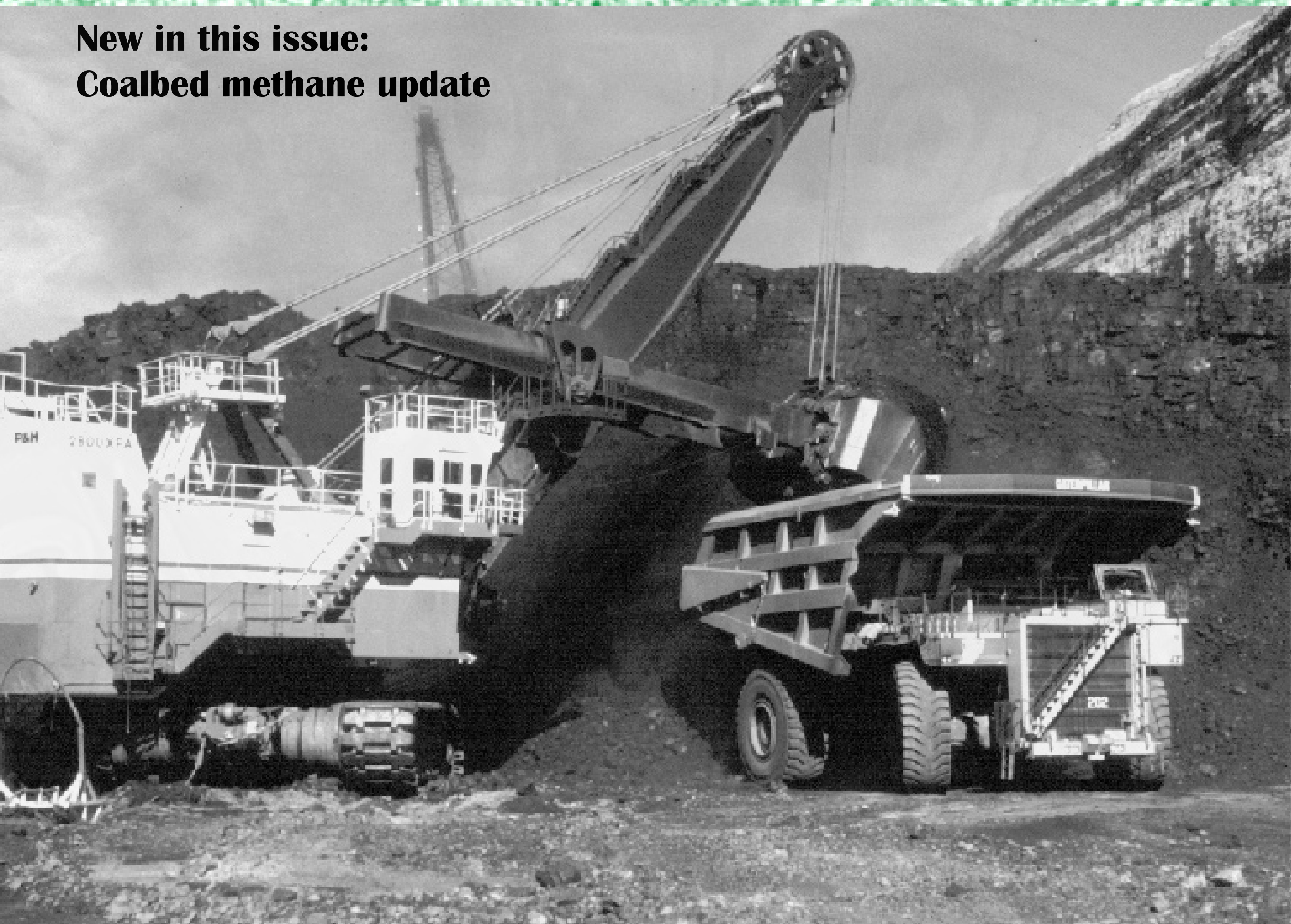
Wyoming Geo-notes

Number 68

New in this issue:
Coalbed methane update



In this issue:

Estimates of coalbed methane in the Powder River Basin

Subsidence potential related to water withdrawal for coalbed methane

Prospecting for platinum group metals

Wyoming State Geological Survey
Lance Cook, State Geologist

Laramie, Wyoming
December, 2000

FEATURED ARTICLES

CONTENTS

WYOMING GEO-NOTES: This quarterly digest on the State's geology and mineral resources and activities of the 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.

Front cover: Coal loading operation at Powder River Coal Company's North Antelope/Rochelle mining complex in the Powder River Basin. The mine is the largest and most productive in the U.S., shipping more than 69 million tons last year. It also produces the lowest sulfur coal in the U.S. The coal shovel is a P&H Model 2800 with a 65 cubic yard bucket that holds 70 tons of coal. The coal hauler is a Caterpillar Model 797 that holds 400 tons of coal. Photograph by L.L. Hallberg while on an October, 2000 coal mine tour for the Introduction to Coal Geology class in the Department of Geology and Geophysics, University of Wyoming. Robert M. Lyman of the Wyoming State Geological Survey was the instructor. Photograph used with permission of Peabody Group.

MINERALS UPDATE

OVERVIEW

Lance Cook
State Geologist-Wyoming State Geological Survey

Starting with this issue of *Wyoming Geo-notes*, we are instituting some changes to improve service to our readers, reduce costs, and respond to changing events in Wyoming. Note the format change to provide a more visually appealing and readable product and to improve the quality of our graphic content. We welcome reader/user comments and other feedback on the new format.

We are also offering supplemental information, such as graphic or tabular data too voluminous for *Wyoming Geo-notes*, on some of our articles via our web site (http://www.wsgsweb.uwyo.edu/ or see specific web pages) and/or geologic section reports. In the **COALBED METHANE UPDATE** on page 15 of this issue is an article on ground subsidence as related to water production practices in coalbed methane development. This article is a less technical description and summary that is more amenable to public consumption. The full technical analysis, complete with the partial derivatives, mathematical equations, and supporting theory, is available on our web site or as a section report for readers who have a hunger for detail.

. . . we believe that coalbed methane will continue to be a hot topic for Wyoming, and we will emphasize it accordingly.

Finally, we are creating a new minerals update section of *Wyoming Geo-notes* devoted to coalbed methane. The WSGS has been spending an increased amount of staff time and budget resources to this issue, and we believe that it is deserving of its own section. Various staff members and guests will be contributing articles on pertinent topics.

This issue contains two guest articles, one on new coalbed methane reserves for the Powder River Basin and the other is the article mentioned above on surface subsidence related to water production in coalbed methane wells. The article by Finley and Goolsby explains their methodology in calculating the 25 trillion cubic feet of recoverable reserves that we are now applying to the coalbed methane play in northeastern Wyoming. In the future, we believe that coalbed methane will continue to be a hot topic for Wyoming, and we will emphasize it accordingly.

New projections for production and prices of Wyoming's major mineral commodities over the next seven years are now available. Several WSGS mineral sections, as well as the State Geologist, contribute to the annual projections made by the State's Consensus Revenue Estimating Group (CREG). These projections are used by the Executive and Legislative branches of Wyoming State Government in their budgeting process.

Production estimates for oil, methane, and *in situ* uranium have been revised upward (**Table 1**) from previous estimates to reflect better market conditions for these Wyoming products. Production of carbon dioxide, helium,

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[7,8]	Sulfur[3,9]
ACTUAL	1985	131.0	597.9	—	—	140.4	10.8	N/A	0.80
	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	1,023.4	149.0	1.10	278.4	18.6	1.9	1.22
	1997	70.2	1,040.7	151.0	1.10	281.5	19.4	2.2	1.23
	1998	65.7	1,072.6	151.0	1.10	315.0	18.6	2.3	1.20
	1999	61.3	1,133.1	161.0	1.10	336.5	17.8	2.8	1.20
FORECAST	2000	60.5	1,237.9	161.0	1.10	346.3	18.0	2.5	1.20
	2001	59.3	1,320.9	161.0	1.10	352.3	20.0	2.0	1.20
	2002	57.5	1,410.9	161.0	1.10	355.8	20.0	2.0	1.20
	2003	54.6	1,491.9	161.0	1.10	359.4	21.0	2.0	1.20
	2004	51.9	1,575.9	161.0	1.10	363.0	21.0	2.0	1.20
	2005	49.3	1,660.9	161.0	1.10	365.6	21.0	2.0	1.20
	2006	46.8	1,746.9	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, 1985-1999); [7]Millions of short tons (Wyoming Department of Revenue, 1985-1999); [8]Millions of pounds of yellowcake (not available [N/A] for 1985 and previous years because it was only reported as taxable value); [9]Millions of short tons.

coal, and sulfur are not expected to change from the previous estimates (see *Wyoming Geo-notes No. 67*, September, 2000) and trona production is expected to decrease slightly (**Table 1**).

The average prices for oil and methane have been revised upward (**Table 2**) from previous estimates to reflect an overall increase in energy prices and a strengthening of those markets in the future. Coal prices are expected to stabilize as more coal from the Powder River Basin dominates the average price at the expense of southern Wyoming coal; trona prices are expected to decrease slightly (**Table 2**). See the mineral update sections that follow for more details on specific markets and the rationale for the forecasts.

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]
ACTUAL	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
FORECAST	2000	26.00	2.85	5.13	37.90
	2001	22.00	2.50	5.07	37.75
	2002	18.00	2.25	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.

OIL AND GAS UPDATE

Rodney H. De Bruin
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Increases in production along with better prices are forecast for Wyoming's natural gas but short-term price hikes forecast for crude oil are not expected to significantly change the decline in Wyoming's oil production. Revenues to the State of Wyoming from production and lease sales of federal oil and gas have increased through the first three quarters of the year. Drilling permits, geophysical activity, and drill rig counts are also up over previous years.

Production and prices

The Consensus Revenue Estimating Group (CREG) released new projections for oil and gas production and prices (**Tables 1** and **2**). Wyoming's oil production will continue to decrease each year, but the amount and rate is less than that predicted earlier (**Table 1** and **Figure 1**). Despite the current enhanced prices for crude oil, this is not causing enough new oil to be discovered in Wyoming to reverse the production decline from the older oil fields that still dominate the production. Natural gas production, spurred by increased demand, increased price, discoveries and developments, and unprecedented growth in coalbed methane, has been revised upward from earlier estimates (**Table 2** and **Figure 2**). Nearly all the increase in natural gas is attributed to coalbed methane (see **COALBED METHANE UPDATE**), although conventional natural gas deposits continue to be discovered and developed. Carbon dioxide and helium production is expected to continue at current rates.

