, 2000). (A) Coal sold on contract and (B) coal sold on the spot market. From Form 423 of the Federal Energy Regulatory Commission (FERC).

Table 13. Breakdown of average prices paid for coal from northeastern Wyoming, southern Wyoming, and Wyoming as a whole (1988 through 1999) with forecasts to 2006.

Year	Northeastern	Southern	Statewide
1988	$7.35	$21.45	$9.16
1989	$6.94	$19.76	$8.63
1990	$6.86	$19.36	$8.43
1991	$6.58	$18.81	$8.06
1992	$6.61	$18.84	$8.13
1993	$6.02	$17.72	$7.12
1994	$5.62	$17.42	$6.62
1995	$5.60	$17.35	$6.38
1996	$5.40	$17.30	$6.15
1997	$5.03	$17.19	$5.78
1998	$4.73	$17.15	$5.41
1999	$4.57	$16.58	$5.19
2000	$4.63	$16.50	$5.13
2001	$4.65	$16.00	$5.07
2002	$4.69	$15.00	$5.07
2003	$4.66	$14.50	$5.07
2004	$4.66	$14.50	$5.07
2005	$4.56	$14.50	$5.07
2006	$4.57	$14.50	$5.07

Statewide data for 1988 through 1990 are from reports by the U.S. Department of Energy's Energy Information Administration; data for 1991-1999 are derived from Wyoming Department of Revenue information; estimates for 2000 through 2006, and all regional breakdowns are estimated by the *Wyoming State Geological Survey, Coal Section, February, 2001.*

and high natural gas prices, have spot market prices responding in an upward trend (**Figure 15**). For example, spot prices for the lower-Btu Powder River coal especially, increased somewhat in mid-November, 2000 and then rose to about 50 cents per ton more in early February. In early March, 2001, prices for low and high Btu coal surged as supplies became scarce from heavy fuel burns at many generating plants.

Using 1999 statistics, the Wyoming Coal Information Committee (2001) showed the economic and other benefits received from selling a trainload of Wyoming coal (**Figure 16**). It is interesting to note that a large portion of the total (42%) goes back into the coal mining sector to keep the mines operating (e.g., equipment and operating costs, environmental, and supplies/services) and the employees paid. In 1999, Wyoming coal mines shipped 25,882 unit trains of coal (each containing approximately 13,000 tons of coal), creating $3.9 billion in total economic activity for Wyoming. That year the coal industry supported 16,000 direct and indirect jobs, contributing $589 million in total payrolls. The coal industry also paid $347.5 million in state and local taxes and royalties.

Developments in the Powder River Basin

Coal production from the Powder River Basin, Wyoming totaled nearly 323.2 million tons in 2000 (**Table 11**). Campbell County mines produced the lion's share with 299.5 million tons, an increase of 5.2 million tons over the 1999 figure. The county accounted for nearly 93% of the PRB total and about 88% of the state's total production in 2000. Converse County mines produced 23.6 million tons, about 2 million tons less than in 1999. The Converse County downturn was related to the end of production at the Dave Johnston mine this past year. The Big Horn mine

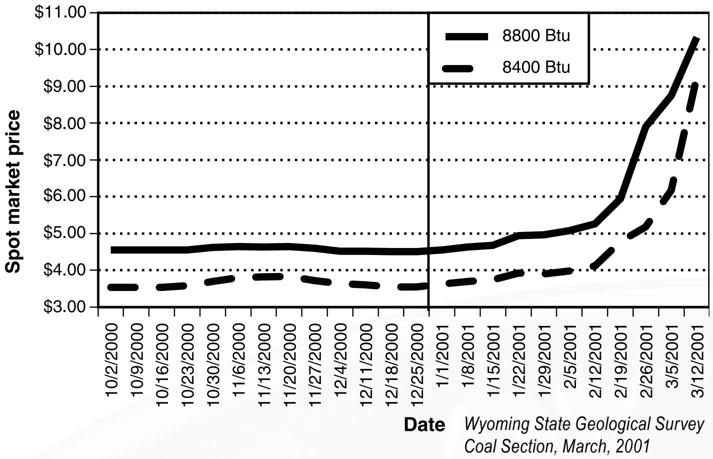

Figure 15. Wyoming PRB coal spot price watch (October 2, 2000 through March 12, 2001). Modified from Coal Daily's spot market index, and Coal Week's short term spot market price index.

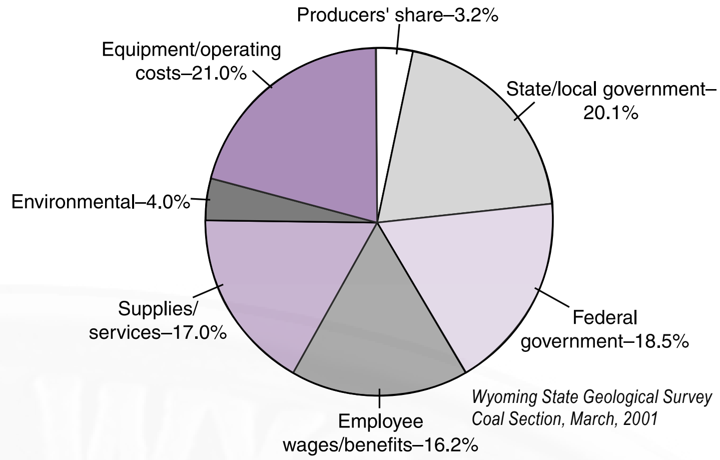

Figure 16. Where the money goes from each train of Wyoming coal sold (modified from Wyoming Coal 2001, Wyoming Coal Information Committee).

in Sheridan County, now in final reclamation, added the remaining 38,411 tons (Office of the Wyoming State Inspector of Mines, personal communication, 2001).

The Bureau of Land Management (BLM) in their draft environmental impact statement recommended moving forward with the North Jacobs Ranch Lease By Application (LBA) tract submitted by Kennecott Energy. The tract would supply its successful bidder with approximately 519 million tons of federal coal. Kennecott nominated the LBA tract to extend the life of the Jacobs Ranch mine. Currently Jacobs Ranch is permitted to mine up to 38 million tons per year in 2001 and up to 50 million tons per year from 2002 through 2004. The mine's production schedule calls for 30 million tons per year; without the new LBA tonnage the mine will exhaust its current reserves in seven years (Coal Daily, 12/18/00).

Arch Coal's Black Thunder mine now has the largest operating dragline bucket in the world. In early February, a 175-cubic-yard bucket was delivered to the mine for use by their giant "Ursa Major" dragline. Minserco, a subsidiary of Bucyrus International Inc., constructed the new 165,000-pound bucket in Gillette. Arch garnered the title of world's biggest operating dragline since the Illinois Basin's "Big Muskie" dragline (with a 225-cubic-yard bucket) was retired and dismantled several years ago. "Big Muskie" is the name now used for one of four draglines currently in service at Black Thunder (Wyoming Tribune-Eagle, 2/9/01).

The BLM announced in the Federal Register (2/14/01) that they had received a proposal to exchange land and mineral properties currently owned by Chevron Corporation's subsidiary Pittsburg & Midway Coal Mining Company (P&M) in Sheridan, Carbon, and Lincoln counties, Wyoming for federal coal underlying P&M controlled surface lands in northern Sheridan County. The BLM intends to begin preparation of an environmental impact statement concerning the proposed exchange. For additional information or questions, contact Nancy Doelger at BLM's Casper Field Office.

Developments in southern Wyoming

Mines located in southern Wyoming produced a total of 15.7 million tons of coal in 2000. Sweetwater County led southern Wyoming with almost 10 million tons of coal followed by Lincoln County with 3.7 million tons, down from 4.3 million tons mined in 1999. The decrease in Lincoln County was related to the protracted labor strike at P&M's Kemmerer mine during May and June of 2000. Carbon County mines decreased their coal production, dropping from 2.7 million tons in 1999 to less than 2.0 million tons of coal in 2000. The state's last active underground mine in the Hanna Basin closed in mid-year 2000.

St. Joseph Power & Light, a Missouri-based utility company, is likely to schedule test burns of various coals to replace coal it currently receives from Arch of Wyoming's Seminoe II mine near Hanna. This surface mine is scheduled to close in 2001 after exhausting its reserves, forcing the utility to seek alternate coal supplies (Coal Week, 11/20/00).

Transportation developments

The Energy Information Administration (EIA) released the Secretary of Energy's third and final report on coal transportation to Congress in October. The report was required by Title XIII of the Energy Policy Act of 1992. It examines changes in domestic coal transportation rates and coal distribution patterns since the Clean Air Act Amendments of 1990. The study, entitled *Energy Policy Act Transportation Rate Study: Final Report on Coal Transportation*, can be acquired from EIA by contacting http://www.eia.doe.gov.

The Union Pacific Railroad (UP) moved a record number of coal unit trains in the year 2000. By mid-December the railroad had moved over 10,000 unit trains of coal out of the PRB, breaking the 1999 record of 9898 coal trains. The increase came mostly from UP's ability to increase the velocity of rail movements, the result of completing the $327 million third main line project between North Platte, Nebraska and Marysville, Kansas last summer. Average speeds on

UP's coal corridor increased from 15.1 mph in 1999 to 20 mph in 2000 (Wyoming Tribune-Eagle, 12/19/00).

Despite the continued strength of coal shipments, UP announced that it would be laying off up to 4% of its work force in the first six months of 2001. The company believes that most of the 2000-employee reduction will come through attrition and early retirements. If the voluntary reductions are not enough, then involuntary layoffs may result. UP said that the slowing economy is driving both the job cuts and the associated reductions in capital spending projected by the railroad for 2001 (Wyoming Tribune-Eagle, 12/19/00).

Dairyland Power Cooperative filed a letter strongly supporting the proposed Dakota, Minnesota and Eastern Railroad's (DM&E's) proposed build-in to the PRB. The utility took strong exception to the U.S. Forest Service's comment that there was enough capacity on the UP and Burlington Northern–Santa Fe Railroad lines already serving the area, making the DM&E project unnecessary. Dairyland burns nearly 2 million tons of PRB coal annually. Dairyland did point out that the DM&E build-in could result in many economic benefits including greater rail competition, lower transportation costs, and lower diesel fuel consumption from the completion of the shorter, more direct line into the upper Mississippi Valley market area (Coal Daily, 12/12/00).

Regulatory developments

The U.S. Senate has passed a bill sponsored by Wyoming Senator Craig Thomas that increases the ceiling on the amount of federal coal acreage that a single company can hold. The Coal Competition Act (S. 2300) raises the maximum acreage that a company can hold in a single state from 46,080 to 75,000 acres and increases the national cap on acreage from 100,000 to 150,000 (Coal Week, 10/9/00). The House passed S. 2300 on October 23 and sent it to President Clinton, which he signed into law in late November.

The Environmental Protection Agency (EPA) announced in January a proposed rule aimed at supplying guidance to states in determining which utility sources must install "best available retrofit technology" (BART) for smokestack emissions. In addition, the EPA proposed that other large stationary emission sources, such as smelters, industrial boilers, and industrial plants (including petroleum refineries, chemical plants, and paper and steel mills) be required to install controls that will protect visibility, especially in "pristine" areas such as national parks (Mining Week, 1/22/01).

In early December the EPA announced its decision to regulate mercury under section 112 of the Clean Air Act. The EPA stated "as part of developing a regulation, the effectiveness and the cost of controls will be examined along with the level(s) of control that may be technically feasible." While pointing to recent research that indicates the risk of adverse effects of mercury exposure is low, the mining industry maintains that any such regulations must be science-based, flexible, and achievable (Mining Week, 12/18/00).

. . . Wyoming's Powder River Coal Field has the coal resources to generate electricity cheaper than any other state in the west.

The BLM in mid-December released a proposed rule that would increase current fees and add new fees to cover BLM's cost of processing documents such as leases and lease applications. The proposed rule will impact all mineral programs controlled by the BLM, including coal, natural gas, and oil. The new rule will result in additional charges of from several hundreds to several thousands of dollars. A copy of the proposed rule can be found on the Internet at http://www.access.gpo.gov/su_docs/aces/aces140.html (Coal Daily, 12/19/00).

Market developments and opportunities

With this winter's electricity crisis in California and soaring electric bills nationally, North American Power Group is looking at a new $150-million transmission project to export additional electricity from Wyoming to Colorado's Front Range. The Denver-based company feels that Wyoming's Powder River Coal Field has the coal resources to generate electricity cheaper than any other state in the west (Casper Star-Tribune, 2/4/01).

Dynegy Coal Trading & Transportation (Dynegy) and SGI International have agreed to extend the delivery date for enhanced PRB coal from the Encoal plant in Wyoming until September, 2001. The agreement also raises the amount of Encoal production Dynegy may elect to take from 500,000 to 750,000 tons. The Encoal plant is the first Liquids from Coal (LFC) commercial plant in the nation (Coal Week, 10/16/00).

San Antonio City Public Service is looking at building another coal-fired 528-megawatt generating plant that could share the infrastructure of their new Spruce plant. Current gas prices and low-priced PRB coal are making the utility company look at Wyoming coal sources to fuel the new plant (Coal Week, 10/30/00).

Northeast Utilities has completed a test burn of PRB coal at its Mount Tom, Massachusetts generating station. This plant is the farthest northeast to have tested PRB coal, which was believed to be from Peabody's North Antelope/Rochelle mine complex. Results of the test were not released by the utility (Coal Week, 1/15/01).

Kennecott Energy launched its web site which features online coal purchasing. Members of the KennecottDirect web site can make monthly and quarterly spot purchases online with next-day loading of coal. Visit their web site at http://www.kennecottdirect.com (Coal Daily, 1/8/01).

Table 14 tabulates some of the contract, spot sales, test burns, and solicitations for Wyoming coal announced during the fourth quarter of 2000.

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Table 14. Marketing activities for Wyoming coal producers during the fourth quarter of 2000*.

	Utility	Power Plant	Coal Mine/Region	Activity	Tonnage	Comments
1	Consumers Energy	System	PRB	Sp	365000 t	Delivery 4th quarter of 2000
2	Consumers Energy	J.H. Campbell	PRB	Sp	800,000 t	Delivery in second half of 2001
3	Detroit Edison	System	PRB	Sp	400,000 t	Delivery in 2001
4	Dynegy Inc.	Hennepin & Baldwin	PRB	C	2 million t	For 2001 delivery
5	FirstEnergy Corp.	System	PRB	So	400,000 t	For delivery in 2001, Minimum 8,800 Btu, Maximum 5.1% ash
6	Grand Island Electric	Grand Island	Black Thunder/PRB	C	350,000 t/y	Two year contract 2001-2002
7	Lansing Bord of Water & Light	Lansing	PRB	So	Unspecified	
8	Lower Colorado River Authority	System	Buckskin/PRB	C	up to 1 m.t.	Delivery in 2001 on either UP or BNSF railroads
9	Northern Indiana Public Service Co.	Sysytem	PRB	SP	2 to 4 trains	8,800 Btu coal for fourth quarter 2000 delivery
10	Pella Municipal Power & Light (through Alliant Energy)	Pella	PRB	C	80,000 to 100,000 t/y	Coal to be trucked from IES Utilities Ottumwa plant
11	Salt River Project	Coronado	Jacobs Ranch/PRB	C	500,000 t	For 2001 delivery
12	San Antonio Public Service	San Antonio	Cordero-Rojo/PRB	SP/C	up to 1 m.t.	For 2001 delivery either spot or contract terms
13	TVA	System	Black Thunder/PRB	C	Up to 3.9 m.t. over three years	Coal to be delivered over 2001 through 2003
14	TXU Electric & Gas	System	Caballo/PRB	C	1 m.t.	For 2001 delivery
15	Xcel Energy Services (for Public Service Co. of CO)	Arapahoe	PRB	Sp	400000 t	For deliver in first and second quarter of 2001
16	Xcel Energy Services (for Public Service Co. of CO)	Valmont & Cherokee	Western bituminous	Sp	up to 1.2 m.t.	Minimum 10,500 Btu and 0.5% sulfur for delivery in 2001

*Data obtained from: COAL WEEK, Coal Daily, Coal Age, FERC database, and personal contacts. Note: C = contract; Ex = export coal Sp = spot coal; So = solicitation; T = test burn; t = short tons; m.t. = million short tons; t/y = short tons per year; UP = Union Pacific Railroad; BNSF = Burlington Northern/Santa Fe Railroad; and PRB = Powder River Basin. *Wyoming State Geological Survey, Coal Section, February, 2001.*

COALBED METHANE UPDATE

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At the start of 2001, over 8000 coalbed methane wells had been drilled in the Powder River Basin (PRB) of Wyoming, and nearly 3400 are currently producing methane. According to Don Likwartz, of the Wyoming Oil and Gas Conservation Commission, the maximum capacity of nearly 650 million cubic feet (MMCF) per day for production gathering systems and pipelines should be reached by the end of the first quarter of 2001. Twice during the year 2000 coalbed methane production reached the PRB's maximum pipeline capacity. In some areas operators had to shut in (not produce) their wells until new pipelines were constructed. 2001 should see healthy growth in the infrastructure of gas gathering and transportation in northeastern Wyoming.