The average price for Wyoming crude oil is expected to top \$25.00 per barrel in 2000, a price not reached since the early 1980s, but will then drop back down and eventually

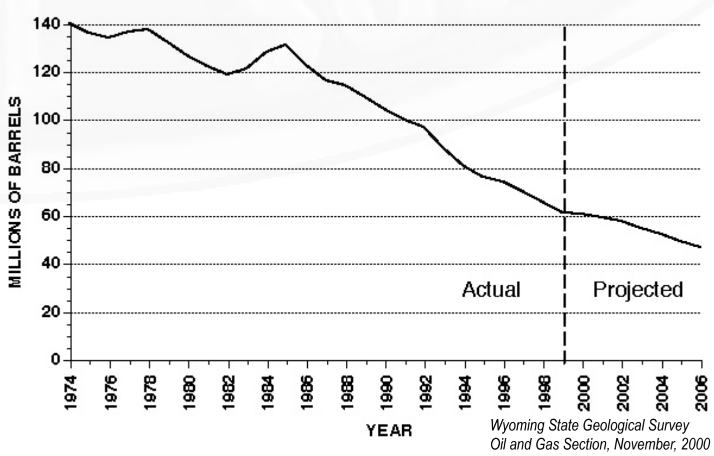

Figure 1. Annual crude oil production from Wyoming (1974 through 1999) with forecasts to 2006.

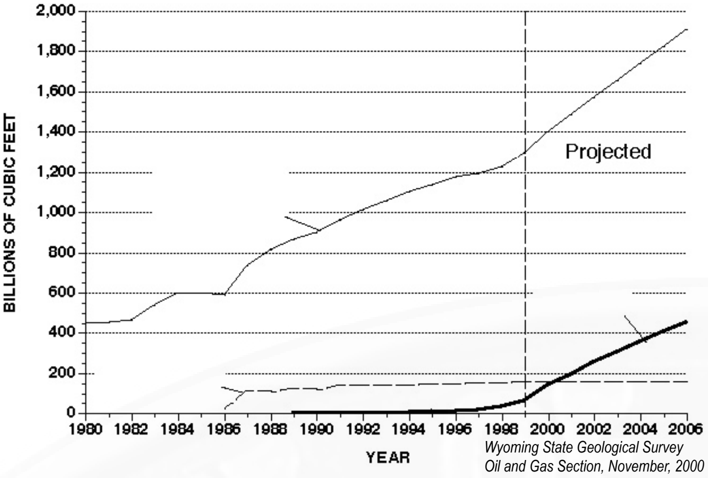

Figure 2. Annual natural gas production from Wyoming (1980 through 1999) with forecasts to 2006.

stabilize at $18.00 per barrel from 2002 through 2006 (**Table 2** and **Figure 3**). The average price will still be $3.00 per barrel higher than our earlier forecast. The price for natural gas is expected to increase to $2.85 per thousand cubic feet (MCF) in 2000 but then drop off slightly and stabilize by 2002 (**Table 2** and **Figure 4**). Natural gas will continue to be Wyoming's greatest source of mineral revenue in the future; even if prices stabilize, the demand will continue to increase and so will the revenues. The relatively conservative (some might argue overly pessimistic) price forecast for natural gas could in fact be a pleasant boon to Wyoming's future when viewed more optimistically.

Prices paid to Wyoming oil producers during the third quarter of 2000 averaged $28.53 per barrel. The average price for that quarter is $9.60 higher than for the third quarter of 1999. The average price in September of $30.50 (**Table 3**) is the highest average monthly price since the early 1980s. The posted sweet and sour crude prices and first purchase price for Wyoming oil averaged by month (**Figure 5**) reflect these rising prices. Crude oil prices have not been affected much by the boost in production by the Organization of Petroleum Exporting Countries (OPEC).

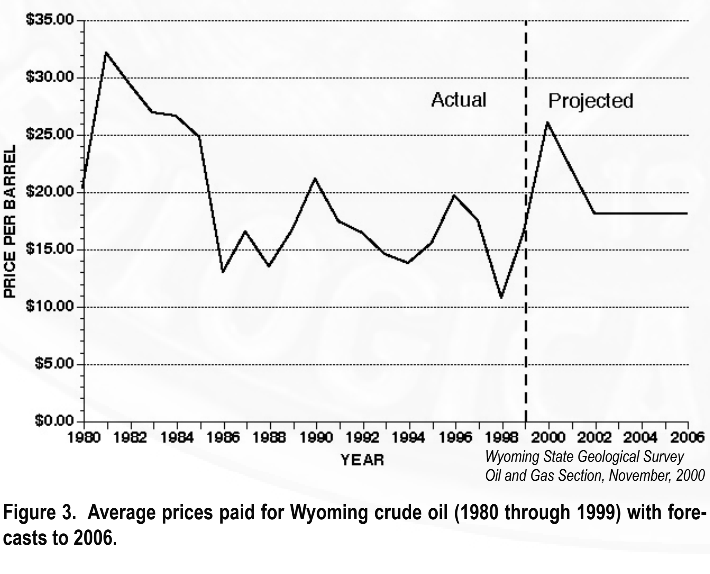

Figure 3. Average prices paid for Wyoming crude oil (1980 through 1999) with forecasts to 2006.

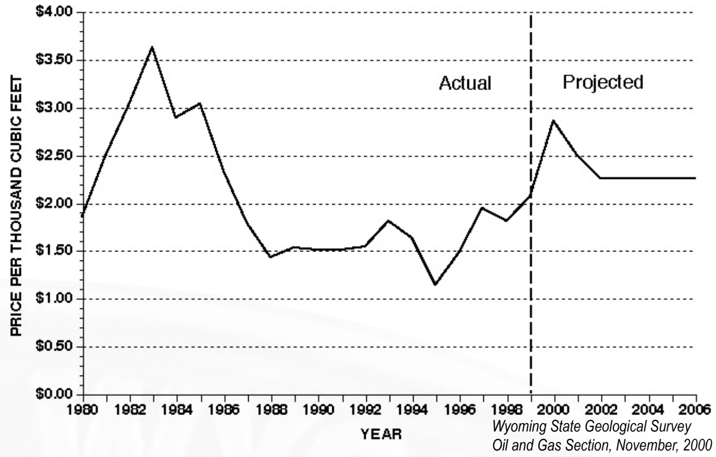

Figure 4. Average prices paid for Wyoming methane (1980 through 1999) with forecasts to 2006.

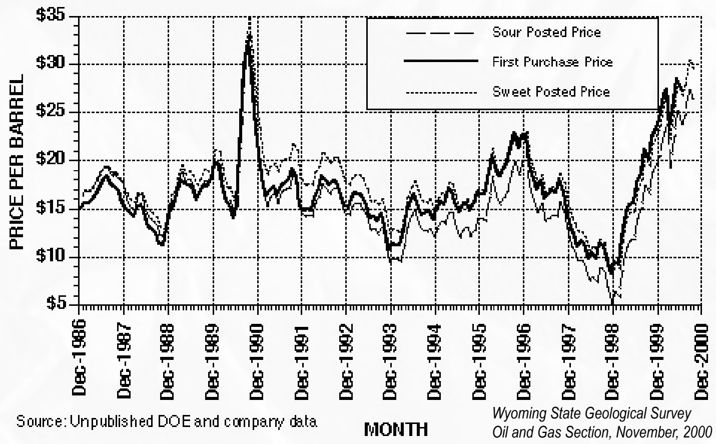

Figure 5. Wyoming posted sweet and sour crude oil prices and first purchase prices, averaged by month (January, 1987 through October, 2000).

Oil production in Wyoming for the first half of 2000 was 30.3 million barrels (**Table 4**), according to figures from the Wyoming Oil and Gas Conservation Commission (WOGCC). This production is a drop of only 1.0 % from the first half of 1999. The decline in production has moderated over the last 10 months because of higher prices for Wyoming oil.

Spot prices for natural gas at Opal, Wyoming averaged $3.47 per MCF during the third quarter of 2000. This is $1.20 higher than the average price for the third quarter of 1999 (**Table 5** and **Figure 6**), and the highest third quarter price recorded in Wyoming since 1983.

Natural gas production in Wyoming for the first half of 2000 was about 708.9 billion cubic feet (BCF) according to production figures from WOGCC. This production is up 13.7% from the first half of 1999 (**Table 6**). Coalbed methane production from the Powder River Basin (PRB) accounted for 61.5 BCF and was 8.7% of that total.

Projects, reports, and transactions

The U.S. Department of Energy (DOE) (2000) released its new reserve estimates for crude oil, natural gas, and natural gas liquids in the U.S. with Wyoming's relative ranking

Table 3. Monthly average price of a barrel of oil produced in Wyoming (1997 through October, 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	$27.10	$26.02
AUG	$16.61	$17.92	$9.58	$11.01	$18.43	$13.86	$28.00	$26.27
SEP	$16.42	$17.75	$11.19	$11.03	$20.97	$14.65	$30.50	$26.74
OCT	$17.89	$17.77	$11.04	$11.03	$20.01	$15.18	$30.00	
NOV	$16.51	$17.65	$9.64	$10.90	$22.20	$15.82		
DEC	$14.72	$17.41	$8.05	$10.67	$23.22	$16.44		
Avg. yearly price		**$17.41**		**$10.67**		**$16.44**		

Source: All averages are derived from published monthly reports by the Energy Information Administration, except that averages in bold print in 2000 are estimated from various unpublished bulletins listing posted prices. Wyoming State Geological Survey, Oil and Gas Section, November, 2000.

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

	1996		1997		1998		1999		2000	
	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative
JAN	6,153,037	6,153,037	5,964,848	5,964,848	5,846,364	5,846,364	5,333,257	5,333,257	5,171,771	5,171,771
FEB	5,693,084	11,846,121	5,459,518	11,424,366	5,233,502	11,079,866	4,744,527	10,077,784	4,856,833	10,028,604
MAR	6,176,805	18,022,926	6,014,780	17,439,146	5,759,176	16,839,042	5,297,674	15,375,458	5,177,472	15,206,076
APR	5,977,362	24,000,288	5,729,869	23,169,015	5,534,568	22,373,610	5,065,591	20,441,049	4,990,099	20,196,175
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	5,172,176	25,368,351
JUN	5,916,019	35,951,812	5,761,549	34,981,535	5,335,463	33,335,198	5,000,039	30,641,119	4,954,824	30,323,175
JUL	6,076,992	42,028,804	5,964,005	40,945,540	5,464,514	38,799,712	5,164,705	35,805,824		
AUG	6,414,850	48,443,654	5,868,789	46,814,329	5,287,415	44,087,127	5,190,052	40,995,876		
SEP	6,180,180	54,623,834	5,710,557	52,524,886	5,109,053	49,196,180	5,081,384	46,077,260		
OCT	6,186,019	60,809,853	5,949,974	58,474,860	5,274,269	54,470,449	5,163,165	51,240,425		
NOV	6,221,912	67,031,765	5,800,811	64,275,671	5,232,287	59,702,736	5,010,985	56,251,410		
DEC	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 are from the 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, November, 2000.