Coalbed methane company activities

Marathon Oil Co. announced it would acquire all outstanding shares of Pennaco Energy Inc. (Pennaco) for $19.00 per share. The transaction has an estimated value of $500 million, including an outstanding debt of $54 million. The boards of directors of both companies have endorsed the agreement pending the usual government approval. Pennaco was founded in 1998 and has been active in the coalbed methane (CBM) play in the PRB since that time. With 400,000 net acres under lease, Pennaco is one of the largest leaseholders in the basin. Their net methane reserves in the basin have been estimated at 200 billion cubic feet (BCF) with potential for nearly 800 BCF. Pennaco currently produces in the neighborhood of 50 MMCF per day in the PRB (PI/Dwights Plus Drilling Wire, 12/27/00).

Prima Energy Corp. (Prima) announced it drilled 171 CBM wells in the PRB in 2000. Prima plans to use up to 40% of its $45 million budget for 2001 to drill and connect to sales pipelines up to 200 additional CBM wells (Casper Star-Tribune, 2/7/01).

Anadarko Petroleum Corp. (Anadarko) is entering its first year of exploration on 4 million acres it acquired in last July's merger with Union Pacific Resources. Anadarko has interests in seven Wyoming CBM projects and in 2001 plans to add 35 wells to the two they completed in 2000. Anadarko is the world's largest independent exploration and production company (Casper Star-Tribune, 2/7/01).

In October, Pennaco revised its estimate of CBM production for the fourth quarter of 2000 from its earlier projection of between 70 to 75 MMCF per day downward to 58 to 63 MMCF per day. One reason Pennaco reduced its estimate was because neighboring producers had placed blowers on wells adjacent to Pennaco's leases, which the company claimed will reduce their production by roughly 4000 MMCF per day. Pennaco has since put blowers on their affected wells and believes this will restore their productivity. The second reason for the downward revision in the Pennaco/CMS Oil & Gas Co. Area of Mutual Interest is that their downhole pumps have had problems caused by coal and shale sloughing and clogging the pumps (PI/Dwights Plus Drilling Wire, 10/20/00).

Barrett Resources reported that their CBM production units in the PRB had reached 207 MMCF per day by mid-December. The company said that they currently have 661 wells in various stages of development and plan to jointly drill 800 additional wells during 2001 (PI/Dwights Plus Drilling Wire, 12/26/00).

Petroleum Development Corp., a Bridgeport, West Virginia independent operating out of a regional office in Gillette, is planning an eight-well CBM project to test coals in the Almond Formation (Mesaverde Group). The project is located in southeastern Carbon County, approximately 22 miles south of Rawlins (**location A, Figure 10**). The wells are projected to intersect the coals at depths between 1800 to 4200 feet (PI/Dwights Plus Drilling Wire, 10/24/00).

Infinity Oil & Gas of Wyoming has scheduled a new exploration program located 25 miles east of Rock Springs (**location B, Figure 10**). Again, the target coals are in the Almond Formation. The company's current plan calls for three CBM wells to be drilled to depths ranging from 2350 to 3050 feet (PI/Dwights Plus Drilling Wire, 12/29/00).

The CBM industry will need an additional 300 megawatts of electricity in the near future.

WBI Holdings Inc., through its wholly owned subsidiary Redstone Gas Partners LLC., has acquired 17 coalbed methane wells and leases on approximately 9700 acres north of Sheridan (**location C, Figure 10**) from El Paso Production Co. and Jolen Operating Co. (PI/Dwights Plus Drilling Wire, 11/17/00).

Pennaco has received four additional water discharge permits from the Wyoming Department of Environmental Quality (WDEQ) for the House Creek project in the PRB (**location D, Figure 10**). This project currently consists of 107 CBM wells drilled into the Big George coal bed. The new permits will enable the company to begin dewatering 70 wells and drill an additional 250 planned wells. Thirty-seven wells are already pumping water under previous permits. Pennaco plans to drill approximately 100 of the new wells into Big George and the rest into other benches in the Wyodak coal zone (PI/Dwights Plus Drilling Wire, 12/8/00).

WDEQ also issued eight new water discharge permits to Barrett Resources for its operations in the PRB. These permits will allow the company and its joint venture partner, Western Gas Resources Inc., to begin dewatering 132 wells already drilled into the Wyodak coal and to develop an additional 281 well sites (PI/Dwights Plus Drilling Wire, 12/18/00).

Phillips Petroleum Co. released figures for its 2001 exploration and production budget. The company earmarked money to participate in CBM plays in the San Juan, PRB, and Uinta basins (PI/Dwights Plus Drilling Wire, 12/13/00).

Coalbed Methane Coordinator

The Coalbed Methane Coordination Coalition named Mickey Steward Wyoming's Coalbed Methane Coordinator. The coalition includes Campbell, Converse, Carbon, Johnson, and Sheridan counties as well as the Campbell and Lake DeSmet conservation districts and the State of Wyoming. Her principal job will be to facilitate understanding, communication, and the exchange of accurate information and productive ideas as well as serve as a resource for all participants and parties with questions and problems related to the fast paced development of the state's coalbed methane industry.

Mickey has lived on a working cattle ranch north of Gillette since 1981. She earned a B.S. in Biology and a M.S. in Ecology from the University of Colorado and a Ph.D. in Range Management from Colorado State University in 1984. She has worked in mining and environmental engineering since 1973 in the western U.S. (including Colorado and the PRB), South America, Panama, and Spain. Mickey began her work as Coalbed Methane Coordinator in January, 2001 and is working out of a Buffalo office (Conservation Winds, January, 2001).

Pipelines

Bighorn Gas Gathering has completed and put into service a 20-inch-diameter, 56-mile extension of its existing 100-mile-long gas gathering system in Sheridan County. This extension will serve the needs of CMS Oil & Gas Co., Pennaco, J.M. Huber Corp., Prima Oil & Gas Co., and others in the Sheridan area CBM play. The new line extends west from Bighorn's western terminus in southeastern Sheridan County to T57N, R83W, where Huber's production is located. The Bighorn gathering system has a capacity of 250 MMCF per day and delivers gas to the Fort Union Gas Gathering System for transportation out of the PRB (PI/Dwights Plus Drilling Wire, 11/17/00).

On January 17, 2001, Fort Union Gas Gathering, LLC., announced plans to increase the capacity of its gas pipeline from Gillette to Glenrock this year. The plan includes a 20-inch-diameter pipeline paralleling the company's existing 106-mile-long, 24-inch-diameter pipeline. The new line will increase the gathering capacity from 434 to 634 MMCF per day (Casper Star-Tribune, 1/19/01).

Electricity needs for coalbed methane

The coalbed methane activity in the PRB is straining the available electrical power supply to run the submersible pumps that produce the water and gas. Powder River Energy Corp. (PREC) currently has 14 contractors helping its own crews string power lines to service CBM wells. The CBM industry will need an additional 300 megawatts of electricity in the near future. Basin Electric Power Cooperative (Basin) supplies the PREC with their electricity. Basin plans to add a new power plant by the end of 2002 to fill this growing need, but has yet to determine its location and its capacity. Basin operates three 580-megawatt units at the Laramie River Station near Wheatland, Wyoming (**location E, Figure 10**).

Three power plant projects will be under construction this year. Black Hills Corp. plans call for a $100 million coal-fired 80-megawatt plant (Wygen No. 1) to be constructed at the Wyodak complex east of Gillette (**location F, Figure 10**). Also at the complex a $20 million gas-fired 40-megawatt booster plant is being constructed by Independent Power Production. The third project is Two Elk Power's 280-megawatt waste-coal-fired plant being constructed near Wright (**location G, Figure 10**) (Casper Star-Tribune, 1/23/01).

Regulatory issues

WDEQ is looking at reducing the barium discharge limit in CBM wells from the current 2000 micrograms per liter of water to 1800. The CBM industry believes this would mean compliance problems for up to 10% of the wells currently producing CBM in the PRB. Barium levels in the CBM waters tend to increase with the depth of the wells and as the play moves west of Gillette toward Sheridan (Casper Star-Tribune, 1/11/01).

Gary Beach director of the Water Quality Division at WDEQ said that CBM water is not the only threat to water quality in the PRB. Flood irrigation also may leach salts out of soils and possibly add pollutants to the streams or rivers in the area. Until studies are completed that look at all sources of water and their interactions with the soil types of the area, regulators do not know what each source contributes to the potential problem (Casper Star-Tribune, 2/8/01).

Revised coalbed methane pamphlet

The WSGS has recently revised their popular Information Pamphlet IP-7, *Coalbed methane in Wyoming*. The new version contains updated sections on coalbed methane activity, production, resource estimates, and points of contact. New sections have been added that address methane seeps, underground fires, and surface subsidence as well as discuss the projected growth of the industry, factors that will affect the growth, and the revenues that CBM production generates.

PYROPHORICITY (SPONTANEOUS COMBUSTION) OF POWDER RIVER BASIN COALS–CONSIDERATIONS FOR COALBED METHANE DEVELOPMENT

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With the recent proliferation of coalbed methane drilling and production, concerned citizens have inquired about the potential for underground coal fires in relation to the coalbed methane extraction process. This article will briefly discuss the chemistry and factors contributing to the pyrophoricity (spontaneous combustion) of coal, how the factors relate to coal mine fires, and how these factors apply to the current coalbed methane play in the Powder River Coal Field. For more details, the reader is referred to a recent article by Lyman and Volkmer (2001) published by the Wyoming State Geological Survey and also available on the Survey's web site (http://wsgsweb.uwyo.edu).

Natural coal fires along coal outcrops in the Powder River Coal Field have occurred throughout the more recent geologic history of the area and have been major contributors to the formation of the topography and landforms of the area (Coates and Heffern, 1999). Early explorers to the area noted the presence of wild coal fires [caused mostly by wildfires started by lightning or sometimes by humans] in the northern part of the coal field and the first settlers extinguished most of the bigger, well-established fires. Abandonment of shallow underground mines that were first opened in the coal field eventually led to their subsidence; related spontaneous coal fires became an environmental concern in the 1950s and 60s (Jolley and Russell, 1959).

Shallow coal fires in areas of abandoned mines continue as a major environmental concern throughout the world. Millions of dollars are spent annually to find ways of extinguishing these difficult to control fires. In the U.S., federal and state agencies continue to fight natural coal fires by extinguishing old fires and preventing new outbreaks.

Low-rank, high-moisture coals exhibited self-heating at temperatures as low as 30° C . . .

Spontaneous combustion of coal

Spontaneous combustion of coal can occur in both surface and underground coal mines, stockpiles and other coal storage facilities, as well as along natural outcrops of coal. Sources of heating that can lead to spontaneous combustion are the low temperature of oxidation (of coal) in combination with absorption of moisture by dried or partially dried coal. Oxidation of coal is a very complex process, but basically the chemical reaction of carbon (coal) plus oxygen is exothermic (about 94 kilocalories per mole), and releases CO_2; the rate of reaction doubles for every increase of 10° C (Speight, 1983). If the heat cannot escape it raises the temperature of the coal past its ignition point and a coal fire occurs. Low-rank, high-moisture coals exhibited self-heating at temperatures as low as 30° C (Kuchta and others, 1980).

However, heating effects of oxidation in low rank coals may not be enough to cause combustion. Coal that has started to dry tends to have an increased level of self-heating when water is reintroduced, which is known as the heat-of-wetting. This is an exothermic process and the liberated heat can accelerate the spontaneous heating of the coal (Kim, 1977).

Kim (1977) identified several other factors that contribute to the pyrophoricity of coal: 1) the flow of air around coal provides both the oxygen necessary for the oxidation process and a way to dissipate the heat as it is generated; 2) particle size has an inverse relationship to spontaneous combustion in coal–the smaller the particle size the greater the surface area available for oxidation; 3) as the rank of coal decreases, the tendency for coal self-heating increases; 4) the higher the temperature, the faster coal reacts with oxygen; 5) the presence of the sulfur minerals pyrite and marcasite in the coal may accelerate spontaneous heating (but pyrite must be present in concentrations greater than 2% before it has a significant affect); 6) geologic factors such as faults and fractures in the overburden can permit water and air to enter a coal seam; and 7) areas within surface or underground coal mines where fine coal particles accumulate, such as at the base of the coal highwall or in gob areas underground, are candidates for potential spontaneous coal fires.

Coal fires in mines

Spontaneous ignition of coal is extremely common within the large surface mines of the Powder River Coal Field. The most vulnerable area is at the foot of a coal highwall (**Figure 17**), when dried coal sloughs off the highwall to form a pile of fine coal particles. When atmospheric moisture is high and strong winds are present (and the piles of coal are of a volume sufficient to hold the generated heat of oxidation and wetting), coal fires start. The fires can be controlled by either spreading out the coal piles (allowing radiation of the heat back into the atmosphere) or re-compacting the heated coal area (which cuts off the oxygen).

While there are no active underground mines in the Powder River Coal Field, abandoned underground mines continue to be sites of hard-to-control coal fires. The Acme mine area north of Sheridan, Wyoming is a prime example of these fires (**Figure 18**). Here, shallow underground mines have undergone extensive subsidence. Air enters the old workings via tensional fractures propagated to the surface with the rock failure associated with the collapse of the roof. Rib failure and pillar crushing (also related to subsidence) can fill the old mine void with relatively fresh, fine coal particles that then start to dry as well as oxidize. Water is introduced both by surface runoff into these same fractures and by seasonal fluctuations of the local groundwater table. Due to the poor thermal conductance of the rock and soil overlying the coal, heat liberated from the reactions cannot readily escape and the coal ignites.

Coal that has started to dry tends to have an increased level of self-heating when water is reintroduced . . .

In active underground room and pillar mines, rib and roof falls are cleaned up as they occur. Rock dusting the mine ribs and inactive faces prevents the liberation of fine coal particles. Haulageways and belt lines are routinely patrolled to pick up any spilled coal. Modern ventilation keeps fresh air moving through the mine and automated air-monitoring devices check for levels of coal-combustion waste gases.

The gob area left behind in a longwall operation is susceptible to fires

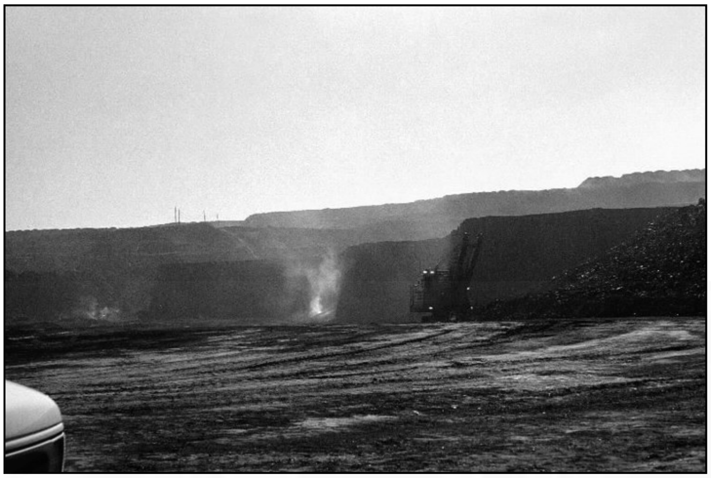

Figure 17. Unidentified eastern PRB surface mine, Wyoming State Geological Survey file photograph by L.L. Hallberg.

Figure 18. November, 1975, eastward aerial oblique view of surface effects of an underground mine fire above the northern part of the Acme mine, Wyoming (from Dunrud and Osterwald, 1980).

started by spontaneous combustion. While most of the coal is removed, floor coal, rider (or roof) coals, and other carbonaceous rock types are sometimes left behind and can be subject to self-heating problems (Kim, 1995; Kim and Chaiken, 1993).