Table 5. Monthly average spot sale price for a thousand cubic feet (MCF) of natural gas at Opal, Wyoming (1997 through October, 2000).

	1997		1998		1999		2000	
	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative
JAN	$3.90	$3.90	$2.05	$2.05	$1.80	$1.80	$2.20	$2.20
FEB	$2.50	$3.20	$1.70	$1.88	$1.65	$1.73	$2.40	$2.30
MAR	$1.40	$2.60	$1.90	$1.88	$1.50	$1.65	$2.35	$2.32
APR	$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
JUN	$1.35	$2.03	$1.65	$1.86	$2.00	$1.76	$3.65	$2.67
JUL	$1.45	$1.95	$1.60	$1.82	$2.00	$1.79	$3.90	$2.84
AUG	$1.40	$1.88	$1.75	$1.81	$2.20	$1.84	$3.10	$2.88
SEP	$1.50	$1.84	$1.60	$1.79	$2.60	$1.93	$3.40	$2.93
OCT	$2.05	$1.86	$1.65	$1.78	$2.40	$1.98	$4.30	$3.07
NOV	$3.00	$1.96	$2.00	$1.80	$2.85	$2.05		
DEC	$1.95	$1.96	$2.00	$1.81	$2.10	$2.06		
Avg. yearly price		**$1.96**		**$1.81**		**$2.06**		

Source: American Gas Association's monthly reports.
Wyoming State Geological Survey, Oil and Gas Section, November, 2000.

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

	1996		1997		1998		1999		2000	
	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative
JAN	101,359,648	101,359,648	99,579,818	99,579,818	103,640,214	103,640,214	108,524,793	108,524,793	121,783,804	121,783,804
FEB	96,303,300	197,662,948	91,766,159	191,345,977	94,501,819	198,142,033	94,288,888	202,813,681	113,184,286	234,968,090
MAR	103,541,127	301,204,075	104,157,578	295,503,555	103,906,999	302,049,032	111,012,987	313,826,668	120,663,020	355,631,110
APR	99,479,609	400,683,684	99,459,039	394,962,594	98,201,007	400,250,039	102,363,550	416,190,218	118,266,662	473,897,772
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	118,130,836	592,028,608
JUN	87,069,612	585,654,159	91,905,308	587,938,273	98,413,520	595,404,796	102,717,295	623,654,210	116,831,983	708,860,591
JUL	100,219,275	685,873,434	100,129,497	688,067,770	102,055,968	697,460,764	106,733,493	730,387,703		
AUG	99,874,019	785,747,453	97,673,622	785,741,392	105,378,334	802,839,098	107,536,099	837,923,802		
SEP	93,510,551	879,258,004	100,028,888	885,770,280	98,474,782	901,313,880	108,200,542	946,124,344		
OCT	95,441,022	974,699,026	102,206,875	987,977,155	96,470,624	990,880,952	118,545,893	1,064,670,237		
NOV	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		
DEC	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 are 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, Oil and Gas Section, November, 2000.

among the top ten states (**Table 7**). At the end of 1999, Wyoming ranked third in dry natural gas reserves, fourth in natural gas liquids reserves, and seventh in crude oil reserves. Wyoming's proved reserves of dry natural gas should increase significantly in the future when coalbed methane reserves are added. Wyoming's dry natural gas reserves increased to their highest level ever, despite record production (**Table 8**). DOE's estimates of crude oil reserves were revised upward, while reserves of natural gas liquids were revised downward.

The Minerals Management Service (MMS) in the U.S. Department of the Interior distributed more than $362 million in revenues from mineral production and lease sales to 34 states during the first six months of 2000, an increase of about 50% from last year's first-half total of $242 million. Wyoming received more than $157 million, which was over 43% of the U.S. total.

Wyoming Interstate Co. (WIC) expanded its Medicine Bow Lateral pipeline in August with additional compression. The lateral extends from near Douglas, Wyoming to WIC's main line southwest of Cheyenne. The line's capacity was increased from 260 million cubic feet (MMCF) to 380 MMCF of gas per day. The company has plans to further increase capacity out of the PRB by looping the existing lateral with 155 miles of 36-inch pipe and adding 14,340 horsepower of compression. The planned Medicine Bow Loop will initially increase WIC's capacity out of the basin by 675 MMCF per day; it is scheduled for completion by the end of 2001.

Williams Gas Pipeline is holding a non-binding open season to solicit expressions of interest for firm natural gas transportation service on the proposed Western Frontier Pipeline from the Cheyenne Hub in northeastern Colorado to Hugoton Station in southwestern Kansas. The new pipeline would provide about 540 MMCF per day of capacity from several Rocky Mountain basins, including the PRB, into the Midwest. Tentative in-service date is November 1, 2003.

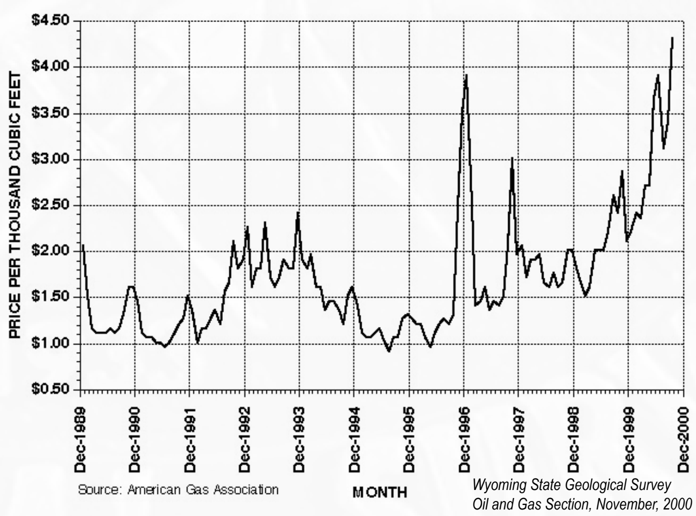

Figure 6. Spot sale prices for methane at Opal, Wyoming, averaged by month (January, 1990 through October, 2000).

Table 7. Wyoming's ranking in proved reserves of crude oil (billions of barrels), dry natural gas (trillions of cubic feet), and natural gas liquids (billions of barrels) at the beginning of 2000.

State	Crude oil	State	Dry natural gas	State	Natural gas liquids
Texas	5.339	Texas	40.157	Texas	2.584
Alaska	4.900	New Mexico	15.449	New Mexico	0.954
California	3.934	**Wyoming**	**14.226**	Oklahoma	0.749
New Mexico	0.718	Oklahoma	12.543	**Wyoming**	**0.515**
Oklahoma	0.621	Alaska	9.734	Louisiana	0.457
Louisiana	0.600	Louisiana	9.242	Kansas	0.358
Wyoming	**0.590**	Colorado	8.987	Colorado	0.303
Utah	0.268	Kansas	5.753	Alaska	0.299
North Dakota	0.262	Alabama	4.287	Alabama	0.107
Montana	0.207	Utah	3.213	Utah	0.100

Source: U.S. Department of Energy, 2000. Wyoming State Geological Survey, November, 2000.

Table 8. Comparison of Wyoing's proved reserves of crude oil (billions of barrels), dry natural gas (trillions of cubic feet), and natural gas liquids (billions of barrels) for the years 1980 through 1999.

Date	Crude oil	Dry natural gas	Natural gas liquids[1]
1980	0.928	9.100	0.239
1981	0.840	9.307	0.269
1982	0.856	9.758	0.477
1983	0.957	10.227	0.552
1984	0.954	10.482	0.602
1985	0.951	10.617	0.664
1986	0.849	9.756	0.665
1987	0.854	10.023	0.647
1988	0.825	10.308	0.808
1989	0.815	10.744	0.627
1990	0.794	9.944	0.568
1991	0.757	9.941	0.524
1992	0.689	10.826	0.462
1993	0.624	10.933	0.420
1994	0.565	10.789	0.395
1995	0.605	12.166	0.415
1996	0.603	12.320	0.505
1997	0.627	13.562	0.600
1998	0.547	13.650	0.535
1999	0.590	14.226	0.515

Source: U.S. Department of Energy, 1999. [1]Estimated from U.S. Department of Energy figures.
Wyoming State Geological Survey, November, 2000.

Trailblazer Pipeline Co. announced that the open season it recently held was a success. Additional capacity of 300 MMCF per day was fully subscribed with fixed rates for a minimum term of 10 years. The pipeline system traverses from Colorado, through southeastern Wyoming, to Beatrice, Nebraska. For the expansion, Trailblazer will install two new compressor stations and add additional horsepower at an existing station. The anticipated completion of the project is the fourth quarter of 2002.

Pioneer Pipe Line Co. started construction on a 262-mile products pipeline from Sinclair, Wyoming to Salt Lake City, Utah. The new 12-inch line replaces an existing 8-inch line. When completed in late 2000, the line will transport three million gallons per day of gasoline, diesel, and jet fuel.

The Bureau of Land Management (BLM) released the Record of Decision (ROD) for the South Baggs Area Natural Gas Development Project. The ROD allows up to 50 additional wells and ancillary facilities within the project area. Merit Energy proposed the 12,352-acre development project, located about three miles west of Baggs in Baggs South Field, near the Wyoming-Colorado state line.

The BLM also issued a ROD approving the Pinedale Anticline Natural Gas Project. The ROD allows 700 producing well pads, with up to 900 drilled wells allowed to achieve the 700 producing wells. Lands associated with the drilling program are located between the town of Pinedale on the north and Jonah Field on the south, and between the Green River on the west and Highway 191 on the east. The area encompasses approximately 300 square miles.

Lease sales

Leasing activity at the August BLM sale was concentrated in the PRB and in southwestern Wyoming (**Figure 7**).

The number of [seismic] permits and miles permitted is up substantially from the first nine months of last year.

Powder River Resources made the sale's high per-acre bid of $475 for a 121.77-acre lease that covers parts of section 21, T45N, R74W (**location A, Figure 7**). The lease is just south of a coalbed methane development operated by Yates Petroleum. Meany Land & Exploration made the sale's second and third high per-acre bids of $460 for a 160-acre lease that covers parts of sections 23, 25, and 26, T49N, R76W (**location B, Figure 7**), and $460 for an 80-acre parcel that covers the E/2 SW section 5, T53N, R76W (**location C, Figure 7**). Both parcels are also in an area of coalbed methane development. There were a total of 79 parcels at this sale that received bids of $50 or more per acre. The sale generated revenue of over $5.2 million and the average per-acre bid was $33.65 (**Table 9**).