Coalbed methane

Coalbed methane is natural gas (CH_4) that has been generated during the coalification process. The coalification process has transformed (through time, heat, and pressure) the original dead, buried plant material into the present deposits of coal. The coalbed methane is trapped in the coal, absorbed and/or adsorbed on the coal particles, and generally held in solution by lithostatic and hydrostatic pressure. To assess the potential for self-heating and ignition of coals, completion methods used for coalbed methane wells in the Powder River Basin (PRB) must be understood. In the PRB, coalbed methane wells are completed open-hole (**Figure 19**).

Using this completion method, casing is set to the top of the target coal bed and the underlying target coal zone is under-reamed and cleaned out with a fresh-water flush. A downhole submersible pump produces water up the tubing; gas released from the coalbed is produced up the annulus. Natural gas and water produced at individual wells are piped to a metering and gathering facility. The methane then flows to a compression facility, where the gas is compressed for pipeline shipment (De Bruin and others, 2000). The water may be disposed via surface release, impondment, or re-injection.

Occasionally a "blower" will be placed in-line at the gathering station. These blowers speed the flow of gas away from the well by slightly lowering the bottom hole pressure in the producing wells. A misconception held by some concerning blowers on coalbed methane lines is that they suck air into the seam, when in fact they create a slight vacuum downhole that speeds the degasification of the bed. Air is a contaminant of coalbed methane production. While this production method is known as an open-hole completion, the well configuration is constructed to keep air out of the system.

Summary

Nearly all the conditions for the self-ignition of coal are absent in the immediate vicinity of coalbed methane wells. The following summary reviews those conditions that favor

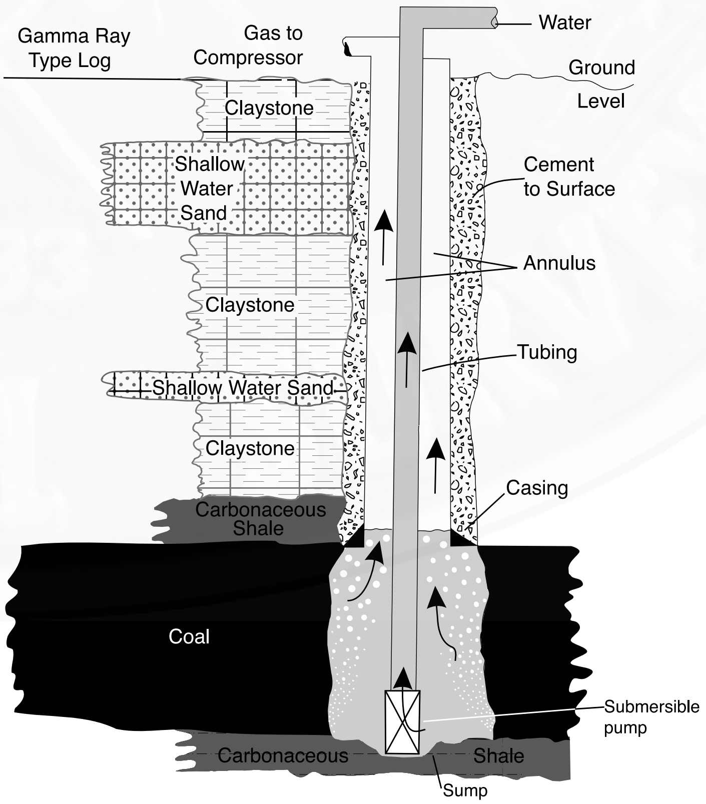

Figure 19. Schematic diagram showing open-hole completion technique for a typical PRB coalbed methane well (De Bruin and others, 2000, as modified from diagram furnished by the Wyoming State Engineer's Office).

spontaneous combustion in subbituminous coals of the PRB and relates those conditions to exploration, well completion, and production of coalbed methane.

- Oxidation of coal. Heat is liberated when oxygen reacts with carbon molecules and other components of coal. Oxygen is kept out of coalbed methane wells since it is a contaminant; subsurface water from coalbed methane wells favors chemical reduction instead of the oxidation reaction. Even where the coal has been completely dewatered, there is little oxygen present for oxidation to occur. During coalbed methane production, any oxygen and heat generated would be quickly vented to the surface before reactions could occur and sufficient heat generated.
- Heat-of-wetting. This requires that a coal bed be exposed long enough to lose some of its inherent moisture, which would only be a problem in areas above the zone of saturation. In coalbed methane production, complete dewatering of the coal is not the objective. Only enough water is pumped to lower the hydrostatic pore pressure in the coal to allow for desorption of methane from the coal bed. If a well did completely dewater part of a coal bed, any heat generated from the heat-of-wetting or oxidation would be vented to the surface before it could build up enough to result in coal ignition.
- Airflow rate. The airflow rate in a coalbed methane well by design is very low to null, and in a direction directly out of the well, providing no oxygen for oxidation and no air to dry out the coal. Several *in situ* underground coal gasification experiments conducted in Wyoming were not able to sustain forward coal ignition even where millions of standard cubic feet of air were injected into dewatered and fractured coal beds.
- Particle size. Particle size has an inverse relationship to spontaneous combustion in coal. In surface coal mines, an appreciable amount of fine material must be present to favor spontaneous coal combustion. The relatively small hole diameter of a coalbed methane well prohibits large volumes of fines to accumulate. Any fines that do collect in the area of the pump can be flushed out.
- Rank. The subbituminous-rank coals in the PRB contain a high percentage of reactive macerals (vitrinite and exinite) and under certain conditions are candidates for spontaneous combustion. However, these conditions appear to be absent in coalbed methane wells.
- Temperature. The higher the temperature, the faster coal reacts with oxygen. Even if oxidation or wetting of dried coal were to occur, construction of coalbed methane wells vents heat out of the coal so that temperatures needed for coal ignition are neither present nor anticipated to occur.

The likelihood of completely dewatering a coal bed and exposing large areas of fine coal particles to oxygen seems extremely remote.

- Pyrite content. Generally pyrite or marcasite must be present in concentrations greater than 2% before it has a significant effect. Tertiary coals of the PRB are very low in the occurrence of these inorganic sulfide minerals.
- Geological factors. While rocks are poor conductors of heat, coalbed methane wells are very efficient (in their design) in carrying heat away from the coal and venting it to the surface. Faults and fractures that may be present in the overburden are sealed via casing and cement to permit dropping the hydrostatic pressure for coalbed methane production.

Finally, during the production and post-production phases of a coalbed methane well, conditions necessary to foster spontaneous combustion of coal are not present. After the coal seam is depleted of economical methane resources, wells must be plugged and sealed. Unlike abandoned underground mines, coalbed methane wells leave no underground voids susceptible to further subsidence and associated spontaneous coal ignition. The likelihood of completely dewatering a coal bed and exposing large areas of fine coal particles to oxygen seems extremely remote.

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INDUSTRIAL MINERALS AND URANIUM UPDATE

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Bentonite production from Wyoming mines in 2000 was about 4.0 million short tons, a little less than that for the peak production year in 1981. Static markets for most uses of bentonite allowed Wyoming to continue as the largest bentonite-producing state in the U.S by far. Construction aggregate, which ranks behind trona and bentonite in value, still accounts for the sixth greatest value of all minerals produced in the state. Dolomite continues to be quarried and used for construction and decorative aggregate. Limestone, quarried for construction aggregate is also used in the manufacture of cement and in emissions control in coal-fired power plants. Phosphate rock has not been mined in Wyoming since 1977 but it is processed (along with sulfur from natural gas) into soil conditioners at a Wyoming plant. Trona production in 2000 was about 17.8 million short tons, the same as in 1999, but is expected to be less in 2001. Only two *in situ* uranium operations are left in Wyoming, with all their production exported and with low prices continuing.

Bentonite

Bentonite is a clay mineral with high cation exchange capacity, high swelling when wet, high cation absorption capability, and adjustable viscosity when mixed with water or other fluids. In the past Wyoming bentonite was used primarily in oil well drilling as the solid material mixed with water or other fluids and circulated through the drill pipe and the drill hole to bring the rock fragments cut by the drill bit to the surface. In 2000, most bentonite was mined, processed, and sold for use in foundry molds and for its absorption capability as required in kitty litter and similar products. Other uses include water and environmental sealants, material spill cleaning agents, odor control, as a mineral filler, and many others.

Six companies operate fifteen bentonite mills in Wyoming (**Figure 20**). About as much bentonite was mined in 2000 (4.0 million short tons) as at the peak of Wyoming bentonite production in 1981. Numerous pits supply bentonite of different properties to the mills. The different bentonites are blended at the mills into the many different bentonite products.

Bentonite formed by the alteration of volcanic ash. Ash clouds from volcanoes to the west of Wyoming fell into

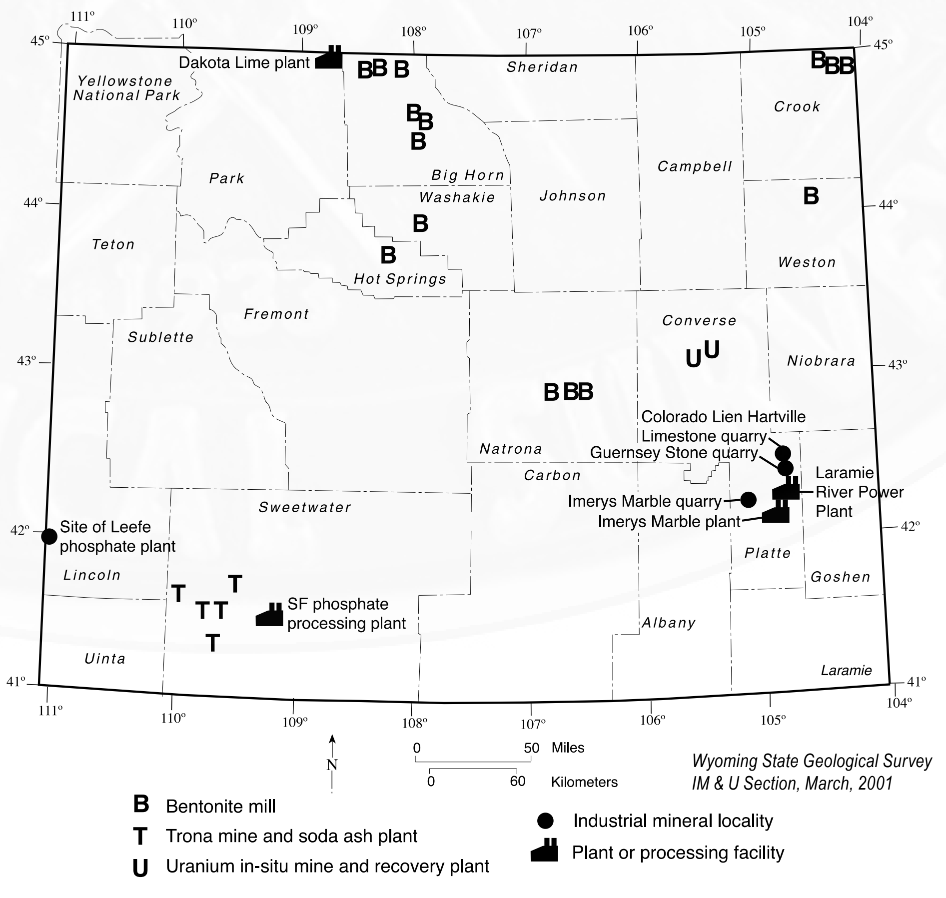

Figure 20. Index map of Wyoming showing the location of industrial mineral and uranium sites mentioned in the text. Locations are approximate and may represent more than one site.

the Cretaceous Interior Seaway, an intercontinental ocean that covered what is now Wyoming and other surrounding states. This material was originally an aluminosilicate glass but as it devitrified (converted from glassy to crystalline texture) in salt water, it crystallized into the sodium-rich montmorillonite clay minerals known as Wyoming bentonite. Bentonite occurs in layers (beds) of commercial thickness and quality in Upper Cretaceous marine sedimentary rocks (**Figure 21**). Bentonite also occurs in Lower Cretaceous and Tertiary rocks of Wyoming, but only the Upper Cretaceous occurrences have proven to be commercial.

Figure 21. The Clay Spur bentonite bed (between the vehicle and the black line) contains a major bentonite resource in the Colony mining district, Crook County.

Construction aggregate

A report entitled *Construction aggregate in Wyoming*, by Ray E. Harris was added to the Industrial Minerals and Uranium section of the WSGS web site (see http://wsgsweb.uwyo.edu/, click on *Geologic Sections*, click on *Industrial Minerals and Uranium*, and click on *Construction Aggregate* in the commodities listing). This report is also available in hard copy as WSGS Industrial Minerals Report IMR 00-01. Ordering information is available in the **PUBLICATIONS UPDATE**.

Construction aggregate includes sand and gravel, scoria (clinker, baked and fused shale), crushed stone, shale, and other materials used in construction. Although Wyoming ranks 46th among the states in the value of construction aggregate produced annually, construction aggregate ranks sixth in value of all mineral products produced in Wyoming after oil, gas, coal, trona, and bentonite.

During the past two years, a new trend in the production of construction aggregate has been developing in Wyoming. Instead of opening small quarries for each construction job, larger quarries have been opened and the material transported to stockpiles some distance from the quarry. Several construction projects can then use material from the stockpiles. For example, limestone aggregate from a site south of Glenrock was quarried in 1998 and 1999 and transported to stockpiles north of Casper for use on construction projects from Casper to Kaycee. It was also transported to stockpiles west of Douglas for use on projects in that area. Limestone quarry sites near Wheatland and Glendo are currently being considered for this kind of operation, with stockpile sites located near Interstate 25 near Cheyenne and Wheatland.

Construction aggregate quarrying in Wyoming is primarily seasonal, with the activity occurring during warm weather, usually from May through October. Stockpiles of aggregate mixed with salt are maintained for use on roads in icy conditions in the winter (**Figure 22**).

Figure 22. Wyoming Department of Transportation sand and salt stockpile near Wheatland for use on highways during icy conditions.

Dolomite

Dolomite is a rock with the chemical composition $CaCO_3 \bullet MgCO_3$. Any rock with $MgCO_3$ content greater than 10% is referred to as a dolomite. Calcium carbonate rocks are limestones. Dolomite is used in certain areas of the U. S. and the world to manufacture cement and as soil conditioners (Carr and others, 1994). In Wyoming, dolomite marble of Precambrian age is quarried by Guernsey Stone, Inc. near Guernsey for construction aggregate and decorative aggregate, and by Imerys Marble of Wheatland (**Figures 20** and **23**). Guernsey Stone has sold small amounts of pink, reddish, and dark marble for decorative aggregate, and Imerys produces white dolomite marble known as Wyoming White®. Dolomite has been quarried at other locations for construction aggregate in the past.

Limestone

Limestone is quarried in Wyoming for construction aggregate, as the primary ingredient in the manufacture of cement, and as an emissions control agent in coal-fired power plants (**Figures 20, 24,** and **25**). Limestone from the Warren quarry in Montana, 6 miles northeast of Frannie, Wyoming, is used for the manufacture of lime at the Frannie plant (**Figure 20**) and as a clarifying agent in the recovery of sugar from sugar beets at plants in western Nebraska.

Figure 23. Imerys Marble processing plant near Wheatland.

Figure 25. Basin Electric's Laramie River power plant northeast of Wheatland. Limestone from the Hartville quarry is used in emissions control, primarily to lessen sulfur dioxide emissions. Most of the emissions seen here on a cold January morning are water vapor. This plant uses around 50,000 short tons of limestone per year for emissions control.

Phosphate rock

According to Bartels and Gurr (1994), phosphate rock is "a rock material that contains phosphate minerals which are sufficient for commercial usage." The primary phosphate minerals are the apatite group $Ca_5(F,CL,OH)(PO_4)_3$, and francolite $Ca_5(F,CL,OH)(CO_3,PO_4)_3$. Phosphate occurs in the Permian Phosphoria Formation in western Wyoming and surrounding states.

Phosphate rock is mined in the U.S. in Florida, North Carolina, Idaho, and Utah. Phosphate rock mined in Utah is transported by slurry pipeline to a plant operated by SF Phosphate Ltd. Corp. near Rock Springs (**Figure 20**), where it is processed with sulfur (recovered from Wyoming natural gas) into agricultural soil conditioners. Phosphate rock is primarily used to produce agricultural chemicals. It is also refined into elemental phosphorus, used as an industrial chemical.