Permitting and drilling

There were 1636 Applications for Permit to Drill (APDs) approved by the WOGCC in the third quarter of 2000. The total for the first nine months is

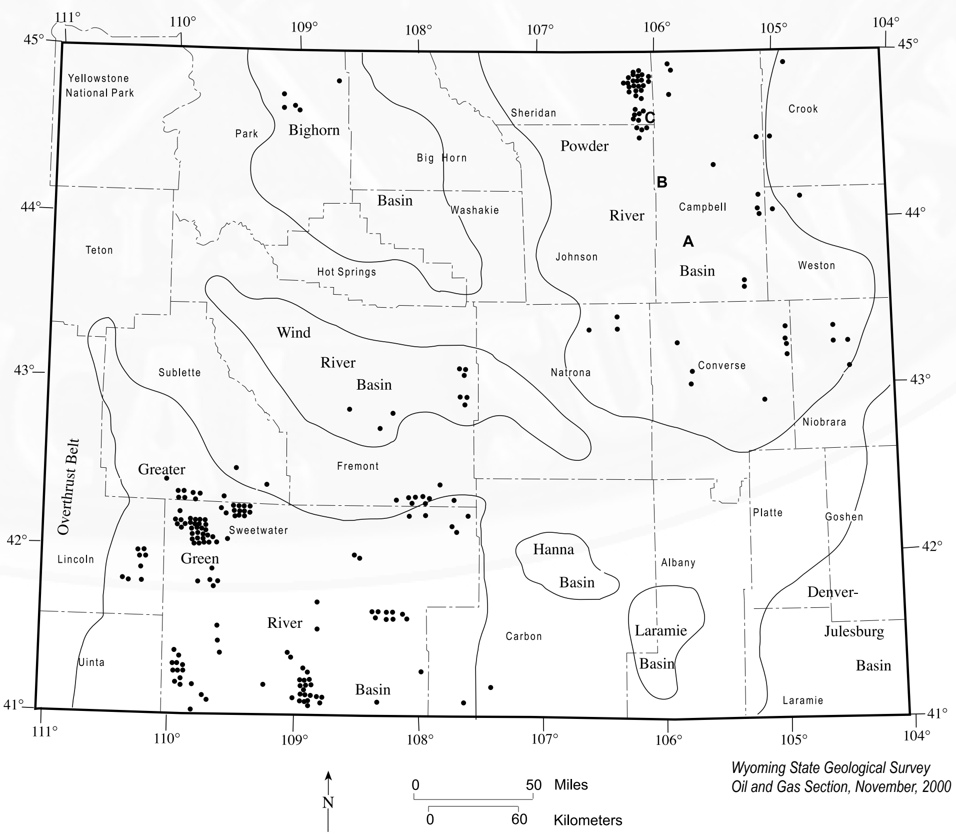

Figure 7. Locations of federal oil and gas tracts leased by the U.S. Bureau of Land Management at its August, 2000 sale.

Table 9. Federal and State competitive oil and gas lease sales in Wyoming (1996 through August, 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							
February	$5,262,908	369	285	366,787	241,654	$21.78	$415.00
April	$10,287,111	247	227	192,561	162,393	$63.35	$395.00
June	$14,737,117	463	367	498,339	368,816	$39.96	$430.00
August	$8,033,029	306	245	349,605	278,095	$28.89	$500.00
October	$10,251,074	455	308	421,900	293,141	$34.97	$430.00
December	$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							
February	$2,734,442	170	138	157,779	124,880	$21.90	$325.00
April	$2,121,220	124	116	129,358	121,421	$17.47	$280.00
June	$8,358,363	179	155	233,599	207,978	$40.19	$32,000.00
August	$3,294,339	206	197	215,631	208,777	$15.78	$290.00
Octoer	$4,395,288	214	175	195,827	142,525	$30.84	$580.00
December	$5,598,020	176	164	128,480	124,093	$28.99	$410.00
TOTAL	$24,197,991	1,069	945	1,060,674	929,674	$26.03	$32,000.00
2000							
February	$5,497,834	192	180	130,289	120,219	$45.73	$525.00
April	$3,057,278	189	161	160,712	128,063	$23.87	$440.00
June	$6,387,887	230	184	260,294	190,306	$33.57	$410.00
August	$5,213,595	240	222	174,040	154,920	$33.65	$475.00

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	$3,151,020	1198	704	438,296	263,230	$11.97	$340.00
1998							
April	$1,203,792	300	161	115,646	63,848	$18.85	$320.00
June	$1,660,438	300	148	108,654	52,501	$31.63	$600.00
October	$1,313,792	298	178	98,856	65,212	$20.14	$590.00
December	$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							
April	$1,815,526	299	196	123,119	89,194	$20.35	$890.00
June	$1,002,039	300	190	108,310	69,858	$14.34	$400.00
October	$2,369,527	300	216	109,140	77,261	$30.67	$475.00
December	$956,113	291	129	115,502	51,674	$18.50	$500.00
TOTAL	$6,143,205	1,190	731	456,071	287,987	$21.33	$890.00
2000							
April	$1,475,661	299	191	120,319	71,933	$19.54	$525.00
June	$2,119,198	300	197	127,798	79,743	$26.58	$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 Surey, Oil and Gas Section, November, 2000.

more than the number of APDs approved the whole year in 1995, 1996,1997,1998, or 1999 (**Table 10**). Campbell County again led with nearly 61% of the total APDs that were approved in the third quarter. Sheridan and Johnson counties combined for another 26.3% of the total APDs. Nearly all of the approved APDs in these three counties were for coalbed methane tests.

Table 10. Number of Applications for Permit to Drill (APDs) approved by the Wyoming Oil and Gas Conservation Commission (1995 through September, 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	4650
Carbon	50	77	84	96	127	135
Converse	29	20	16	6	19	52
Crook	15	37	26	29	30	44
Fremont	30	26	58	76	67	98
Goshen	0	0	0	0	0	0
Hot Springs	13	24	42	1	8	6
Johnson	6	16	6	49	304	632
Laramie	10	2	3	2	0	2
Lincoln	64	55	122	105	51	60
Natrona	80	74	59	36	51	45
Niobrara	4	7	8	8	5	15
Park	20	30	25	11	12	15
Platte	0	0	0	0	0	0
Sheridan	0	0	2	35	416	658
Sublette	61	118	179	230	189	262
Sweetwater	153	136	210	181	124	221
Teton	0	0	0	0	0	0
Uinta	11	10	27	26	26	42
Washakie	31	30	36	9	0	2
Weston	10	10	5	6	4	15
Totals	755	1280	1908	2505	5900	6965

Source: All data are from the Wyoming Oil and Gas Conservation Commission. Wyoming State Geological Survey, Oil and Gas Section, November, 2000.

The WOGCC permitted 19 seismic projects in the third quarter of 2000. The number of permits and miles permitted is up substantially from the first nine months of last year. The number of permitted conventional miles is already higher than the annual totals for 1998 and 1999 and the area of permitted 3-D seismic projects has already surpassed the total for all of 1997, and is nearing the totals for 1998 and 1999 (**Table 11**). Geophysical activity is a good indicator of future exploration and production drilling.

The average daily rig count for the third quarter of 2000 was 46, nine more than for the third quarter of 1999 (**Figure 8**). The rig count does not include rigs drilling for coalbed methane.

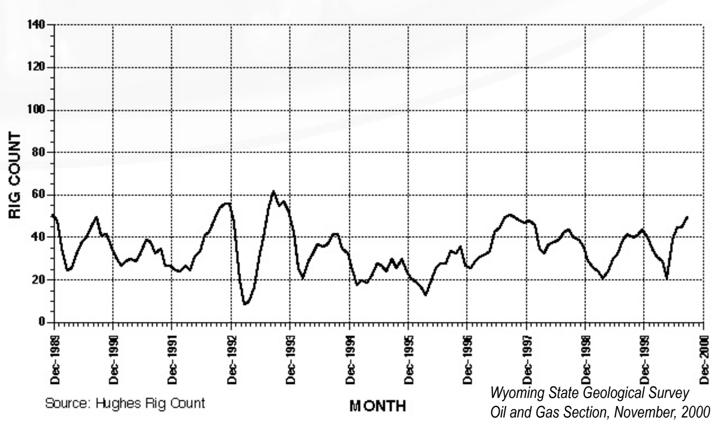

Figure 8. Wyoming daily rig count, exclusive of coalbed methane rigs, averaged by month (December, 1989 through September, 2000).

Table 11. Number of seismic projects and miles permitted by the Wyoming Oil and Gas Conservation Commission (1997 through September, 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	10	51	33
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	3	0	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	1	3	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	0	0	0
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	3	70	44
Sweetwater	4	66	296	6	214	66	9	0	530	12	54	904
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**	**44**	**645**	**1254**

Source: All data are from the Wyoming Oil and Gas Conservation Commission.
Wyoming State Geological Survey, Oil and Gas Section, November, 2000.

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 activities in Wyoming. **Table 12** reports the most significant activities exclusive of coalbed methane (see the **COALBED METHANE UPDATE** for developments in this industry) during the third quarter of 2000. The numbers correspond to locations on **Figure 9**.

Reference cited

U.S. Department of Energy, 2000, U.S. crude oil, natural gas, and natural gas liquids reserves: 1999 Annual Report, Advance Summary: Washington, D.C., 15 p.

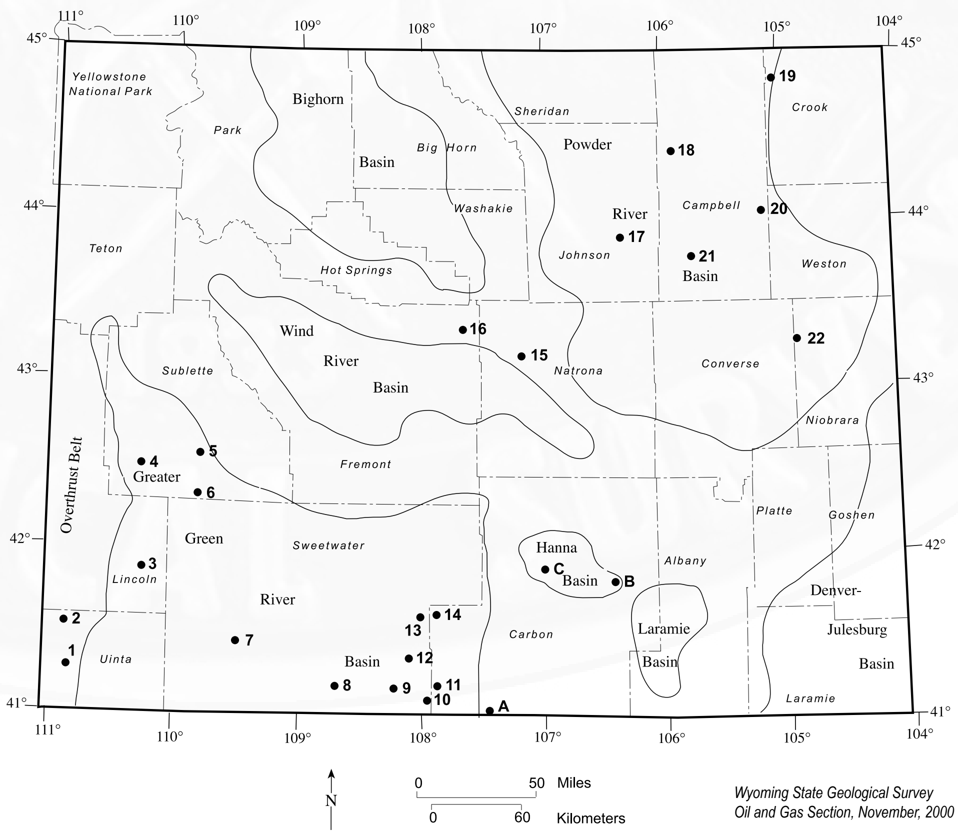

Figure 9. Oil and gas exploration and development activities (numbers) and coalbed methane activities (letters) in Wyoming during the second quarter of 2000. Locations are approximate and may represent more than one well location or project.

Table 12. Significant exploration and development wells in Wyoming during the third quarter of 2000[1]. Number corresponds to location on Figure 9 and may indicate more than one well.

	Company name	Well name/number	Location	Formation tested	Depth(s) of interval(s) tested	Tested production (per day)	Remarks
1	Chevron USA	31-18AH	SE SE sec 7, T15N, R119W	Nugget Ss.	13,574-13,973	1203 BBL Oil 3.7 MMCF	Horizontal redrill in Painter Reservoir Field
2	Amoco Production	2 Champlin 457 Amoco-B	SW NE sec 31, T18N, R119W	Mission Canyon Ls. Lodgepole Ls.	13,838-13,874 14,124-14,203	4.5 MMCF from both zones	Directional redrill in Whitney Canyon-Carter Creek Field
3	Kaiser-Francis Oil	30-12 Blackjack-Federal	SW SE sec 12, T22N, R113W	Dakota "B" sand	11,714-11,722	1.8 MMCF	Cow Hollow Field
4	EOG Resources	120-13 "B"	NW SW sec 13, T29N, R113W	"transition zone"	3174-3342	162 BBL Oil 154 MCF 16 BBL H_2O	Big Piney Field area
5	Forest Oil	23-14 Elm-Federal	NE NE sec 23, T28N, R109W	Lance Fm.	5 intervals N/R	9.6 MMCF 120 BBL Cond	Southwestern flank Jonah Field
	Ultra Petroleum	10-23 Stud Horse Butte	NW SE sec 23, T29N, R108W	Lance Fm.	11 intervals N/R	9.0 MMCF 129 BBL Cond	Jonah Field
	McMurry Oil	12-36 Stud Horse Butte	NW SW sec 36, T29N, R108W	Lance Fm.	several intervals 8810-10,511	11.6 MMCF 150 BBL Cond	Jonah Field
	Forest Oil	23-14 Elm-Federal	NE NE sec 23, T28N, R109W	Lance Fm.	8 intervals 7780-9660	10.8 MMCF 110 BBL Cond 22 BBL H_2O	Jonah Field
	Wexpro Co.	1 Jean Harmon	NE NE sec 7, T32N, R109W	Lance Fm.	4 intervals 9769-11,657	1.5 MMCF 10 BBL Cond 20 BBL H_2O	Recompletion on Pinedale anticline
	Amoco Production	15-29 Rainbow	SW SE sec 29, T30N, R107W	Lance Fm.	7 intervals 8912-12,628	1.0 MMCF	2 miles NE of nearest producer in Jonah Field area
	CamWest	1-28 Poblano-Federal	NE SE sec 28, T28N, R107W	Almond Fm. Ericson Ss.	11,930-11,934 3 intervals 12,578-12,663	778 MCF 75 BBL Cond 144 BBL H_2O	Discovery 7 miles SE of Jonah
	Ultra Petroleum	2-23 Stud Horse Butte	NW NE sec 23, T29N, R108W	Lance Fm.	15 intervals 9388-12,515	10.4 MMCF	Jonah Field
	Ultra Petroleum	4-24 Stud Horse Butte	NW NW sec 24, T29N, R108W	Lance Fm.	11 intervals 9636-12,727	4.6 MMCF	Jonah Field
	Amoco Production	7-11 Corona Unit	SW NE sec 11, T28N, R109W	Lance Fm.	9 intervals 7339-10,278	13.2 MMCF	Jonah Field
	Amoco Production	7-19 Corona Unit	SE NE sec 19, T29N, R107W	Lance Fm.	several intervals 8150-11,260	9.0 MMCF	Jonah Field
6	HS Resources	11-24 Scarlet Unit	NE SW sec 24, T27N, R109W	Lance Fm.	several intervals 7240-8994	249 MCF 43 BBL H_2O	Discovery
7	Saurus Resources	7 shallow wildcats scheduled	sec 5, 7, and 9, T17N, R107W	Green River Fm.			Only previous production in area is the Massacre Hills Field discovery, a non-commercial Mesaverde producer
8	Basin Exploration	33-30 Chicken Springs-Federal	NW SE sec 30, T14N, R100W	Almond Fm.	3 intervals 5215-5473	346 MCF 3 BBL Cond 5 BBL H_2O	Discovery
9	EOG Resources	1-13E Powder Mountain Unit	SE NE sec 13, T14N, R96W	Lewis Sh.	13,333-13,367	3.2 MMCF 22 BBL H_2O	Offset to 1999 discovery
10	EOG Resources	7-5 Cedar Chest Unit	SE NE sec 5, T13N, R94W	Almond Fm.	2 intervals 12,447-12,470	4.7 MMCF 1 BBL Cond 1 BBL H_2O	Cedar Breaks Field
11	Tom Brown Inc.	10-9 TBI-Federal	NW NW sec 9, T14N, R93W	Almond Fm.	11,066-11,076	1.4 MMCF	Discovery
12	Questar Exploration and Production	2A Wedge Unit	SE SE sec 13, T16N, R95W	Almond Fm.	12,709-12,720	1.8 MMCF 12 BBL H_2O	Mulligan Draw Field
13	Amoco Production	21-3 Two Rim Unit	NW SW sec 21, T19N, R94W	Almond Fm.	several intervals 9774-10,135	4.0 MMCF	Two Rim Field
14	Amoco Production	4 Amoco Champlin 242 "J"	NE NW sec 23, T19N, R93W	Almond Fm.	6 intervals 9091-9389	4.6 MMCF	Echo Springs Field
	Marathon Oil	21-2 Echo Springs	NE SW sec 2, T19N, R93W	Almond Fm.	2 intervals 9480-9899	3.3 MMCF 77 BBL Cond 73 BBL H_2O	Echo Springs Field
15	Barrett Resources	6-29 Cave Gulch-Federal	C SE sec 29, T37N, R86W	Frontier Fm.	4 intervals 17,131-17,792	20.3 MMCF 148 BBL H_2O	First subthrust Frontier producer in Waltman Field
	Barrett Resources	11-28 Deep	SE SW sec 28, T37N, R86W	Lakota Ss.	19,402-19,482	8.4 MMCF 110 BBL H_2O	Subthrust Lakota in Waltman Field
	Barrett Resources	3-29 Cave Gulch-Federal	NW SW sec 29, T37N, R86W	Lakota Ss.	18,095-18,148	1.3 MMCF 212 BBL H_2O	Subthrust Lakota in Waltman Field
16	Double Eagle Petroleum & Mining	1-24 Leonard	NW NW sec 24, T39N, R90W	Lance Fm.	about 13,300	2.0 MMCF	Madden Field recompletion
	Burlington Resources	7-34 Bighorn	NW SW sec 34, T39N, R91W	Madison Ls.	24,500		Sixth deep Madison test in Madden Field
	Burlington Resources	5-6 Bighorn	SW NW sec 6, T38N, R89W	Madison Ls.	24,706-24,968	162 MMCF[2]	Fourth deep Madison producer in Madden Field
17	Westport Oil & Gas	32-19 ST Reno Unit-Federal	SW NE sec 19, T45N, R79W	Minnelusa Fm.	15,034-15,096	98 BBL Oil 6 BBL H_2O	Reno Field
18	Gulf Production	14 Cedar Draw-Federal	NW NW sec 14, T51N, R75W	Muddy Ss.	9514-9524	1.5 MMCF 160 BBL Cond 10 BBL H_2O	Cedar Draw Field stepout
19	Ballard Petroleum	33-3 Federal	NW SE sec 3, T56N, R68W	Minnelusa Fm.	4754-4774	200 BBL Oil	Discovery
20	Stone & Wolf	10-5H Bishop	SW NW sec 10, T47N, R69W	Mowry Sh.	below 7000	100 BBL Oil	Horizontal Mowry discovery
21	Yates Petroleum	18 K-Bar-State	SE NW sec 36, T44N, R74W	Parkman Ss.	7583-7589	58 BBL Oil	Stepout from K-Bar Field
22	Abraxas Petroleum	3H-10-38 Middleton	SW SW sec 10, T38N, R67W	Turner Ss.	Unknown		

[1]Abbreviations include: sec=section; N/R=not reported; 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. [2]Calculated absolute open flow.
Wyoming State Geological Survey, October, 2000.

COAL UPDATE

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New projections for production and prices of Wyoming coal have been made by the State of Wyoming's Consensus Revenue Estimating Group (CREG). Only some minor changes in the coal production forecast have been made since last year, reflecting a slight downturn in production as noted below. Total production from all Wyoming mines in 2000 is now estimated at 346.3 million short tons (**Table 1**), a modest net increase of about 2.9% from 1999. The increase in coal production from Campbell County is now less than predicted earlier, and decreased production is expected from both Carbon County, where closure of the state's only underground coal mine occurred in July, and Lincoln County, where a strike at the Kemmerer mine slowed production (**Table 13**). Statewide coal production will continue to increase through 2006, with any decreases in southern Wyoming more than offset by slight increases in the Powder River Basin (PRB) (**Figures 10** and **11**).

Coal prices are projected to continue their decrease on a statewide basis, probably leveling off at $5.09 per short ton in 2001 (**Table 14**). The final

Table 13. Wyoming coal production by county[1, 2] (in millions of short tons) from 1995 through 1999 with forecasts to 2006.