Phosphate was mined in Wyoming from 1926 to 1930 and from 1947 to 1977 (**Figures 20** and **26**). Currently,

Figure 24. Colorado Lien, Inc's Hartville limestone quarry. Limestone from this quarry is used at Basin Electric Power Cooperative's Laramie River power plant for emissions control.

phosphate is being mined in Idaho less than a mile from the Wyoming border. Wyoming contains important phosphate resources, mostly confined to the Overthrust Belt and to the northeastern flank of the Wind River Range. It is likely that phosphate may again be mined in Wyoming in the future as the higher grade resources in Idaho and Utah are depleted, and Eastern phosphate becomes more expensive to produce due to its location in high population areas. The Wyoming phosphate areas should be kept open to mineral location or leasing due to their resource potential.

Trona

According to figures from the U. S. Geological Survey, cumulative soda ash production in the U.S. through November, 2000 was the same as in 1999 (Kostick, 2001). Over 90% of the soda ash produced in the U.S. is from plants in Wyoming west of Green River. Unless the December, 2000 production of soda ash from mined trona in Wyoming was quite different from previous years, approximately 17.8 million tons of trona were mined in Wyoming in 2000, the same as in 1999. We had earlier forecast production of about 18 million short tons (**Table 1**). Official production figures are reported to the State Inspector of Mines of Wyoming and will be released later this year.

Wyoming's four soda ash producers (FMC, General Chemical Soda Ash Partners, OCi, and Solvay Minerals) (**Figure 20**) are anticipating a reduction in demand and production in 2001 due to a projected downturn in the world economy and competition from China. However, Solvay Minerals continues with plant expansion construction in preparation for a future increase in demand.

Uranium

The spot market price of yellowcake continued to fall during the fourth quarter of 2000. At the end of the quarter, the price according to the Uranium Exchange web site (see http://www.uxc.com/top_review.html) was US$7.10, the

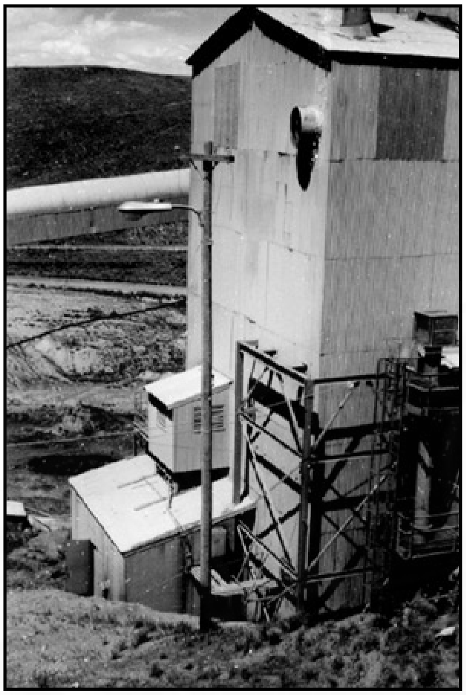

Figure 26. Leefe phosphate calcining plant, circa 1987. This plant operated from 1947 to 1977 at Leefe, near the Utah border west of Kemmerer. The plant has since been torn down and the site reclaimed.

Figure 27. Spot market yellowcake prices, January, 1995 through December, 2000. Source: Uranium Exchange weekly reports.

lowest since 1994 (**Figure 27**) [Note: Since January 20, 2001, the spot market price of yellowcake has risen US$0.40 per pound, to US$7.50, according to the Uranium Exchange (February 5, 2001).] Russia and other countries of the former Soviet Union continue to sell yellowcake on the world market at US$6.50 per pound, according to the Uranium Exchange.

Uranium is mined in Wyoming at two *in situ* operations: by CAMECO at the Highland and Morton Ranch location, and by Rio Algom at Smith Ranch, both in central Converse County in the southern Powder River Basin (**Figure 20**). Wyoming's uranium production may have peaked in 1999 at 2,760,255 pounds of yellowcake. COGEMA closed its Christiansen Ranch *in situ* operation in early 2000, and less yellowcake is anticipated to be produced under contract by the two remaining producers.

At the *in situ* operations, a solute containing sodium carbonate is used to dissolve uranium from the permeable sandstone host at depth. Yellowcake, primarily oxides of uranium, is recovered from the solute in surface plants (**Figure 28**) and shipped to contract purchasers for enrichment into nuclear fuel. Currently, all Wyoming yellowcake is shipped to France.

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Figure 28. Yellowcake in vat at CAMECO's recovery plant. This material will be dried and shipped in airtight containers. This material poses no radiation threat to the photographer or the plant workers, since pure uranium emits only alpha particles, which do not penetrate the skin or clothing. The only radiation safety equipment needed is a respirator.

METALS AND PRECIOUS STONES UPDATE

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Gold prices remained low, hovering around $260 an ounce; still, prospectors, some consultants, and a few companies showed interest in the precious metal. We have compiled some information on the South Pass area to assist individuals inquiring about and searching for easily recoverable gold. Interest continues in platinum-group metals as companies explore their mining claims and investigate other exploration targets in Wyoming. An iolite-gneiss deposit in the Laramie Mountains, as reported in *Wyoming Geo-notes No. 68* (December, 2000), continued to be of interest and results of some diamond exploration at Iron Mountain are now on the Section's web site.

Gold at South Pass

Several Wyoming State Geological Survey (WSGS) publications have provided information on gold-prospecting targets in the state. We also recommend reviewing the bibliography on Wyoming gold at http://wsgsweb.uwyo.edu/metals/author.html.

The best place in the state to search for high-grade gold is South Pass. Historically, this greenstone belt has been the most productive region in Wyoming. Based on research and mapping, the area offers considerable opportunity to search not only for specimen-grade gold in lode deposits, but also provides an opportunity for nugget shooting and recovering placer gold.

Much of South Pass is underlain by an Archean (greater than 2.5 billion years old) greenstone belt formed of metaigneous and metasedimentary rocks folded into a tight synclinorium. Due to intense deformation, numerous strike-trending shear zones and quartz veins developed parallel or nearly parallel to regional foliation. These structures periodically host localized ore shoots in fold closures, fracture intersections, and in some pinches and swells. The gold in these structures is almost always associated with quartz, wall rock silicification, and/or sulfides.

The best placer deposits are located immediately downstream from these lodes. We recommend that the prospector study the available geologic maps (that show shear zones and faults) and locate potential gold traps simply by highlighting drainages downstream from these structures. A generalized 1:48,000-scale geologic map of the South Pass greenstone belt was published in Hausel (1991). This map was compiled from eight detailed (1:24,000) geologic maps listed at the end of this article.

South Pass contains dozens of old mines and placer deposits, which at one time were separated into several mining districts. Hausel (1991) combined the historical districts into four districts based on geology (see the generalized map in Hausel and Sutherland, 2000, p. 105). The South Pass-Atlantic City and Lewiston districts contain lode, modern placer, and some small paleoplacers and are favorable regions to search for nuggets and specimen-grade gold. In contrast, the Twin Creek and Oregon Buttes districts (north and south of the greenstone belt, respectively) host Tertiary paleoplacer gold deposits with small gold flakes and some flattened nuggets.

Many lode gold deposits in the South Pass region are localized in shear zones. Typically, these shears consist of distinct cataclastic zones that can be traced on the surface for a few hundred feet to several thousand feet. In many of the shear zones, anomalous, low-grade gold concentrations occur along the entire length of the cataclastic zone with periodic ore shoots containing specimen-grade gold. The shoots may be localized by a number of factors–most notable are steeply plunging folds within the zone of intense deformation. Where enclosed by folds, the shoots continue down-plunge to unknown depths. Such shoots represent excellent places to search for specimen-grade samples with visible gold. Rich placers often develop immediately downstream from these shoots.

The greatest number of gold-bearing shears are located near the margin of a prominent belt of mafic amphibolites (metagabbro and metabasalt) that run from South Pass City through Atlantic City to Miners Delight. The close association of these gold-bearing structures with this belt of amphibolites is interpreted as the result of the competency contrast between amphibolite and metagreywacke, which favored the development of shears along the margin of the amphibolites during regional deformation. However, anywhere in the district where shear zones occur, gold is typically found.

Each year, new discoveries in the area are made by prospectors searching for nuggets. For example, a 7.5-ounce nugget was recently found by a prospector searching old tailings with a metal detector (Toussaint, 1998; Mattingly, 1998). Another prospector recovered more than 100 nuggets during the past few years using similar prospecting techniques. The available historical records indicate many large nuggets have been found in this region including 24, 7.5, 6.0, 5.3, 5.2, 5, 3, and 0.75 ounces. Another nugget weighing 2 pounds reportedly ended up in a museum in Los Angeles (Ralph Platt, personal communication, 1998). However, most nuggets have gone unreported.

While mapping the 450 mi^2 greenstone belt in the 1980s, I noticed a considerable amount of relatively untouched placer ground in the district, some of which had only been partially prospected, and much of

ROCK HOUND'S CORNER: FELDSPAR

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Feldspars form solid solution minerals between the end members of anorthite (calcium rich), albite (sodium rich), and orthoclase (potassium rich). Feldspars are common rock-forming minerals in many rock types found on the earth's surface; however, only rarely do they produce gemstones. For additional information the reader should refer to Hausel and Sutherland (2000).

Labradorite, a plagioclase feldspar of the general composition [Na, Ca (Al,Si) $AlSi_2O_8$], forms a solid solution mineral between the calcium and sodium end members. Sometimes specimens of labradorite produce very attractive semi-precious stones with a distinct "fire." In addition to labradorite, a few other feldspars are known to occur as gems. These include moonstone, adventurine, sunstone, and amazonite.

Moonstone, is a translucent, high-temperature variety of orthoclase, known as andularia that is the most important feldspar gem. Some varieties of andularia exhibit a bluish sheen known as *schiller* or *adularescence*, which appears to move across the surface of the stone when the mineral is rotated. The sheen is the result of the interference of light reflected from submicroscopic intergrowths of orthoclase and albite. A similar mineral, sanidine, is sometimes found as glassy, colorless, transparent grains that are also fashioned into gems.

Another rare gem feldspar is yellow orthoclase, which is sometimes faceted. Amazonite, a variety of microcline feldspar, generally is a distinct green to blue-green mineral that is often opaque. It is frequently seen in carvings and as cabochons and used in pendants and brooches. The green color is due to vacancies in the crystal lattice resulting from the substitution of lead for potassium (Hurlbut and Switzer, 1979). The only report of amazonite in Wyoming is from the Laramie Mountains in T22N, R69W. The only other gem variety of feldspar that has been found in Wyoming is labradorite.

Labradorite typically occurs as a gray or dark-brown to dark-gray nondescript triclinic mineral with polysynthetic twinning. The mineral has two directions of cleavage at nearly right angles to one another. In Wyoming, labradorite has been found northeast of Laramie in the anorthosite batholith of the Laramie Mountains. Labradorite has a hardness of 5 to 6 and specific gravity of 2.6 to 2.75.

The only report of amazonite in Wyoming is from the Laramie Mountains in T22N, R69W. The only other gem variety of feldspar that has been found in Wyoming is labradorite.

Some specimens of labradorite from the central Laramie Mountains show brilliant displays of blue and red color known as *fire*, or *iridescence*, similar to some opals. The iridescence results from light reflecting along thin exsolution lamellae comprised of different mineral inclusions within the feldspar. When some specimens of labradorite are rotated in the sunlight, colors of blue, green, yellow, and red play across the basal [m{010}] cleavage, or along polished planes nearly parallel to this cleavage. Such specimens with brilliant fire are generally sought by mineral collectors, and will produce attractive decorative stones, museum specimens, and semi-precious gems.

Specimens of labradorite have been found in the Buttes area south of Sybille Canyon near Sheep Rock and in road bed material of Albany County 12 (Norma Beers and Letty Heumier, personal communication, 1999). Near Sheep Rock, specimens of labradorite can be found along Highway 34 about 4 miles southwest of the Sybille Canyon State Game Reserve. Some bulldozed areas along the side of the highway were cut during exploration for labradorite in years past. Good specimens can also be found in the drainages, as well as along the edge of the highway. Much of the material has a brown iron stain, but the color on a fresh break may be gray or blue.

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which appeared to have never been mined. Based on the location of some of these placers as related to auriferous shears and ore shoots, many of these placers could be a source of rich pay streaks. A number of areas have potential for placer gold and the maps and discussions below may assist prospectors in their search. For a summary of the mining history, location, access, geography, and the regional geology of South Pass, the reader should consult Hausel (1991).

South Pass-Atlantic City district

Several drainages downstream from the principal lodes in the South Pass City area may be of interest (**Figure 29**). Localities near the village of South Pass City may be inaccessible due to private property, mining claims, etc. [Note: always consult land and property ownership maps and obtain permission if necessary before entering onto lands.]

South Pass City area. The Carissa mine located near South Pass City was the principal source of gold in the district. Past production is not well documented, but estimates and production records indicate that the mine produced from 50,000 to over 180,000 ounces of gold prior to 1950. Based on the extent of the mine workings, the latter production figure is probably more realistic (Hausel, 1999).

The Carissa mine was developed on a shear in metagreywacke (a metamorphosed micaceous sandstone), amphibolite, and actinolite schist (metakomatiite). The gold-bearing structure averaged 6 feet wide. At the surface, the primary shear is 2 to 3 feet wide, but swells to 50 feet at depth (**Figure 30**). This primary shear is also enclosed within a much larger, less obvious shear which forms an envelope surrounding the primary shear that is more than 1000 feet wide. Much of the larger shear is untested. This envelope is expressed by numerous parallel fractures with common quartz veinlets, some brecciation, and silicification. Samples in this envelope over an aggregate width of 300 feet in 1926 indicated that the envelope was mineralized in low-grade gold. I confirmed this by collecting a 97-foot composite chip sample that yielded similar gold values. Thus, the property appears to have good potential for open pit or underground mining.

The ore tenor ranged from a trace to 2.6 ounces per ton of gold (opt Au) and averaged 0.3 opt Au. Drilling has shown that the structure is still significantly mineralized below the current mine workings. Drilling in the 1980s showed an 80-foot mineralized structure beneath the mine workings that assayed 0.031 to 2.54 opt Au. There are also reports of specimen-grade ore being found in the mine that contained values as high as 260 opt Au.

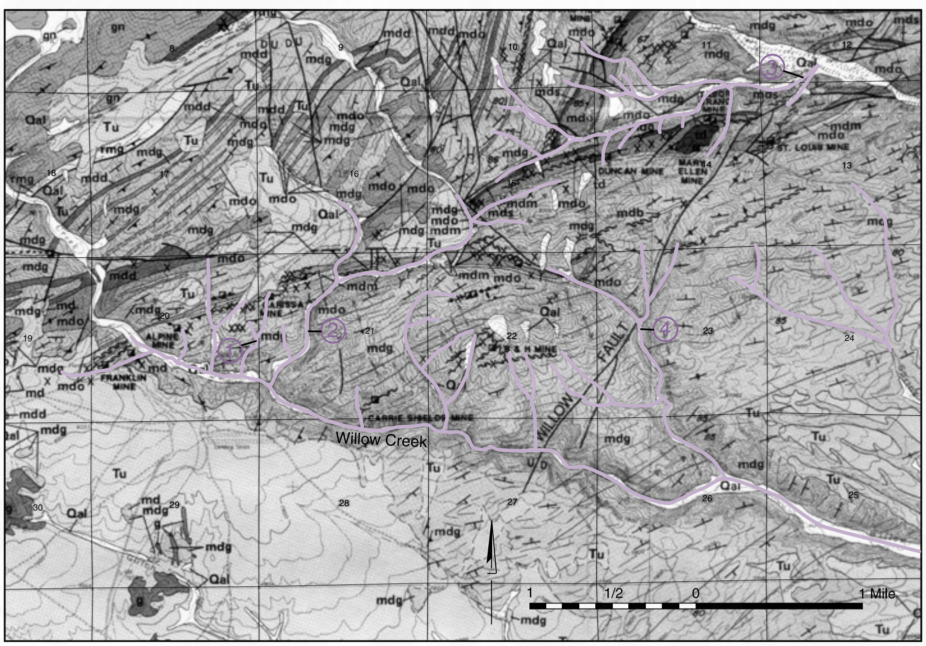

Figure 29. Placers near South Pass City and the Duncan mine showing locations discussed in text (from Hausel, 1991, Plate 1. For more detailed maps at 1:24,000 scale, refer to Hausel, 1986; 1987; 1988a-1988e; and 1989b).

The data shows that this structure is an excellent source for gold. Yearly erosion must have supplied a considerable amount of gold to the nearby drainages, and Willow Creek, in particular, probably represents an excellent placer (**Figure 29**). Only small portions of Willow Creek have been mined in the past, primarily because it is narrow, and has a low gradient, which made it unfavorable for historical placer mining by sluicing.

There are some other drainages of note around the Carissa shear. Carissa Gulch (**number 1, Figure 29**), a dry gulch draining south from the Carissa shaft into South Pass City, does not have a great volume of alluvium, but it should host some specimen-grade gold including nuggets. The gulch is relatively untouched by mining. The eastern extent of the Carissa lode is drained by Hermit Gulch (**number 2, Figure 29**). This gulch is much more extensive than Carissa Gulch, and should contain considerable gold. Hermit Gulch also contains some unmined gravel.

Duncan Mine area. The Duncan mine (**Figure 31**) is located on a folded shear zone northeast of the Carissa mine. A few other mineralized lodes, including the Tabor Grand and the Mary Ellen mines, are located in this region. The Tabor Grand is possibly situated on the same shear as the Duncan, and the Mary Ellen mine was developed in a quartz vein in a tonalite porphyry, which intruded the shear zone. A group of drainages head near the gold-bearing structures (**Figure 29**).

At the Duncan mine, a 1-foot composite chip sample collected in a steeply plunging fold assayed 0.96 opt Au, indicating that portions of this structure are well mineralized. Production records indicate that 3800 ounces of gold were recovered from the mine. However, it is likely that three to

Figure 30. View of the gold-bearing shear exposed in the glory hole at the Carissa mine.

Figure 31. Duncan mine headframe and mine dump.

five times more gold was produced from this property than reported. The shaft at the Duncan mine was sunk to a depth of 250 feet with at least 1255 feet of drifts. Drainage from the ore shoot empties into Little Beaver Creek to the north as do drainages from the nearby Tabor Grand, Mary Ellen, and other mines and prospects (**number 3, Figure 29**).

Sampling and mapping at the 120-foot level of the Tabor Grand showed that the shear zone contained anomalous gold along the entire length of the shear exposed on the mine level (the upper and lower levels were inaccessible). The samples ranged from a trace to 58 ppm (1.8 opt) Au. The mine was estimated to have produced 2400 ounces of gold.

The Mary Ellen mine south of Tabor Grand reportedly produced 6050 ounces of gold, and the ore reportedly averaged 0.4 opt Au. Historical reports indicated that the ore tenor ranged from 0.25 to 5.25 opt Au; pockets of ore were intersected that assayed as high as 50 opt Au. Based on the presence of some well-mineralized ore shoots in this area, Little Beaver Creek north of the mines should contain anomalous auriferous gravels derived from these and other mines and prospects. The creek appears to have received only minimal mining interest in the past, and may be difficult to work due to the lack of water in the upper reaches, beaver ponds near the mouth of the creek, and private land.

There are several other drainages of interest in this same area. For example, Deep Gulch (**number 4, Figure 29**), a tributary of Willow Creek to the south, cuts across the same rock units as Rock Creek, yet it remains relatively unprospected.

Rock Creek. Most pre-1911 mining on Rock Creek apparently was a limited hydraulic operation. Other pre-1911 placer mining was probably ineffective due to the low (2°) gradient of Rock Creek. Some early hydraulic mining on Mill Hill (**number 1, Figure 32**) recovered an estimated 10,500 ounces of gold. This is an extraordinary amount of gold for this site, as shear zones and veins are not well developed on Mill Hill. If this amount could be verified, it might suggest hidden shears, some mineralized wall rock, or simply that the hydraulic operations incorporated a much larger area than just Mill Hill.

Historical reports indicate that rich quartz specimens were found in Rock Creek. For instance, one fist-size piece of quartz was reported to contain about 24 ounces of gold. A boulder found nearby in 1905 contained an estimated 630 ounces of gold!

Rock Creek is one of the principal drainages in the district. The creek cuts across 12 to 14 miles of greenstone terrain before draining into the Sweetwater River. Along the way to the Sweetwater River, it receives alluvial material from several tributaries including Little Beaver Creek. Rock Creek runs perpendicular to rock foliation and across many strike-trending, gold-bearing structures. The stream channel is 100 to 250 feet wide and locally narrows to several feet wide. The average gravel depth is about 10 feet. The upper 3 feet of the deposit consists of barren loam, and much of the gold recovered from the placer was reportedly found within 1 to 3 feet of bedrock. The gold was reported as rounded nuggets and flakes that typically had a fineness of 0.84 to 0.90 (84 to 90% pure).

Between 1933 and 1941, E.T. Fisher Company constructed a concentrating plant and dredged about 6 miles of Rock Creek from Atlantic City downstream to the Mormon Cemetery with a dragline. Approximately 3 million yds^3 of gravel were processed that averaged 0.012 ounces per yd^3 and production reportedly totaled 11,500 ounces of gold. However, based on the volume of gravel and average grade, production may have been three times that reported, more on the order of 36,000 ounces. Nuggets up to 3.4 ounces were recovered, but operations terminated in 1941, due to the outbreak of war.

Based on the available information, the operation may have been fairly inefficient. Some old timers who worked on the operation indicated security

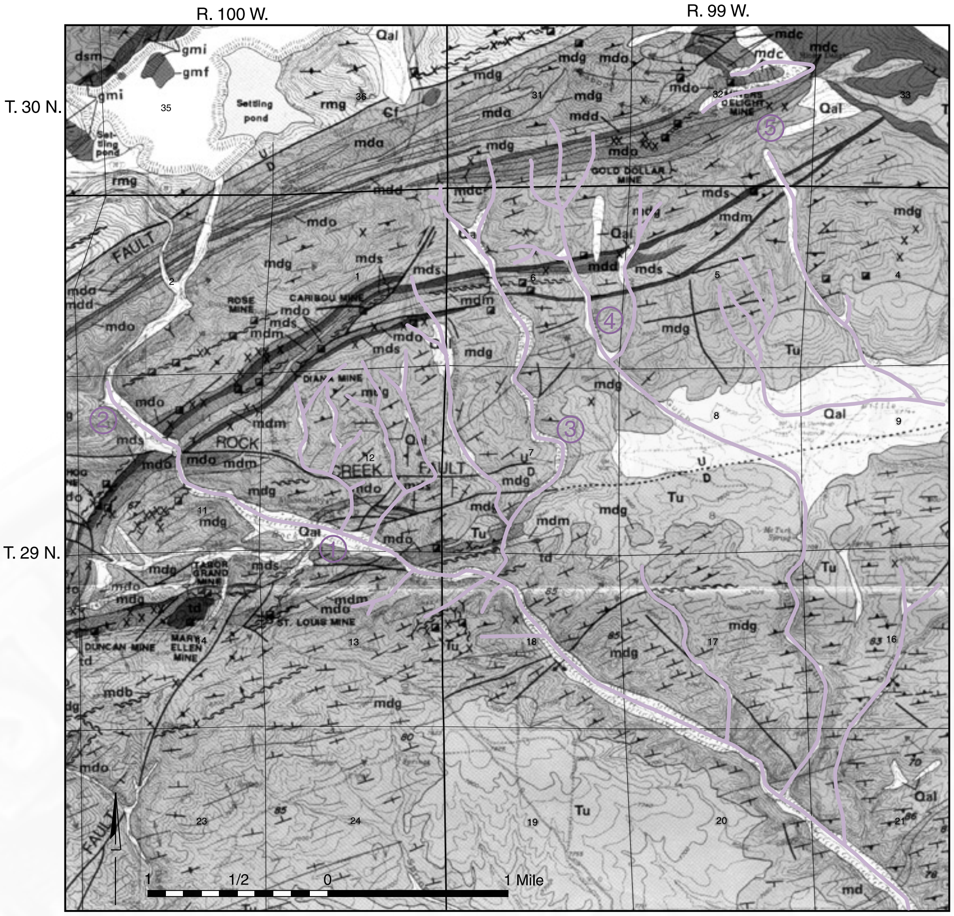

Figure 32. Drainages near the Rock Creek placer showing locations discussed in text (from Hausel, 1991, Plate 1. For more detailed maps at 1:24,000-scale, refer to references on Figure 29).

was a problem, as nuggets were high-graded from the concentrator. One individual even received the nickname "wet pockets" apparently from his high-grading wet nuggets from the concentrating table. In addition, considerable gold may have been lost to the tailings. A few modern placer operations on Rock Creek, which concentrated on reprocessing the tailings (as well as some small, unmined parts of the creek), successfully recovered several nuggets (**Figure 33**).

In addition to several unmined tributaries, Rock Creek also has 3 miles of unmined gravel downstream from the Mormon Cemetery. Some unmined gravel also lies upstream from Atlantic City (**number 2, Figure 32**). In particular, unmined gravel from Atlantic City upstream some 3500 feet to the Rose shear may be relatively auriferous, as this gravel was derived from nearby shear zones. The 6 miles of tailings and underlying gravel downstream from Atlantic City should be of further interest, as the tailings contain anomalous gold. Possibly, the discrepancy between reported gold production and the average ore grade may indicate that the concentrator lost as much as two-thirds of the gold to the tailings.

Big Atlantic Gulch. Prior to 1911, 750 ounces of gold were mined from Big Atlantic Gulch. The gulch was later dredged, possibly by the Fisher dragline. Near the mouth of the gulch, the streambed narrows considerably. Farther upstream, the tailings (**number 3, Figure 32**) may also be a source for rejected gold, similar to Rock Creek. The upper reaches of Big Atlantic Gulch, from near the Snowbird mine north into Cole and Placerita gulches, should provide enough gravel for a small operator.

Little Atlantic Gulch, a tributary of Big Atlantic Gulch, lies west of and parallel to Big Atlantic Gulch, and cuts across the same rocks and shear structures. Past mining activity in this gulch has been limited, so this gulch should offer potential for placer gold. Farther west is a group of small gulches that are dry much of the year but drain south into Rock Creek. These do contain some alluvial deposits and include Basket Gulch, Beer Garden Gulch, and others.

East of and parallel to Big Atlantic Gulch, are Smith and Promise gulches (**number 4, Figure 32**). Prior to 1911, 1500 ounces of gold were recovered from Smith Gulch and 1500 ounces of gold from Promise Gulch, yet portions of gravel remain unmined.

In the 1980s, a two-man operation tested some gravel on Smith Gulch with a trommel and backhoe (**Figure 34**). The operation recovered about 20 ounces of gold per week, and periodically struck pay streaks that yielded 20 ounces in a day (**Figure 35**). The gravels were 6 to 10 feet deep, and much of the gold occurred as flattened nuggets

Figure 33. Gold recovered from the Stout placer mine on Rock Creek.

Figure 34. Placer mining in Smith Gulch in 1987.

and flakes near bedrock and in sandy layers overlying thin clay-rich zones. The gravel averaged about 0.1 ounce per yd^3 (Hausel, 1991). Irish Gulch lies about a mile east of Smith Gulch and south of Miners Delight. There are no reports of gold from this gulch.

Miners Delight. The Miners Delight mine (**number 5, Figure 32**), one of the two principal lode mines in the district, intersected a rich pocket of gold in the 1800s. The mine was developed in a 3- to 16-foot-wide, 2500-foot-long, folded shear zone hosted by metavolcanic rocks. Little modern information is available on this mine, and estimated production was 60,000 ounces prior to 1911.

The mine apparently pumped sufficient water from the shaft to use for placer mining of Spring Gulch downstream from the mine. Spring Gulch is a dry gulch, but production from it was estimated at 1500 ounces of gold. Several 1- and 2-ounce nuggets were found in the gulch as well as one 6-ounce nugget. One piece of specimen-grade quartz was also recovered in 1873 that was described to be as large as a water bucket. According to one witness, it looked as if it could contain a pound of gold.

Yankee Gulch, to the northeast of the Miners Delight mine, was also auriferous, as the Miners Delight shear appears to continue north of the mine under alluvial cover. One operator in the 1800s recovered 8 to 15 ounces of gold per day in this gulch, including one nugget that weighed nearly 5 ounces.

Oregon Buttes district

A few paleoplacers have been identified in the region. Placer gold was discovered in 1863 along the southern flank of South Pass in the vicinity of Oregon Buttes; a handful of prospectors worked the placers with hand tools and mortars, recovering more than 400 ounces of gold in the ensuing winter. An additional 4 tons of gravel were reportedly hauled to Utah, which yielded about 1400 ounces of gold. Placers in the area have been estimated to host 2.2 million ounces of gold, and the U.S. Geological Survey estimated that the paleoplacers contain about 28.5 million ounces of gold. Even though the paleoplacers are very low grade, a systematic search with a magnetometer might reveal some pay streaks. The source terrain for the entire deposit, as well as for the McGraw Flats paleoplacer along the northern flank of South Pass, have yet to be discovered!

. . . miners in the 1930s reportedly intersected a rich shoot that produced several sacks of specimen-grade ore assaying 75 to 3100 opt Au!

Lewiston district

The Lewiston district lies near the eastern flank of the South Pass synclinorium. Rock types are similar to those in the South Pass-Atlantic City area, although the Lewiston district lacks the prominent mafic amphibolites which localized several shear structures in the western part of the synclinorium. As a result, many of the auriferous shears are not as well developed in this district, and widths of the shears are typically less; however, some shears are quite rich in gold. Some of the gold-bearing shears are strike shears, although others cut regional foliation at acute angles.

Rich pockets of gold were found in 1878 at Wilson Bar at the mouth of Burr Gulch on the Sweetwater River (**number 1, Figure 36**). In the 1890s, a 500-foot strip of gravel was mined at Wilson Bar, which yielded 370 ounces of gold. The gold was traced upstream to the Burr lode. In 1893, a pocket of ore intersected in the Burr mine reportedly yielded 3000 ounces of gold. Some specimen-grade ore was claimed to have contained as much as 1690 opt Au. The lode reportedly varied from 7 to 10 feet wide and averaged 2 to 3.5 opt Au [in all probability, either the ore grade was exaggerated or the ore was very selectively mined].

Northeast of the Burr mine at the Hidden Hand mine, miners in the 1930s reportedly intersected a rich

Figure 35. Some gold recovered from Smith Gulch in 1987.

shoot that produced several sacks of specimen-grade ore assaying 75 to 3100 opt Au! Samples collected northeast of the Hidden Hand mine at the Mint-Gold Leaf mine included two 2.5-foot-wide composite chip samples that assayed 1.29 and 3.05 opt Au (Hausel, 1991). A narrow and presumably shallow drainage next to this locality (**number 2, Figure 36**) might provide some interesting specimens.

All of the excitement about platinum group metals deals with their worldwide rarity, favorable geology in Wyoming, and high prices.

The gold in these ore shoots is probably pockety, since none of the mines were developed to any great depth (presumably less than 150 feet deep). But because of the fabulously rich pockets, placers in the district may be worth taking a look at. Unfortunately, very few streams cut through the area, and the few that do are small with limited gravel.

Strawberry Creek appears to be one of the district's better placers (**number 3, Figure 36**). The creek cuts several of the principal shears, and is probably enriched in gold. Historical estimates suggest that 21,000 ounces of gold were mined from the Bullion mine, located on Strawberry Creek at the historical site of Lewiston. About 10 years ago, a prospector working near the mouth of Strawberry Creek (where it flows into the Sweetwater River) recovered about 25 ounces of gold including nuggets up to 1/2 inch in length. Historical reports indicate that some nuggets (3 and 4.5 ounces) were recovered from Two Johns Gulch in 1905. In 1944, five "good-sized" nuggets were found in the Big Nugget placer. Possibly, these two are the same placer as Giblin Gulch (**number 4, Figure 36**) where in 1932 several nuggets were found, including two weighing 5.2 and 5.3 ounces. Another gulch of potential interest is Deep Creek (**number 5, Figure 36**), as it also cuts across gold-bearing shear structures.

Platinum group mineralization

Companies are anticipating spring exploration following their staking more than 2000 mining claims in the Medicine Bow Mountains and Sierra Madre for platinum-group metals over the past two summers. The WSGS has received inquiries from several other companies interested in pursuing exploration targets in Wyoming this coming summer. To assist these activities, a summary of known targets in the Wyoming platinum-palladium-nickel province is located on the WSGS web site at http://wsgsweb.uwyo.edu/metals/platinum/index.html.