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Powder River Basin												
Campbell County232.4	245.3	246.3	274.1	296.3	305.5	309.3	312.8	314.4	323.0	325.6	330.3	
Converse County14.1	15.8	17.8	23.4	24.0	27.0	30.0	30.0	30.0	25.0	25.0	25.0	
Sheridan CountyM	M	M	M	M	M	M	M	M	M	M	M	
Southern Wyoming												
Carbon County	3.8	4.7	5.0	3.5	3.5	2.0	M	M	2.0	2.0	3.0	3.0
Sweetwater County	9.1	8.2	7.8	9.2	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Lincoln County	4.5	4.4	4.6	4.7	4.7	3.8	5.0	5.0	5.0	5.0	5.0	5.0
Total Wyoming263.9	**278.4**	**281.5**	**314.9**	**336.5**	**346.3**	**352.3**	**355.8**	**359.4**	**363.0**	**365.6**	**370.3**	
Annual Change11.4%	5.5%	1.1%	11.9%	6.9%	2.9%	1.7%	1.0%	1.0%	1.0%	1.0%	1.0%	
Higher-priced coal[3]	**26%**	**24%**	**22%**	**17%**	**13%**	**9%**	**6%**	**4%**	**4%**	**4%**	**4%**	**4%**

[1]Tonnage from the Wyoming State Inspector of Mines, 1995-1999 (Stauffenberg, D.G., 2000). [2]County estimates by the Wyoming State Geological Survey, October, 2000, for 2000-2006. [3]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 means minor tonnage (less than 50,000 tons)]. Wyoming State Geological Survey, Coal Section, October, 2000.

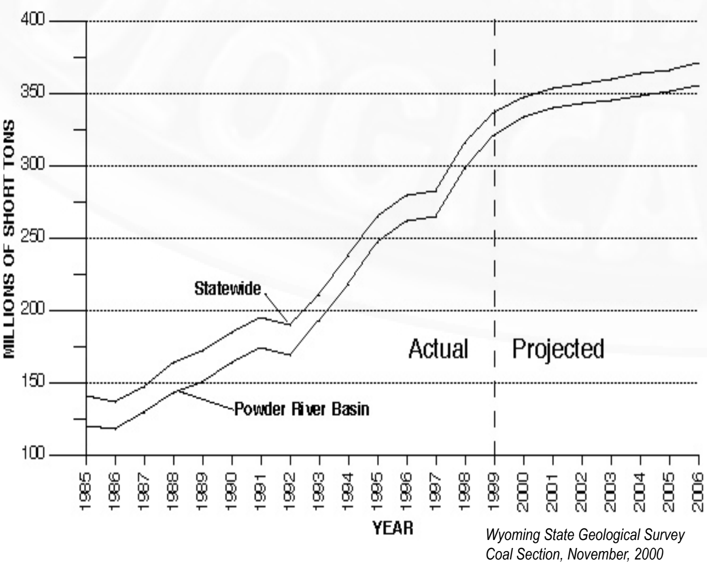

Figure 10. Annual coal production from Wyoming and the Powder River Basin (1985 through 1999) with forecasts to 2006. Sources: Wyoming State Inspector of Mines (1985 through 1999), CREG (2000 through 2006), and Wyoming State Geological Survey.

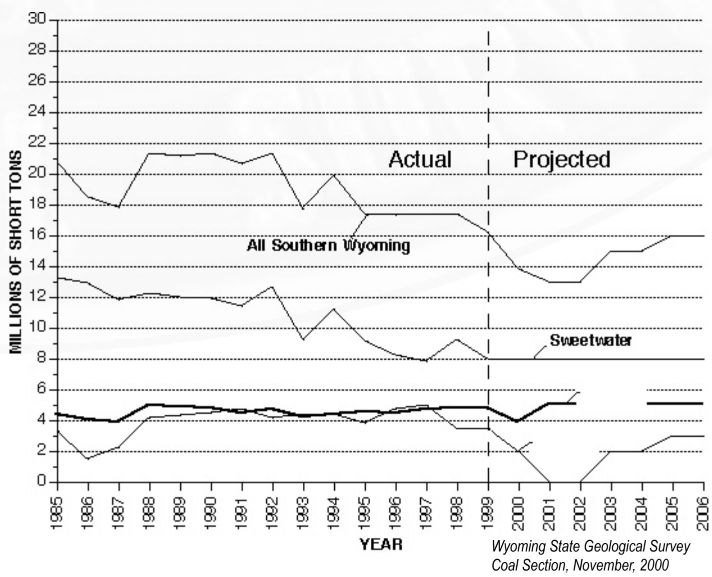

Figure 11. Annual coal production from southern Wyoming counties (1985 through 1999) with forecasts to 2006. Sources: Wyoming State Inspector of Mines (1985 through 1999) and Wyoming State Geological Survey (2000 through 2006).

average price of coal for 1999 has been changed slightly (see *Wyoming Geo-notes No. 67*, September, 2000). Coal prices for the PRB (northeastern Wyoming) may rebound slightly in the next few years as predicted earlier, but this may be short lived (**Figure 12**). The biggest change in forecast prices is in southern Wyoming, where the average price in future years will be even lower than predicted earlier. The loss of the high-priced underground coal in the Hanna Basin, along with decreased production of other high-priced coal, will depress these average prices.

While Wyoming continues to lead the nation in coal production (approximated by coal deliveries) through the second quarter of 2000, production trails that for the same period in 1999 by about 9% and even trails the same period in 1998 by about 2% (**Table 15**). Early indications for the third quarter, supported by a rebound in spot coal prices, point to stronger steam coal deliveries in the last half of 2000. Coal deliveries from January, 1996 through June, 2000 show that monthly totals dropped below 1998 levels (**Figure 13**) and contract coal even dropped below 1997 levels (**Figure 14a**). Deliveries of spot coal are making up the deficit in delivered contract coal,

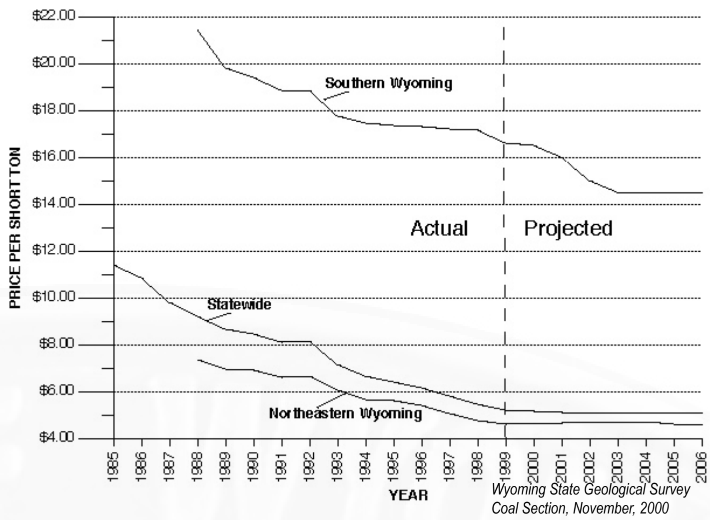

Figure 12. Average prices paid for Wyoming coal by producing area (1985 through 1999) with forecasts to 2006. Sources: U.S. Energy Information Administration (1985 through 1990); Wyoming Department of Revenue (1991 through 1999); and CREG (2000 through 2006).

Table 14. Average prices paid for coal by producing area (1985 through 1999) with forecasts to 2006.

Year	Northeastern	Southern	Statewide
1985			$11.36
1986			$10.85
1987			$9.80
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 1985-1990 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; statewide estimates for 1999-2006 are by CREG, and all regional breakdowns are estimated by the Wyoming State Geological Survey (October, 2000).

and **Figure 14b** indicates that spot coal deliveries may indeed have bottomed out. The early arrival of winter weather in many parts of the country, and the predicted severity of winter weather this year should help Wyoming's steam coal markets.

During the third quarter of 2000, the prices for Wyoming coal on the spot market have apparently strengthened by nearly 10%. The discipline of the PRB coal producers discussed in the last issue of *Wyoming Geo-notes* (No. 67, September, 2000, p. 24) appears to have spot market prices responding upward. According to the COAL Daily Spot Index, spot prices for PRB coal had risen approximately 33 to 36 cents per ton from the end of May to the end of September.

Developments in the Powder River Basin

At a recent lease sale, Kennecott Energy's Antelope Coal Company was the successful bidder on the Horse Creek Federal Coal Lease By Application (LBA) tract (see *Wyoming Geo-notes No.67*, September, 2000, p. 30), with a bonus bid of $91,220,120.70 (**Table 16**). The new lease adds approximately 264.5 million tons of additional recoverable coal reserves to Antelope's current mine plan. The LBA tract consists of 2819 acres containing an estimated 356 million tons of in-place coal. The subbituminous coal reserves are from the Anderson and Canyon splits of the Wyodak coal zone. The coal has an average estimated quality of 8890 Btu per pound, 26.83% moisture, 4.28% ash, and 0.22% sulfur, all on an as-received basis (COAL WEEK, 9/18/00)

Bonus bid monies are paid in equal installments over a five-year period beginning in the year each LBA is successfully acquired. Half of the monies from the bonus bids go to the Federal Government, the other half is received by the State of Wyoming. Deferred bonus payments for LBAs are currently being received from six winning bidders, and payments will continue through 2004 (**Figure 15**).

Phillips Petroleum completed the sale of its Wyoming coal interests in the PRB. On October 12, 2000, Phillips sold its 50% interest in the Dry Fork mine to its long-time partner, Western Fuels Association (COAL Daily, 10/13/00). This transaction marks the final exit of companies whose primary interest was petroleum from the PRB coal scene.

Coal production figures for the third quarter showed that Kennecott is now increasing production at its PRB mines. In the previous issue of *Wyoming Geo-notes* (No. 67, September, 2000, p. 28-29) it was reported that Kennecott was reducing production in response to low prices. Apparently the current prices for coal are driving the increased

Table 15. Monthly coal deliveries from Wyoming's mines in short tons (January, 1996 through June, 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		
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		
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		
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		
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**		

[1]From Federal Energy Regulatory Commission (FERC) Form 423, 1996-1999. [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, October, 2000.

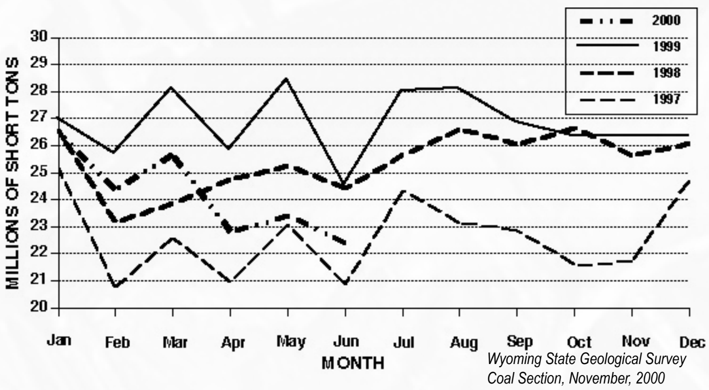

Figure 13. Reported monthly deliveries from Wyoming coal mines (1997 through June, 2000). From Form 423 of the Federal Energy Regulatory Commission (FERC).

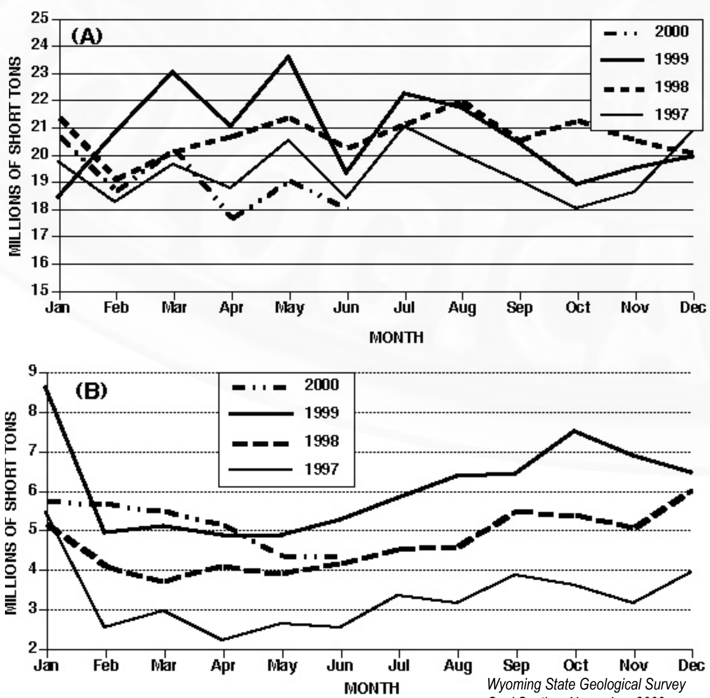

Figure 14. Monthly coal deliveries from Wyoming (1997 through June, 2000). (A) Coal sold on contract and (B) coal sold on the spot market. From Form 423 of the Federal Energy Regulatory Commission (FERC).

production now reported. Total output from Kennecott's Antelope, Caballo Rojo complex, and Jacobs Ranch mines reportedly jumped 11% over second quarter output (COAL Daily, 10/27/00). The company's mines in Wyoming produced a total of about 21.9 million short tons (tons) during the third quarter of 2000. Despite the increased production, in 2000, Kennecott mines had only produced about 59.8 million tons through three quarters compared to about 65.0 million tons through three quarters of 1999.

SGI International (SGI) announced in October it had reached an agreement with AEI Resources, Inc. extending SGI a financing deadline for purchase of AEI's ENCOAL plant in Campbell County. AEI will give SGI additional time to finalize the $10.1 million needed to close the acquisition and to make numerous upgrades to the plant. The deal was to be completed by the end of September, 2000, but the parties agreed to an October 31st deadline (COAL Daily, 10/12/00).

RAG Coal West (RAG) announced that it will lay off 48 workers in the Gillette area by the end of the year (Casper Star-Tribune, 11/5/00). RAG said it is realigning its work force to make it consistent with market conditions in the PRB. RAG owns and operates the Belle Ayr and Eagle Butte mines in Campbell County.

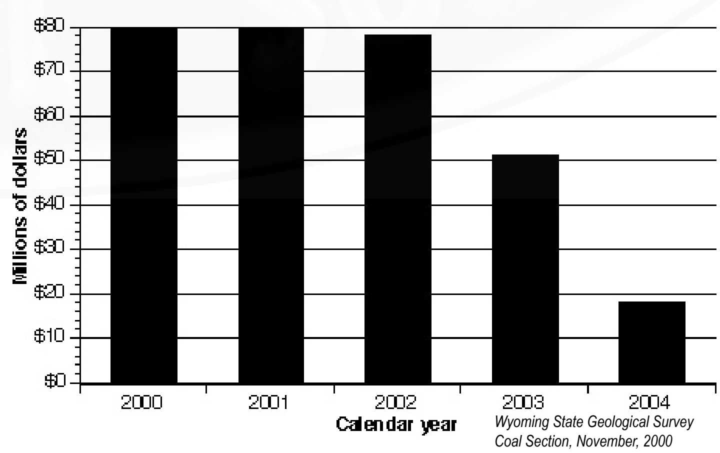

Figure 15. Deferred bonus payments for LBAs in Wyoming for the period 2000 through 2004. Source: Wyoming State Department of Revenue, November, 2000.

Table 16. Summary of Leases by Application (LBAs) in the Powder River Coal Field, Wyoming.[1]

LBA tract name/ Company applicant	Application date	Applied for Acres	Applied for Tons x 10^6	Offered for Bid Acres	Offered for Bid Tons x 10^6	Status	Total bid	Cents/Ton
Jacobs Ranch/Kerr-McGee	10/10/89	1,465	123	1,709	147.4	Accepted 9/26/91	$20,114,930	13.6
West Black Thunder/ Thunder Basin Coal Co.	12/22/89	3,225	400	3,492	429	Accepted 8/12/92	$71,909,282	16.8
North Antelope & Rochelle/	03/03/90	954	120	3,064	403.5	Accepted 9/28/92	$86,987,765	21.6
Powder River Coal Co.	(2 Applications)	1,196	150	(Offered as 1 Tract)				
West Rocky Butte/	12/04/90	390	50	463	56.7	Rejected 12/3/92	$14,200,000	25.8
Northwestern Resource Co.						Accepted 1/7/93	$16,500,000	29.1
Eagle Butte/AMAX Land Co.	07/21/91	915	150	1,059	166.4	Accepted 4/5/95	$18,470,400	11.1
North Rochelle/Zeigler Coal Co.	07/22/92	1,440	144	1,482	157.6	Rejected 7/29/97	$26,800,000	17.0
						Accepted 9/26/97	$30,600,000	19.4
Antelope/Antelope Coal Co.	12/29/92	617	60	617	60.4	Rejected 9/28/96	$6,645,045	11.0
						Accepted 12/4/96	$9,064,600	15.0
Powder River/ Powder River Coal Co.	03/23/95	4,200	555	4,224	532	Accepted 7/3/98	$109,600,000	20.6
Thundercloud/Kerr-McGee[2]	04/14/95	3,396	427	3,545	412	Accepted 10/1/98	$158,000,009	38.3
Horse Creek/Antelope Coal Co.	02/14/97	1,471	177.5	na	na			
Amended	05/01/98	2,838	356.5	2,819	264.5	Accepted 9/17/00	$91,220,121	34.5
New Keeline/Evergreen Enterprises	05/13/96	7,841	675	na[4]	na	Appeal withdrawn September, 2000		
Belle Ayr/AMAX Land Co.	03/20/97	1,579	200	na	na	PRRCT reviewed & approved to proceed 4/23/97		
North Jacobs Ranch/Jacobs Ranch	10/02/98	4,821	519	na	na	PRRCT reviewed & approved to proceed 10/27/99		
State Section/Evergreen Enterprises	01/31/00	8,494	712	na	na	Application withdrawn September, 2000		
NARO/ Powder River Coal Co.	03/10/00	4,501	564	na	na	Waiting on PRRCT review		
Little Thunder/Black Thunder	03/23/00	2,710	384	na	na	Waiting on PRRCT review		

[1]Adapted from 1997 Draft EIS, Powder River and Thundercloud leases, prepared by the U.S. Bureau of Land Management; revised by Wyoming State Geological Survey, Coal Section, October, 2000. [2]Arch Coal successful bidder. [3]PRRCT = Powder River Regional Coal Team; [4]na = not available.

Wyodak Resource Development Corp. filed suit in U.S. District Court (Wyoming) against PacifiCorp. Wyodak claims that PacifiCorp has failed to comply with the terms of a 1987 contract under which Wyodak supplies coal to the mine-mouth Wyodak generating station. Wyodak claims that they are owed $4.83 million from PacifiCorp for various coal deliveries made to the Wyodak plant in 2000. PacifiCorp filed a countersuit accusing Wyodak of overcharging for its coal, claiming the producer has failed to make adjustments to reflect changes in market price or other factors such as operating costs (COAL Daily, 9/28/00).

Developments in southern Wyoming

A report from Hill and Associates stated that coal demand from southern Wyoming will be static for the next ten years and decline after that. According to the report, the region is very vulnerable competitively because of the inroads subbituminous coals from the PRB have made into the traditional western bituminous markets served by southern Wyoming mines. This competition and tightening of environmental factors under the second phase rules of the Clean Air Act will continue to squeeze southern Wyoming coal prices (COAL WEEK, 9/18/00).

Black Butte Coal Company will explore 2559 acres within the Rock Springs tract in Sweetwater County. The parcel is located next to Black Butte's northwestern boundary. Permission for the work came from the U.S. Bureau of Land Management (COAL Daily, 8/1/00).

At the MinExpo International 2000 convention in Las Vegas in October, two Wyoming mines were honored with the coveted Sentinels of Safety awards, cosponsored by the National Mining Association and the Mine Health and Safety Administration. Pittsburg & Midway Coal Mining Company's Kemmerer mine received recognition for working 513,301 man-hours the past year without a lost-time accident or fatality. Kennecott Energy's Cordero mine in the PRB was also honored, having worked 814,451 man-hours without a lost-time accident or fatality.

Chevron Corporation's third quarter filing with the Federal Securities and Exchange Commission revealed that Pittsburg & Midway Coal Mining Company (P&M) posted an operating loss of $3 million. P&M's earnings also were down for the first three quarters of 2000, decreasing from $29 million in 1999 to losing $2 million this year. Chevron blamed the poor earnings in large part to the lengthy United Mine Workers of America strike at their Kemmerer (Wyoming) and McKinley (New Mexico) mines.

On July 29, 2000, an accident at the Black Butte mine claimed the life of a 45-year-old haul truck driver. The driver, a mine employee with 9 years of mining experience, lost control of a loaded coal haul truck and traveled through the berm along the haul road. The victim, believed to not be wearing a seat belt, was thrown from the cab and received fatal head injuries. This was the first reported fatality from a Wyoming coal mine this year and the 17th coal mine fatality for the nation.

On September 19, 2000, a 33-year-old mechanic with 8 years of mining experience was fatally injured while changing a track on a D11N Caterpillar bulldozer at the Jim Bridger mine. The fatal injury occurred when a set of chains holding the bulldozer off the ground broke loose and one of the chain hooks hit the mechanic in the head. The injured man was air lifted to a hospital, but died of his injuries on September 25. This was the second fatal coal mine fatality in Wyoming and the 29th fatality for the nation's coal mining industry in 2000.

These two fatalities have made this one of the worst years in recent history for Wyoming mining safety. Last year there was only one mining fatality in the state. These dreadful reminders should reemphasize the importance of keeping safety in the forefront of each mine employee's thoughts.