All of the excitement about platinum group metals deals with their worldwide rarity, favorable geology in Wyoming, and high prices. For example, the asking price for three of the six platinum group metals on February 16, 2001, was $605 per ounce for platinum, $992 per ounce for palladium, and $2375 per ounce for rhodium. This may bode well for Wyoming, as the state had a historical palladium and platinum mine (the New Rambler mine) which operated from 1900 to 1918. In addition, several palladium and platinum anomalies have been detected in southeastern Wyoming.

Diamonds

Some results (including maps of sample results) from the Iron Mountain kimberlite district were recently placed on the WSGS web site at http://wsgsweb.uwyo.edu/metals/legis_

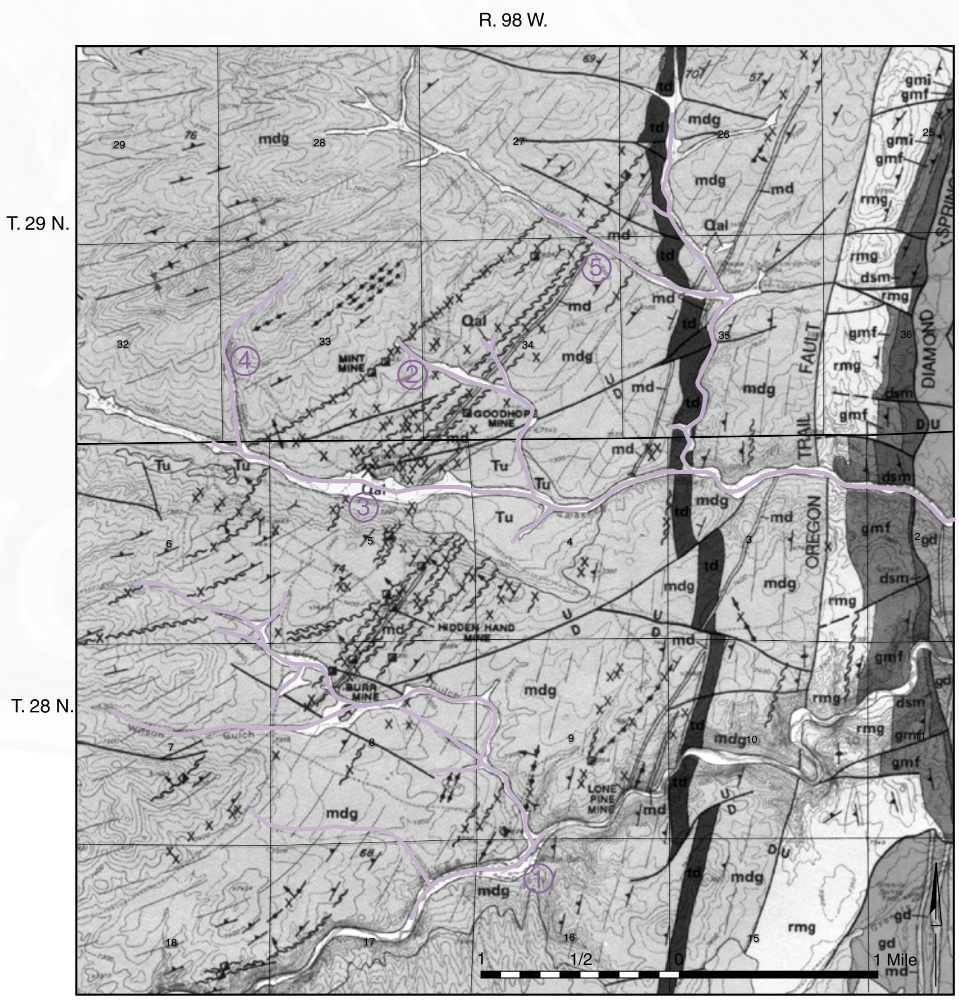

Figure 36. Placers in the Lewiston district showing locations discussed in text (from Hausel, 1991, Plate 1. For more detailed maps at 1:24,000-scale, refer to references on Figure 29).

rep.asp. The information includes a few hundred kimberlitic indicator mineral anomalies that were identified by the WSGS. These data provide more evidence that Wyoming is underlain by a significant diamond province.

In diamond related news, the WSGS was contacted by the organizing committee for the 8th International Kimberlite Conference. This prestigious conference will conduct at least a week of field trips in the Wyoming Craton in 2003 and the WSGS expects to participate. The conferences are typically held every four years, and attract researchers and industry geologists from all over the world. Some previous conferences have been located in South Africa, Australia, France, and Russia.

Talks and field trips

Several upcoming talks and field trips planned by the Metals and Precious Stones Section are listed on the WSGS web site at http://wsgsweb.uwyo.edu/metals/talks.html. If you would like information on these upcoming lectures and field trips, contact Dan Hausel at dhause@wsgs.uwyo.edu.

Hausel slated for Hall of Fame

According to the Jade State News, W. Dan Hausel will be inducted into the National Rockhound and Lapidary Hall of Fame for his contributions to the education of rock hounds, gemologists, prospectors, mineralogists, and the general public. His induction will be featured in an upcoming issue of Lapidary Digest. A commemorative award will be presented to Dan at the 2001 Natrona County Gem and Mineral Show on June 3, 2001 in Casper. Dan's induction was made through the efforts of several people in Wyoming including Ed McKnire, Dave Sims, Norma Beers, Carl Uchwat, Gail Uchwat, the Natrona County Rockhounds, the Casper Gem and Mineral Club, and other clubs around the state.

Book review

A new mystery novel written by Carol Caverly, entitled *Death in Hog Heaven*, is a murder mystery involving diamonds near the Leucite Hills, western Wyoming. This book has an exciting plot, and is recommended to geologists, gemologists, the Wyoming community, as well as anyone interested in murder mysteries. The Metals and Precious Stones Section provided some information for the book and was appropriately acknowledged.

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MAPPING AND HAZARDS UPDATE

GEOLOGIC MAPPING, PALEONTOLOGY, AND STRATIGRAPHY UPDATE

Alan J. Ver Ploeg
Senior Staff Geologist-Geologic Mapping, Wyoming State Geological Survey

Geologic maps of the Buffalo and Recluse, Wyoming 1:100,000-scale quadrangles are being compiled and digitized to support a geologic database project for the northern Powder River Basin. An additional bedrock geologic map of the Casper 1:100,000-scale Quadrangle and a surficial geologic map of the Midwest 1:100,000-scale Quadrangle are also being digitized in support of the project. STATEMAP 2000 and 2001 are supplying funds for the Buffalo, Casper, and Midwest quadrangles. Maps of the Basin and Rattlesnake Hills 1:100,000-scale quadrangles, which are outside the project area, are also being prepared using STATEMAP funding. Additional funds have been requested to enter bibliographic information on Wyoming maps into the National Geologic Map Data Base.

Current geologic mapping efforts

The Geologic Mapping Section of the Wyoming State Geological Survey (WSGS), with the aid of funding from the STATEMAP 2000 Program, recently began compiling a geologic map of the Buffalo 1:100,000-scale Quadrangle. The recent activity in coalbed methane exploration and production and the fact that the Buffalo area is a population center prompted the Section to choose this quadrangle. Geologic mapping of different vintages and at a wide variety of scales and coverages existed over much of the quadrangle and this information is being compiled at the 1:100,000 scale.

Expanding construction in the Buffalo area, as well as in other localities within the quadrangle, requires accurate, up-to-date mapping for the construction and concrete industries to locate aggregate and construction materials. Clinker, rock baked or partially fused by recent naturally ignited coal fires, is used locally as aggregate and light duty construction material. As the new map will show, numerous clinker quarries already exist and additional clinker deposits are common in the weathered outcrops of the Wasatch and Fort Union formations, which occur over most of the quadrangle. The new mapping will aid in the mitigation of identified geologic hazards in the area, as numerous landslides have been mapped. In addition, accurate geologic information depicted on the map can enhance predictability in siting for coalbed methane and water wells.

The Buffalo Quadrangle is located in northern Wyoming, on the west side of the Powder River Basin (**Figure 37**). The quadrangle includes bedrock ranging from Precambrian to Eocene in age. The structural axis of the Powder River Basin runs southeast to northwest through the central part of the quadrangle, with the Bighorn Mountains uplift impinging on the western part of the quadrangle. The boundary between the Bighorn uplift and the Powder River Basin is characterized by high-angle reverse faulting and folding, bringing Precambrian and Paleozoic rocks of the uplift in contact with Tertiary and Cretaceous outcrops in

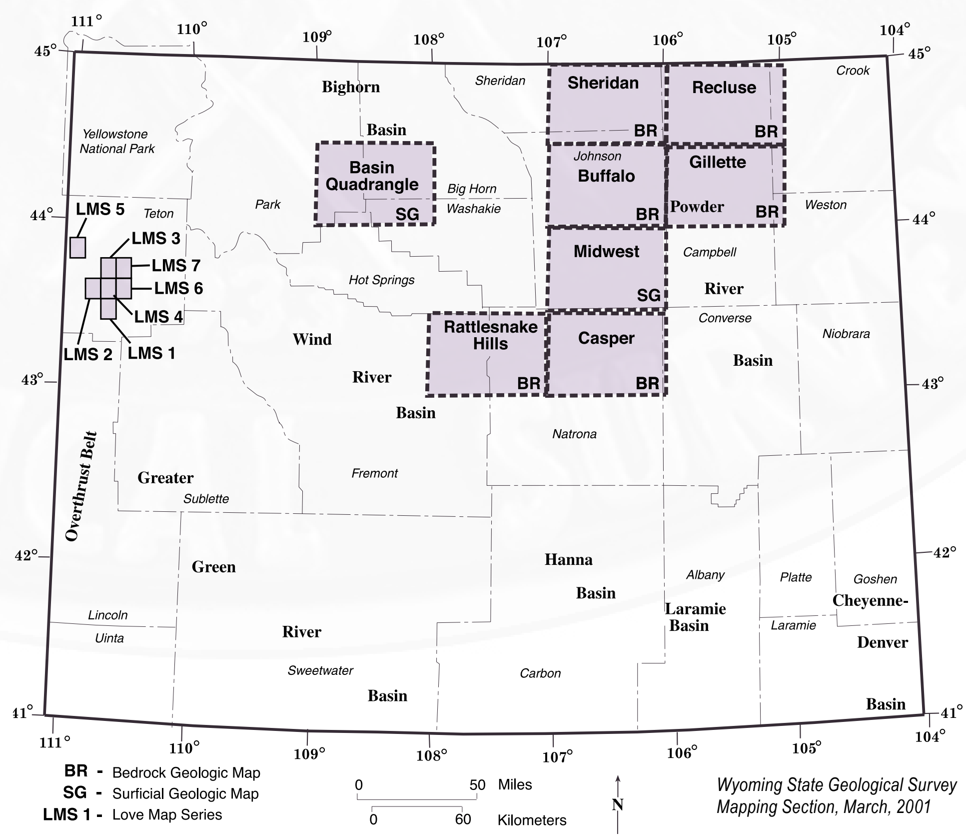

Figure 37. Index map to current geologic mapping projects in Wyoming, including STATEMAP 2000, STATEMAP 2001, Northern Powder River Basin database, and the Love Map Series (LMS) [see NEW PUBLICATIONS AVAILABLE FROM THE WYOMING STATE GEOLOGICAL SURVEY, p. 41-42].

the basin. The remainder of the quadrangle is characterized by outcrops of relatively flat-lying Tertiary Wasatch and Fort Union formations that contain numerous coal beds and associated clinker deposits. Historically, the coal beds have been underground and surface mined and are currently being tested for coalbed methane.

The WSGS will release a Preliminary Geologic Map (PGM) of the Buffalo 30′ x 60′ Quadrangle upon its completion in July, 2001. This will be a blackline map accompanied by a pamphlet containing descriptions of map units, symbols, and the sources of geologic data used in compilation. An entirely digital version of the geologic map and base will be completed later as part of STATEMAP 2001.

In addition to the Buffalo map, the Geologic Mapping and Coal Sections are cooperating to compile and digitize the Recluse 1:100,000-scale Quadrangle (**Figure 37**). The map will be compiled and modified from an earlier geologic map (Kent and Berlage, 1980) and will be merged with the geologic maps of the Buffalo, Sheridan, and Gillette 1:100,000-scale quadrangles (**Figure 37**). The maps will then serve as a digital geologic base map, part of a new WSGS-headed project (see the *Wyoming Geo-notes* article that follows: **INTERACTIVE GEOLOGIC, HYDROLOGIC, AND WATER QUALITY DATABASE FOR THE NORTHERN POWDER RIVER BASIN**). This geologic base map will assist in projecting subsurface data (from a drill hole and water well database) to the surface.

STATEMAP 2001 funded

The U. S. Geological Survey recently notified the WSGS that their proposed projects for the STATEMAP 2001 Program was funded in full. The two mapping subprojects include a geologic map of the Rattlesnake Hills 1:100,000-scale Quadrangle (**Figure 37**) and digital maps of four existing 1:100,000-scale maps–two bedrock geologic maps (Casper and Buffalo, **Figure 37**) and two surficial geologic maps (Basin and Midwest, **Figure 37**). For a detailed discussion of these proposals see *Wyoming Geo-notes No. 68* (December, 2000, p. 29-30). The WSGS will receive $48,929 in funding for the two projects, which requires a dollar-for-dollar match by the WSGS. The STATEMAP Review Panel judging the proposals awarded a total of $6,326,156 to 45 states for mapping projects.

After the STATEMAP Review Panel finished its deliberations, $334,393 remained to be awarded. The National Cooperative Geologic Mapping Program (NCGMP) then issued a second call for proposals to support their two top priorities: 1) to enter bibliographic information for a state's published geoscience maps into the Map Catalog part of the National Geologic Map Data Base (NGMDB); and 2) to convert geologic maps to digital format. Each state proposal could request additional funds up to $8000 to accomplish one or both of these priorities and the WSGS requested that amount to complete entry of bibliographic information for Wyoming's published geoscience maps into the NGMDB. Funding of these proposals will be announced in late February, 2001.

Comparison of the Tate specimens with a photograph of *Supersaurus* vertebra in a publication by the BYU researchers showed the Tate find was a dead ringer.

Funds from the STATEMAP Program have already helped the WSGS to accelerate geologic mapping efforts in Wyoming from 1992 through 2000. The 21 maps were completed using funding from this program since 1992 and an additional 11 maps were completed independent of STATEMAP funding. Six additional maps are in progress with STATEMAP 2000 funding.

Tate Museum unveils Supersaurus *bones*

In October, 2000, the Tate Museum in Casper unveiled a 4-foot-long vertebra and a 10-foot-long rib bone of what museum paleontologist Bill Wahl identified as a *Supersaurus* (species). The fossil bones were discovered by a rancher in Converse County who contacted Wahl. The 130-foot-long *Supersaurus* is one of the largest sauropod dinosaurs to roam Wyoming. Wahl and a crew of excavators removed these specimens from rocks of the Jurassic Morrison Formation (over 138 million years old) and prepared them over a five-year period. Identification of the bones resulted from comparing notes with Brigham Young University (BYU) researchers who had published on their discovery of *Supersaurus* bones in Colorado. Comparison of the Tate specimens with a photograph of *Supersaurus* vertebra in a publication by the BYU researchers showed the Tate find was a dead ringer. The Tate Museum intends to continue searching the area for additional bones from *Supersaurus* and any other dinosaur species that may have been preserved.

New publications on Wyoming geology

Two new articles relating to structure, stratigraphy, and sedimentation in oil and gas exploration and development were released in the October, 2000 and January, 2001 issues of *The Mountain Geologist*, a publication of the Rocky Mountain Association of Geologists (RMAG). These articles relating to Wyoming geology are summarized below.

Schmude (2000) detailed the interaction of paleostructure, sedimentation, and preservation of Middle Jurassic rocks in the Bighorn Basin. Rock units included the Gypsum Spring, Piper, and lower Sundance formations. Over 500 well logs, 21 previously published and several new measured sections by the author, were used to construct cross-sections and maps depicting the geologic history of the Middle Jurassic section. Three significant uplift episodes are indicated by J1, J2, and J4 unconformities. The position and timing of these events resulted in changes in the preservation potential of the underlying sedimentary package.

Landon, Longman, and Luneau (2001) reported on the hydrocarbon source rock potential of the Upper Cretaceous Niobrara Formation in the western part of the Western Interior Seaway, which includes southeastern Wyoming. The authors used wireline log data, lithologic descriptions, and analytical data to examine the distribution of source rock potential within the Niobrara. A one-dimensional maturity model calibrated with measured thermal maturity from vitrinite reflectance (R_o) and temperature of oil generation (T_{max}) values is used to predict timing, relative volumes, and composition for hydrocarbons generated in Laramide basins in the five-state area.

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INTERACTIVE GEOLOGIC, HYDROLOGIC, AND WATER QUALITY DATABASE FOR THE NORTHERN POWDER RIVER BASIN, WYOMING

James C. Case
Staff Geologist-Geologic Hazards, Wyoming State Geological Survey

This article presents a generalized view of an interactive database project for the northern part of the Powder River Basin (PRB), Wyoming. Although the primary emphasis is coalbed methane and related issues, the entire northern part of the basin underlain by Tertiary geologic formations will be addressed. This is a new project undertaken by the Geologic Hazards, Oil and Gas, Geologic Mapping, and Coal sections at the Wyoming State Geological Survey (WSGS) in cooperation with entities from the state, federal, university, and private sectors. The Wyoming State Legislature approved spending $400,000 for the 18-month project, which is due to begin in June, 2001. The interactive database will allow resource managers, planners, and resource developers to quickly access data and information vital to decision making.

Introduction

The Wyoming State Legislature has approved funding for the Wyoming Water Development Commission and the WSGS to develop and generate an interactive geologic, hydrologic, and water quality database for the northern PRB. The project will provide information on the surficial, bedrock, and subsurface geology, groundwater hydrology, and surface and subsurface water quality for part of the PRB. In addition, the project will include available information on water well completion reports. The data will emphasize coalbed methane producing formations in the area, and will contain links to information on coalbed methane production and produced water.

This is a cooperative effort amongst the WSGS, the U.S. Geological Survey (USGS)–Water Resources Division, Goolsby and Associates, LLC., the Water Resources Data System (WRDS) and the Spatial Data Visualization Center (SDVC) at the University of Wyoming, the Wyoming Department of Environmental Quality (WDEQ), the Wyoming Oil and Gas Conservation Commission (WOGCC), and the Wyoming State Engineer's Office (WSEO). The Geologic Hazards, Oil and Gas, Geologic Mapping, and Coal sections at the WSGS will each contribute to the project.

Background

The coalbed methane play in the PRB is currently one of the most active in the U.S. The play now has more than 3700 producing gas wells, which collectively produced 89.3 billion cubic feet of gas from January through August, 2000. The average water production per well is approximately 330 barrels per day, which equates to approximately 1.2 million barrels per day currently being discharged to the surface. The U.S. Bureau of Land Management (BLM) projects that between 35,000 and 70,000 wells may ultimately be completed (but not necessarily at any one time).

Groundwater quality associated with coalbed methane production in northeast Wyoming is variable. Produced water quality varies for total dissolved solids (TDS), iron, barium, calcium, magnesium, and sodium, as well as other constituents. If concentrations are high enough, there may be problems associated with the disposal of the water.

Especially because of current and potential coalbed methane development in the PRB, there is a need for a database that incorporates surface and subsurface geology, groundwater hydrology, and surface and subsurface water quality data. Even in areas not affected by coalbed methane development, there is still a need for the same accessible information. These data can then be used in decision-making related to water development, National Pollution Discharge Elimination System (NPDES) permitting, Non Point Source (NPS) issues, and Total Maximum Daily Load (TMDL) issues. A database and data serving mechanism that will cover the above issues is addressed in the project.

Project area

The project area is bounded on the south by the 12th Standard Parallel North (about 44°15′N), on the north by the Wyoming state line (45°N), and on the east and west by the geologic contacts between the Fort Union and Lance formations (about 105°W and between 106°45′W and 107°15′W, respectively). It covers Townships 49 through 58 N and Ranges 67 through 82 to 86 W, in parts of Crook, Weston, Campbell, Sheridan, and Johnson counties. More approximately, the project extends to Moorcroft on the east, to Buffalo, Sheridan, and Dayton on the west, to the Wyoming state line on the north, and to an area approximately eight miles south of Gillette on the south.

Project tasks

The proposed project consists of nine components or parts, all being worked on concurrently. The following paragraphs summarize the nine tasks needed to complete the project.

Part one–compile geologic maps of the northern part of the PRB and generate a 1:100,000-scale digital geologic map of the bedrock. This map will be used to extrapolate subsurface data to the surface. The only known digital map for the entire area is the1:500,000-scale *Geologic map of Wyoming*, which is inadequate for this project because of the small scale and digitally inaccurate 1:250,000-scale source maps. In some areas not covered by existing maps, original mapping will be done using aerial photography.

Part two–map and compile information on the subsurface contacts of Upper Cretaceous and lower Tertiary formations and major coal beds. The mapping will be accomplished through interpretation of geophysical logs from oil, gas, and coalbed methane drill holes through assimilation of existing data and maps. The contacts between the Wasatch, Fort Union, and Lance formations, Fox Hills Sandstone, and Lewis Shale will be mapped. Goolsby and Associates has correlated and mapped all the main coal beds in the coalbed methane producing area and their data will be purchased and used. All pertinent data will be used to generate digital structure contour maps (using ArcInfo® and ArcView®) for all formations and the main coal beds.

Part three–acquire published USGS data and maps on the formations beneath the Tertiary outcrops in the basin. These data will be scanned and served through the WRDS.

Present available data from pre-coalbed methane development, and data on quality of produced water associated with coalbed methane development.

Part four–inventory available surface water and groundwater quality data sets. At a minimum, the following organizations will be contacted concerning applicable data: BLM, Gillette Area Groundwater Monitoring Organization (GAGMO), U.S. Office of Surface Mining, WDEQ–Land Quality and Water Quality Divisions, WSEO, USGS–Water Resources Division, Wyoming Department of Game and Fish, U.S. Forest Service, WOGCC, private consulting firms, municipalities, and others. The groundwater data will include, but will not be limited to, all coalbed methane data from produced water, water quality analyses for domestic wells from the Wyoming Department of Agriculture's State Chemistry Lab, and data associated with Environmental Impact Statements (EISs), Environmental Analyses (EAs), and mine permits. Completion reports for wells with associated water quality analyses will be scanned, and pertinent data, such as well name, perforated interval, elevation, location, water level, storage coefficient (where available), hydraulic conductivity (where available), and water quality will be entered into an Oracle® database. Surface water quality data will also be entered into the Oracle® database. Data that are not in a digital form will have to be manually entered on a case-by-case basis. All data will be subjected to a basic Quality Assurance/Quality Control (QA/QC) analysis.

Part five–digitally compare the perforated or producing interval(s) for each well (that has water quality data) with the digital structure contour maps. The water quality can then be associated with a specific geologic formation or coal bed. Water quality data from selected coalbed methane wells will be examined to determine if the data represent a single well producing from a single bed or multiple wells discharging through a collector pipe. If all the multiple wells are producing from multiple beds, their water quality cannot be used in further analyses.

Part six–use the Oracle® database, ArcInfo®, and ArcView® to generate groundwater quality maps for all formations sampled in the project area. Maps of TDS and of individual constituents will be generated where data permit and a report of findings will be published.

Part seven–analyze surface water quality data, and digitally associate the data with a lake, pond, or reach of a stream. Present available data from pre-coalbed methane development, and data on quality of produced water associated with coalbed methane development. Data on stream baseflow and flow duration before and after coalbed methane development will be presented as it becomes available.

Part eight–analyze the remaining completion reports for all water wells in the project area from the WSEO. This could be as many as 18,000 completion reports. Data from these completion reports, such as well name, perforated intervals, elevation, location, and water quality will be entered into the Oracle® database.

Part nine–assemble digital data from all the preceding parts and from other cooperators and serve it to the public.

The groundwater data will include, but will not be limited to, all water produced from coalbed methane wells, water quality analyses for domestic wells from the Wyoming Department of Agriculture's State Chemistry Lab, and data associated with EISs, EAs, and mine permits.

Methods

The WSGS, WRDS, USGS, WSEO, WOGCC, and SDVC will develop a database and interface that significantly expands the type developed earlier for the Little Snake River drainage basin. That database and interface (available under *Cooperative Projects with the Wyoming State Geological Survey* at http://www.wrds.uwyo.edu/ or directly at http://www.wrds.uwyo.edu/wrds/view/view.html) contains and allows the following:

- The geologic column can be viewed beneath any point in the project area (formations, depths encountered, generalized aquifer characteristics);
- Geologic cross sections can be constructed between any two user-defined points in the project area;
- Well construction information including lithologies and casing schedules where available;
- Well water levels;
- Surface and groundwater quality of sample points;
- Literal display of WSEO water well completion reports; and
- Zooming and panning of the map interface as well as overlaying of key layers (transportation, hydrography, and public land survey system) to aid the user.

The Little Snake River Drainage Basin Database will be modified to accommodate additional coverages and data sources, as described in the previous section.

WYDOT'S WATER WELL AT MULE CREEK JUNCTION REST AREA, NIOBRARA COUNTY, WYOMING

Mark Falk
Project Geologist-Geology Program, Wyoming Department of Transportation

Mule Creek Junction is located along the eastern border of Wyoming at the intersection of U.S. Highways 18 and 85 (**Figure 38**). It is approximately 34 miles south of Newcastle, 47 miles north of Lusk, and 37 miles from Hot Springs, South Dakota. As a child on a family vacation in the late 1960s, we stopped at the filling station and café at Mule Creek Junction. In the café there was a sign that read "water served with meals only by special request." At the time, this seemed very strange, because that was some time before conserving water was politically correct. Almost two decades later I finally understood why the café and filling station at the junction operated as they did. There simply was no water source near the junction and all the water had to be delivered by truck.

Finding a water supply

In the early to mid-1980s, the Wyoming Highway Department (WHD) (as it was then known) began a program to upgrade existing rest areas and build new rest areas to serve the traveling public. Mule Creek Junction was chosen as the optimum site for a new rest area since it was at least 30 miles from any Wyoming town and at the junction of two U.S. highways which are the primary routes between the Black Hills and Denver. The only drawback to this site was the lack of water. During the planning process for the rest area, the WHD Geology Program drilled several test wells at the site and within a 2 to 3 mile radius of the junction. Some of the wells were drilled up to 800 feet deep and yielded nothing but dry holes. At this time (1985), it was decided to build the rest area without a water source. This required the use of Clivis Multrum® composting toilets and the installation of a small water storage system to provide drinking and wash water that had to be hauled in.

In 1988, the design process to reconstruct U.S. 85 from Mule Creek Junction to Newcastle began and once again WHD was looking for a source of water–this time construction was the goal. This search encompassed a much larger area, which included a band 6 to 8 miles wide on either side of U.S. 85 for the entire distance between Mule Creek Junction and Newcastle. It became very evident that this was one of the most difficult areas in the state to obtain useable quantities of groundwater. There were two entire townships, some 72 square miles, that did not contain a permitted water well. Of the other permitted wells researched, most of them were shallow (less than 150 feet), low production (less than 5 gallons per minute or gpm) wells drilled into the alluvium of the Cheyenne River and its tributaries (**Figure 38**).

After researching this entire area, the best potential source of water for these projects appeared to be a series of wells drilled into the Cretaceous Lakota Sandstone in section 7, T41N, R60W, approximately 19 miles south of Newcastle and 5 miles east of U.S. 85 along the Beaver Creek drainage. Three wells were completed in this area to depths of approximately 600 feet and

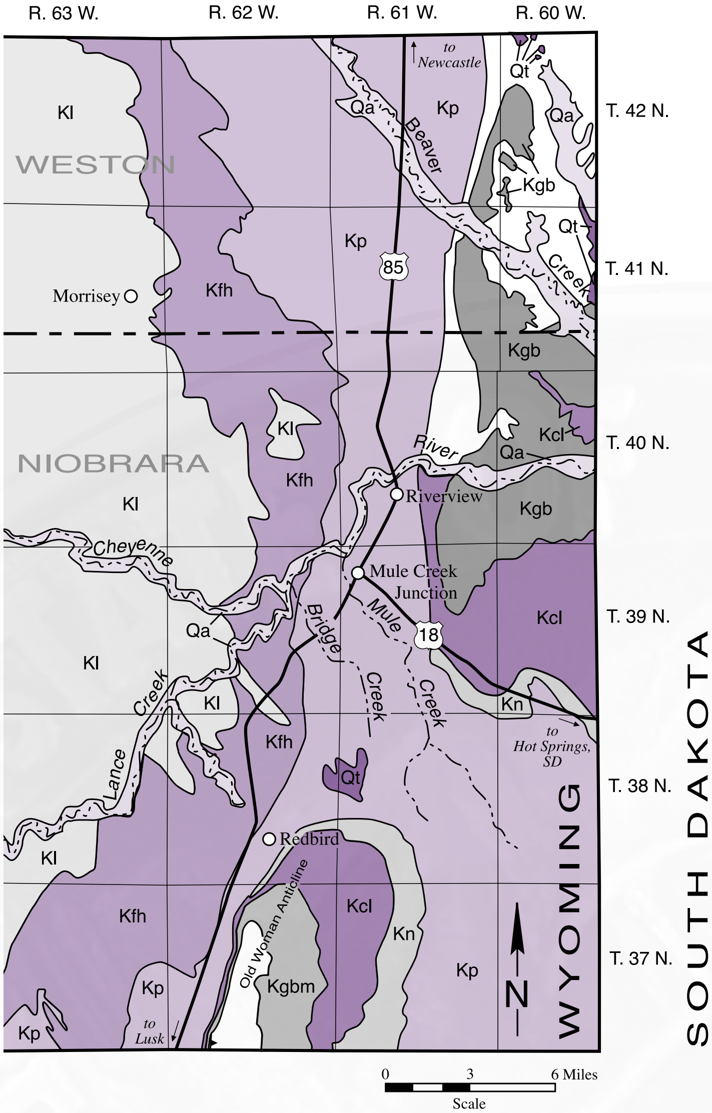

Figure 38. Generalized map of the Mule Creek Junction area, showing geology and other features mentioned in text. Geologic units include Qa, alluvium; Kl, Lance Formation; Kf, Fox Hills Sandstone; Kp, Pierre Shale; Kcl, Carlisle Shale; Kn, Niobrara Shale; Kgb, Greenhorn Formation and Belle Fourche Shale, undivided; and Kgbm, Greenhorn Formation, Belle Fourche Shale, and Mowry Shale, undivided. White areas are Lower Cretaceous and Jurassic rocks. Geologic map from Love and Christiansen, 1985.

they yielded artesian flows averaging 30 gpm. These wells were set up as water sources for all five of the construction projects on U.S. 85. It was going to be very expensive to temporarily pipe or truck-haul this water to the construction projects. As it turned out, the weather cooperated during the construction years and there was enough surface runoff water available from the Cheyenne River and Beaver Creek to meet the needs of the construction.

During the 1990s traffic on both U.S. 85 and U.S. 18 continued to increase and along with this increase, the rest area at Mule Creek Junction experienced dramatic growth in its use. By 1997 it was one of the most highly used rest areas on the state primary highway system. One of the most severe consequences of this increased use was that the capacity of the composting toilets was being exceeded and it became necessary to pump them out once or twice a year. Along with the increased maintenance problems, the Wyoming Department of Transportation (WYDOT) was also starting to receive increased complaints from the traveling public about the smell associated with the composting toilets. Improvements to the rest area would be in the public's best interest and once again, WYDOT'S Geology Program was tasked with trying to find a water source in this dry area.

Geologically, the rest area lies on the western flank of Black Hills uplift where the beds dip westward into the Powder River Basin. Very little faulting has been identified in the immediate area surrounding the site. The Upper Cretaceous Pierre Shale is exposed at the rest area and U.S. 85 generally follows the strike of beds in the Pierre between Mule Creek Junction and Newcastle (**Figure 38**). The nearest structure is the Old Woman anticline, a north-plunging anticline about 10 miles to the south.

Two formations were researched as potential sources of water. The wells in the Cretaceous Lakota Sandstone within a 5-mile radius of the rest area ranged in depth from 500 feet to 880 feet and had yields of 2 to 25 gpm. A review of the logs from many of these wells indicated that the porosity of the formation varied greatly within a relatively small area and that the yield of these wells was directly related to the porosity of the formation. The quality of the water was also highly variable between the wells. In general, wells with the lower production rates had very high sulfates and total dissolved solids in the water.

In the Black Hills area, the Mississippian Madison Limestone is the source of many high-yield, high-quality water wells which supply water to numerous towns including Rapid City, Newcastle, and Gillette. There were no wells within a 5-mile radius of the rest area which were specifically drilled into the Madison for water, so there was little information available about the potential quantity or quality of water. Most of the wells which had penetrated the Madison were abandoned oil tests. There was one Madison well approximately 9 miles south of Mule Creek Junction which had produced in excess of 100 gpm of high quality water when tested in 1978.

From all of this information, drilling a Madison well at the rest area appeared be the best alternative. The challenge was to predict, as accurately as possible, the depth of the Madison at the site. Using all of the information from surrounding wells (depths of formation tops, formation thickness, etc.), the top of Madison at the rest area site was projected to a depth of 5190 feet. With information obtained from the State Engineer's office, WYDOT estimated that the static head would be 200 feet below the ground surface. WYDOT also estimated that the temperature of the water would be between 100 and 120° F.

Drilling and completion

In May, 2000, a contract was awarded to Water Systems Drilling Inc. to drill a well to a depth of 5500 feet, and on July 20, 2000 the contractor began drilling (**Figure 39**). A mud logging unit and a consulting geologist were contracted to continuously monitor the drilling. The 10 3/4-inch diameter surface casing was cemented in place to a depth of 1173 feet. The Cretaceous Lakota Sandstone was encountered at 2695 feet. If the Lakota showed good porosity or signs of water, the plan was to run a drill stem test to determine if there was enough water present to warrant completion in that zone. However, drilling rates and cuttings samples indicated very poor porosity in the Lakota so drilling continued without testing.

One of the major safety concerns during drilling was that the Leo sandstones within the Pennsylvanian Minnelusa Formation may locally produce poisonous hydrogen sulfide (H_2S) gas. Given the well's proximity, the rest area was closed during drilling through the Minnelusa Formation. Unfortunately, this closure occurred at the most inopportune time because it fell during the heart of the Sturgis Motorcycle Rally.

The 2nd Leo Sand was cut at a depth of 4598 feet. This unit consisted of 40 feet of friable sandstone with very good porosity, oil staining, a significant gas kick, and a film of live oil on the mud pits. This oil show was described by the well site geologist as excellent for the Leo Sand. Fortunately, no evidence of H_2S accompanied this oil show. The oil show did present its own set of problems though, considering that this was to be a water well. The cementing of the production casing became critical to ensure that the water from the Madison would not be contaminated by the oil.

The top of the Madison was encountered at 5265 feet on August 25, 2000. Large fractures in the upper part of the Madison resulted in total loss of circulation at 5271 feet. At this point, the well was logged and 7-inch production casing was cemented to a depth of 5248. The well was then drilled without circulation to a total depth of 5322.

The plan was to blow the well bore clean with compressed air and then pump test with a submersible pump to accurately determine the yield. Soon after the blowing of the well commenced, two things became readily apparent–the well was producing a significant amount of water, and the water was hot! The temperature of the water at the outlet of the flowline was measured at 160°F. The flow of water during the 9-hour air lift was estimated to be 350 gpm (**Figure 40**). At this point, a submersible test pump which could operate in such high temperatures could not be located, so the water was sampled, final logs were run, and the well was completed. After completion, the static water level was 70 feet below the ground surface. The final cost of drilling the well was $332,000.

Results and conclusions

Analyses of the water samples from the well indicated that the water met all applicable standards for public drinking water and would require minimum treatment for use in the rest area. The biggest concern is a cooling system which will be required to provide water at a useable temperature for the rest area. At the present time, WYDOT is contracting with engineering design consultants to design a high temperature pump system, a water cooling system, and modifications to the rest area.

This project was definitely a new and different challenge for the WYDOT Geology Program. The biggest unanswered question remains: why is the temperature of the water from this well 30 to 40°F higher than any other recorded Madison well in the region? The author would welcome any theories regarding this.

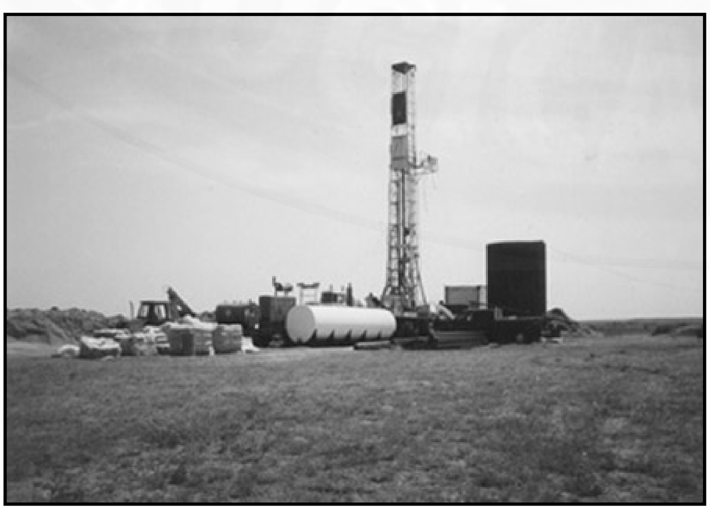

Figure 39. Water Systems Drilling Inc. rig on site at the Mule Creek Junction water well.

Figure 40. Hot water (160°F) from the Madison Limestone being produced during testing of the Mule Creek Junction well.

Acknowledgements

The author would like to acknowledge the following individuals for their valuable contributions to this project: the Wyoming Transportation Commission and WYDOT Executive Staff for supporting this unusual project, Consulting Geologist Miles J. "Todd" Davis for his many hours of well site analysis and expertise, and Scott Heimer from Water Systems Drilling Inc. for all of his hard work in getting the well completed.

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Love, J.D., and Christiansen, A.C., 1985, Geologic map of Wyoming: U.S. Geological Survey, scale 1:500,000, color.

Wyoming State Engineer's Office, 1974, Underground water supply in the Madison Limestone of northeastern Wyoming: Wyoming State Engineer's Office report, 117 p.

Wyoming State Engineer's Office data base of registered water wells.

PUBLICATIONS UPDATE

NEW PUBLICATIONS AVAILABLE FROM THE WYOMING STATE GEOLOGICAL SURVEY

Wyoming State Geological Survey publications

*Construction Aggregate in Wyoming, by R.E. Harris, 2000: Industrial Mineral Report IMR 00-1, photocopy only - $1.50.

*Preliminary geologic map of the Laramie 30′ x 60′ Quadrangle, Albany and Laramie counties, southeastern Wyoming, by A.J. Ver Ploeg and C.S. Boyd, 2000, scale 1:100,000: Hazards Section Digital Map HSDM 00-1 (supercedes PGM 99-1), on-demand plotted color map, rolled only - $25.00; CD-ROM with digital coverages (ArcInfo®/ArcView® format) under development.

* Preliminary surficial geologic map of the Buffalo 30′ x 60′ Quadrangle, Johnson and Campbell counties, Wyoming, by L.L. Hallberg, J.C. Case, and A.L. Kirkaldie, 2000, scale 1:100,000: Hazards Section Digital Map HSDM 00-2, on-demand plotted color map, rolled only - $25.00; CD-ROM with digital coverages (ArcInfo®/ArcView® format) under development.

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* Preliminary surficial geologic map of the Kaycee Quadrangle, Johnson and Campbell counties, Wyoming, by L.L. Hallberg, J.C. Case, and A.L. Kirkaldie, 2000, scale 1:100,000: Hazards Section Digital Map HSDM 00-4, on-demand plotted color map, rolled only - $25.00; CD-ROM with digital coverages (ArcInfo®/ArcView® format) under development.

* Preliminary surficial geologic map of the Newcastle Quadrangle, Weston and Niobrara counties, Wyoming and western South Dakota, by L.L. Hallberg, J.C. Case, and A.L. Kirkaldie, 2000, scale 1:100,000: Hazards Section Digital Map HSDM 00-5, on-demand plotted color map, rolled only - $25.00; CD-ROM with digital coverages (ArcInfo®/ArcView® format) under development.

* Preliminary surficial geologic map of the Worland Quadrangle, Big Horn, Washakie, and Johnson counties, Wyoming, by L.L. Hallberg, J.C. Case, and A.L. Kirkaldie, 2000, scale 1:100,000: Hazards Section Digital Map HSDM 00-6, on-demand plotted color map, rolled only - $25.00; CD-ROM with digital coverages (ArcInfo®/ArcView® format) under development.

* Pyrophoricity (spontaneous combustion) of Powder River Basin coals–considerations for coalbed methane development, by R.M. Lyman and J.E. Volkmer, 2001: Coal Report CR 01-1, 12 p. - $2.00.

* Geologic map of the Moose Quadrangle, Teton County, Wyoming, by J.D. Love, 2001, scale 1:24,000: J. David Love Historical Geologic Map Series, Geology of the Teton-Jackson Hole region, LMS-3, on-demand plotted color map, rolled only - $20.00; CD-ROM of digital map coverages in ArcInfo® format plus viewable, printable version in MrSid® - $10.00.

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* Coalbed methane in Wyoming, by R.H. De Bruin, R.M. Lyman, R.W. Jones, and L.W. Cook, 2001: Information Pamphlet 7 (revised edition) - Free upon request; larger quantities may be purchased for $1.00 each.

* Glacial records in the Medicine Bow Mountains and Sierra Madre of southern Wyoming and adjacent Colorado, with a traveler's guide to their sites, by B. Mears, Jr., 2001: Public Information Circular 41, 26 p., ISBN1-884589-16-2 - $6.00.

* Wyoming geologists field camp, by P.A. Ranz, 2001: Postcard (4" x 5") - $0.25 each or 5 for $1.00.

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Hydrology of Area 48, Northern Great Plains and Rocky Mountain Coal Provinces, Montana and Wyoming, by S.E. Slagle and others, 1986, U.S. Geological Survey Water-Resources Investigations Open File Report 84-141. Includes Yellowstone, Clarks Fork of the Yellowstone, Musselshell River, and Pryor Creek drainages (mostly northern Bighorn Basin).

Hydrology of Area 50, Northern Great Plains and Rocky Mountain Coal Provinces, Wyoming and Montana, by M.E. Lowry, and others, 1986, U.S. Geological Survey Water-Resources Investigations Open File Report 83-545. Includes Powder River, Crazy Woman Creek, Clear Creek, Little Powder, Belle Fourche, and Cheyenne rivers, and Lance Creek (Powder River Basin, Wyoming and Montana) drainages.

Hydrology of Area 51, Northern Great Plains and Rocky Mountain Coal Provinces, Wyoming and Montana, by D.A. Peterson and others, 1987, U.S. Geological Survey Water-Resources Investigations Open File Report 84-734. Includes Shoshone, Bighorn, Greybull, Wind, and Popo Agie rivers (Bighorn and Wind River basins) drainages.

Hydrology of Area 52, Rocky Mountain Coal Province, Wyoming, Colorado, Idaho, and Utah, by H.W. Lowham and others, 1985, U.S. Geological Survey Water-Resources Investigations Open File Report 83-761. Includes Green, New Fork, and Big Sandy rivers, Blacks Fork, Bear River, and Great Divide Basin (Thrust belt, Greater Green River Basin) drainages.

Hydrology of Area 54, Northern Great Plains and Rocky Mountain Coal Provinces, Colorado and Wyoming, by G. Kuhn and others, 1983, U.S. Geological Survey Water-Resources Investigations Open File Report 83-146. Includes North Platte, Laramie, and Medicine Bow rivers (North Park, Saratoga Valley, Hanna, and Laramie basins) drainages.

Other publications

*(Topographic) Travel map of Yellowstone and Grand Teton National Parks and adjacent areas, by GTR Mapping, 2000: Folded map, scale 1 inch=4 miles, ISBN 1-881262-15-4 - $3.95.

*Roadside geology of the Yellowstone Country, by W.J. Fritz, 1985: Roadside Geology Series, 149 p., ISBN 0-87842-170-X - $12.00.

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There were about 113 registered attendees at the conference and probably half as many University of Wyoming students from various classes and programs. The conference brought together members of industry, researchers in government, academia, and the private sectors, and regulatory and conservation groups. It provided a forum to meet and discuss the issues and appeared to stimulate an exchange of ideas and information. A program with abstracts was prepared for the conference and is available from the Wyoming State Geological Survey. Titles of the papers and posters presented at the conference are given below. Asterisks indicate speakers where more than one author is listed.

Oral presentations

General coalbed methane-related geology of the Powder River Basin, Wyoming—Gene R. George

Coal resources of the Powder River Basin, Wyoming—Robert M. Lyman

Correlation of Fort Union coals in the Powder River Basin, Wyoming: A proposed new concept—Jimmy E. Goolsby* and Andrew K. Finley

Uses and limitations of coal analyses—Jane V. Thomas

Oil and gas resources of the Powder River Basin, Wyoming—Rodney H. De Bruin

What is coalbed methane? And recent developments in the Powder River Basin play—Lynn E. Rust

Coalbed methane of the Wyodak-Anderson coal in the Powder River Basin, Wyoming: A USGS, BLM, and Coalbed Methane Operators cooperative program—Gary D. Stricker*, Romeo M. Flores, Allan M. Ochs, and Ronald W. Stanton

Enhanced coalbed methane recovery in the San Juan Basin, Colorado—John Mansoori*, Daryl Erickson, and Bill Pelzmann

Coexistence of coalbed methane and coal mining in the Powder River Basin, Wyoming—Lynn E. Rust

Managing the coalbed methane resource–State mineral lands perspective—Harold D. Kemp

The role of the Federal Government in coalbed methane development—Richard Zander

Recharge from clinker in the Powder River Basin—Edward L. Heffern

Groundwater flow and recharge implications of the oxygen and deuterium isotopes, eastern Powder River Basin, Wyoming—Kathy Muller-Ogle

Water quality and environmental isotopic analyses for ground water from the Wasatch and Fort Union Formations, eastern Powder River Basin, Wyoming—Tim Bartos

Water quality and sodium adsorption ratio of coalbed methane product water—K.J. Reddy*, Q.D. Skinner, and I.H. McBeth

Strontium isotopic characterization of coal and sandstone aquifers, Powder River Basin, Wyoming: Monitor of aquifer interactions—Carol D. Frost*, Kathy Muller-Ogle, and Robert M. Lyman

GIS erosion potential model for coalbed methane water impacts—Gregory V. Wilkerson* and Jeffrey C. Baxter

Poster sessions

Coalbed methane in Wyoming—Rodney H. De Bruin, Robert M. Lyman, Richard W. Jones, and Lance W. Cook, Wyoming State Geological Survey

An update on digital map production at the Wyoming State Geological Survey: STATEMAP and Love Map Series projects—James C. Case and Abby L. Kirkaldie, Wyoming State Geological Survey

Geology, diamond potential, geochemistry, and geophysics of the Iron Mountain kimberlite district and

Grant Creek anomaly—W. Dan Hausel and Robert W. Gregory, Wyoming State Geological Survey; Wayne M. Sutherland and Woody Motten, Consulting Geologists

Potential effect of coalbed methane water discharge on the agricultural use of surface waters in the Powder River Basin—Larry C. Munn, Department of Renewable Resources, University of Wyoming

The Teapot Sandstone in the Powder River Basin: A prograding strandplain—Antonio Cattaneo, Institute for Energy Research, University of Wyoming

Perched deltas during sea level fall and rise: Architecture of Eocene slope sand accumulations, Spitsbergen—Piret Plink-Bjorklund and Ronald J. Steel, Institute for Energy Research and Department of Geology and Geophysics, University of Wyoming

The Twenty-Mile Sandstone in northeastern Colorado: Architecture and sequence stratigraphy—Tara Benda and Ronald J. Steel, Department of Geology and Geophysics, University of Wyoming

Tectonically influenced architecture of mud-dominated clastic successions in the Cody Shale, Powder River Basin, Wyoming—Mark Olsen, Loyd Chism, and Randi S. Martinsen, Department of Geology and Geophysics, University of Wyoming

Improving reservoir characterization techniques with behind-outcrop coring and logging studies: Preliminary results of the UW Rock Springs Drilling Project—Mark Olsen, Randi S. Martinsen, Diane M. Burns, and Ronald J. Steel, Department of Geology and Geophysics, University of Wyoming

Applying Geographic Information Systems technology to hydrologic resource assessment in the Powder River Basin, NE Wyoming—Jeffrey D. Hamerlinck, Spatial Data Visualization Center, University of Wyoming

An update on geologic mapping and STATEMAP at the Wyoming State Geological Survey—Alan J. Ver Ploeg, Wyoming State Geological Survey

Powder River Basin coalbed methane resource assessment applications, methodology, and preliminary results—Karl S. Osvald, U.S. Bureau of Land Management, and Cindy Rice and Romeo M. Flores, U.S. Geological Survey

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