Transportation developments

On September 27, 2000, the Surface Transportation Board (STB) released the Draft Environmental Impact Statement (DEIS) covering the Dakota, Minnesota & Eastern Railroad's (DM&E's) proposed $1.4 billion, 278-mile-long build into the PRB. The DEIS makes recommendations on several of the plan's construction and refurbishment proposals, as well as several recommended routings of the line. In a key decision, the STB's Section of Environmental Analysis (SEA) recommended approval of new construction in parts of South Dakota and Wyoming. The modified route would enable the expansion project to avoid environmentally sensitive areas located along the Cheyenne River.

The STB will take comments on the DEIS for 90 days following its release date. Consisting of over 2000 pages covering a wide range of environmental issues, alternates, and recommended environmental mitigation issues, the document is available for viewing on the STB web site at www.stb.dot.gov (COAL Daily, 9/28/00).

The U.S. Department of Agriculture (USDA) sent a letter in early September supporting the DM&E build in, expressing their expectation that the new rail line will be a positive boost to agricultural shippers. The USDA stated that the rail project's proposed upgrades and new construction are necessary for economic expansion of agricultural markets. The USDA also stated that the project will "improve farm income, boost rural economic development and reduce pressure and deterioration on local roads" (COAL Daily, 9/20/00).

Triton Coal Company's North Rochelle mine has signed a contract with Rail Link, Inc. for coal loading services at its mine in the PRB (COAL Daily 8/31/00). Rail Link will help in the efficient movement of trains in and out of the mine. Rail Link also provides third party loading service to Peabody's North Antelope/Rochelle mine complex and Kennecott's Antelope mine.

A train derailment near Bill closed all three main lines in the eastern PRB for approximately 18 hours in early September (COAL Daily, 9/15/00). A loaded Burlington Northern-Santa Fe (BNSF) unit train derailed nine coal cars while heading east on main track number one. A loaded Union Pacific (UP) train crossing from main track number three to main track number two collided with the derailed BNSF cars, causing derailment of two locomotives and two coal cars on the UP train. The result of the accident fouled all three main tracks, but no major injuries were reported.

As PRB coal prices appear to be turning around and getting modestly stronger, UP announced it was hiking rates on all traffic, including coal (COAL Daily, 9/11/00). UP cited "rapidly changing market conditions" plus labor and fuel increases as causes. While the majority of the rate increases are being laid at the feet of higher fuel costs, the company said that the increases are not likely to be lowered in the future even if fuel prices recede. According to UP, the rate hikes were designed to enable the railroad to continue to make improvements in their rail network.

Regulatory developments

The Department of Energy (DOE) is contributing $5.5 million to two research projects aimed at better mercury control for coal-fired power plants. Each of the partners in the project will supply approximately $3 million each to their prospective projects.

McDermott Technology's affiliate, Babcock & Wilcox, will test ways to increase mercury reduction using "wet scrubbers" currently used in many plants to lower sulfur emissions. ADA Environmental Solutions will test a portable system that works with a plant's baghouse or electrostatic precipitator to remove particles from the plant's exhaust gas (COAL WEEK, 10/21/00).

Market developments and opportunities

Kennecott Energy Company launched a new web site featuring online spot coal purchasing and other features. Currently in beta-testing, the site (www.kennecottdirect.com) will let customers track their coal shipments, obtain data about Kennecott's coal products, and communicate with the coal company's sales staff. In addition, the site will offer limited spot coal sales based upon short-term coal availability at each of Kennecott's mines.

Black Hills Corp. announced on September 27, 2000 that it is advancing the construction schedule for its Wygen #1 facility. The new 80-megawatt (MW) coal-fired plant is being built next to the company's Wyodak mine near Gillette. Started in the third quarter of 1999, the new plant will be operational sometime in 2003. The plant will consume nearly 0.5 million tons of coal per year from the nearby Wyodak mine. The coal will be transported from the mine to the plant by conveyor (Coal Daily, 9/28/00).

Consolidated Engineers and Materials Testing (CE&MT), located in Gillette, won a Tibbetts Award from the U.S. Small Business Administration (SBA) for the company's work in transforming bottom ash into a useful product (Casper Star-Tribune, 10/9/00). CE&MT has developed a way to turn the bottom ash from coal-fired utilities into an aggregate suitable for pavement repairs. Tibbetts Awards go to small companies that show high achievement in technology development in the SBA-sponsored Small Business Innovation Research Program.

Table 17 tabulates some of the contract, spot sales, test burns, and solicitations for Wyoming coal, announced during the third quarter of 2000.

References cited

Federal Energy Regulatory Commission (FERC) Electric Form 423 (http://www.ferc.fed.us/electric/f423/form423.htm).

Stauffenberg, D.G., 2000, Annual report of the State Inspector of Mines of Wyoming for the year ending December 31, 1999: Office of the State Inspector of Mines, Rock Springs, 79 p.

Table 17. Marketing activities for Wyoming coal producers during the third quarter of 2000*.

	Utility	Power plant	Coal mine/region	Activity	Tonnage	Comments
1.	Aliant Energy	Columbia	PRB	C	3.5 to 4.5 MM t	Suppliers not identified. 3.5 MM t in 2001 and 4.5 MM t in 2002 through 2003.
2.	American Electric Power Energy Services	System	PRB	So	unspecified	Delivery late 2000 and early 2001. Greater than 8300 Btu/lb.
3.	Consumers Energy	System	PRB	Sp	800,000 t	Delivery July through December, 2000.
4.	Dairyland Power Coop.	System	PRB	So	1.65 MM t	Delivery in 2001, coal with minimum of 8300 Btu/lb.
5.	Dynegy Inc.	various utility customers	PRB	So	up to 4 MM t/y	Delivery begins in 2001, continues through 2005.
6.	FirstEnergy Corp.	System	PRB	C	500,000 to 1.5 MM t	FreeMarets on-line 500,000 t in 2001, 1 MM t in 2002, and 1.5 MM t in 2003 through 2005.
7.	Ontario Power	Nanticoke	Triton and Powder River Co./PRB	Sp	2.5 MM t	Delivery in 2001. After winter burn utility will consider 2002 and 2003 year needs.
8.	PacifiCorp	Dave Johnston	Dry Fork/ Southern Co./PRB	C	3.0 MM t	Split between Dry Fork mine and Southern Energy Marketing whose source is not identified.
9.	Portland General Electric	Boardman	Buckskin/PRB	C	1.9 MM t	Delivery in 2001 with option to take up to 2.1 or as little as 1.4 MM t.
10.	PP&L Generation LLC- Montana	Corette	Eagle Butte/PRB	C	700,000 t	Delivery in 2001.
11.	Salt River Project	Craig	Colorado or PRB	So	600,000 t	Delivery in 2001.
12.	Western Fuels Assn.	Laramie Plant	PRB	So	925,000 t	Delivery in 2001.

*Data obtained from: COAL WEEK, Coal Daily, Coal Age, FERC database, and personal contacts. Note: C = contract; Sp = spot coal; So = solicitation; MM = million; t = short ton; t/y = short tons per year; and PRB = Powder River Basin. Wyoming State Geological Survey, October, 2000.

COALBED METHANE UPDATE

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The Consensus Revenue Estimating Group (CREG) now projects coalbed methane production separately (**Table 18**) as a segment of total natural gas production in the state. Coalbed methane is expected to account for 9.6% of Wyoming's total natural gas production in 2000; by 2006 it will account for 23.6% of Wyoming's total (**Table 18**). Coalbed methane production and the number of producing wells have increased dramatically over the last 11 years (**Figure 16**). Production of coalbed methane had reached 61.8 billion cubic feet (BCF) through the first six months of 2000 and there were 2908 producing and 2009 shut-in wells by June, 2000.

Table 18. Wyoming coalbed methane production and producing coalbed methane wells (1989 through 1999) with production forecasts to 2006.

	Calendar Year	Production (billions of cubic feet)	% of total natural gas production	Number of producing wells
ACTUAL	1989	.9	0.10	20
	1990	.7	0.08	30
	1991	.9	0.09	52
	1992	.9	0.09	51
	1993	1.1	0.10	121
	1994	2.5	0.23	125
	1995	5.3	0.47	152
	1996	8.8	0.75	174
	1997	14.0	1.17	363
	1998	30.6	2.50	649
	1999	58.1	4.49	1673
FORECAST	2000	135.0	9.64	
	2001	190.0	12.81	
	2002	250.0	15.89	
	2003	300.0	18.14	
	2004	350.0	20.14	
	2005	400.0	21.94	
	2006	450.0	23.57	

Wyoming State Geological Survey, November, 2000.

The Bureau of Land Management (BLM) is preparing a Drainage Environmental Assessment (EA) that will allow up to 2500 new coalbed methane wells on federal oil and gas leases. Federal coalbed methane is currently being drained by wells on adjacent state and fee land; some estimate the Federal Government may be losing as much as $20,000 per day in royalties due to drainage and thus, the State of Wyoming may be losing as much as $10,000 per day since it is entitled to half of those federal royalties. Although over 50% of the oil and gas estate in the Powder River Basin (PRB) is federally owned, there were only 614 completed coalbed methane wells on federal land through June, 2000. In contrast, there were 3635 wells completed on fee (private) land and 668 wells completed on state land. A Record Of Decision (ROD) from BLM is expected in January, 2001.

Phillips Petroleum Co. acquired the coalbed methane properties of three unidentified companies in the PRB. These acquisitions will increase the company's gross acreage position in that basin by 90,000 acres, with Phillips as operator with more than a 90% working interest. Phillips now has 430,000 gross acres in the PRB, including the 50% interest in the acreage the company acquired from Yates Petroleum Corp. Phillips plans to drill more than 500 wells in 2001.

Wyoming Oil & Minerals Inc. announced that Phillips Petroleum acquired a 50% interest in its Slater Dome/Coal Bank Draw prospect (**location A, Figure 9**) in Colorado and Wyoming. With this transaction, Wyoming Oil & Minerals now owns a 16.7% interest, Phillips owns 50%, and Skyline Resources owns 33.3% interest in the 16,000-acre coalbed methane prospect. Phillips has been designated as the operator of the project and has drilled the first three of eight wells in the pilot drilling program that will be completed later this year. These first wells encountered gas in several coal beds in the Mesaverde Group. The partners anticipate that the wells will be tested after all eight wells are drilled and the water disposal system is installed. If the pilot program is successful, Phillips plans to drill 16 development wells and construct a pipeline in 2001 and drill an additional 32 wells in 2002.

Barrett Resources Corp. has staked six 3600-foot-deep tests of Hanna Formation coal beds in an area about 7 miles northeast of the town of Hanna (**location B, Figure 9**). The tests are scheduled for sections 13, 23, and 24, T23N, R81W, and will offset a well already drilled. The 1 Hanna Draw Unit well in SW SW section 13, T23N, R81W, was drilled in July, but no details have been released by Barrett. The area is within 2 miles southeast of Metfuel's coalbed methane project in the early 1990s.

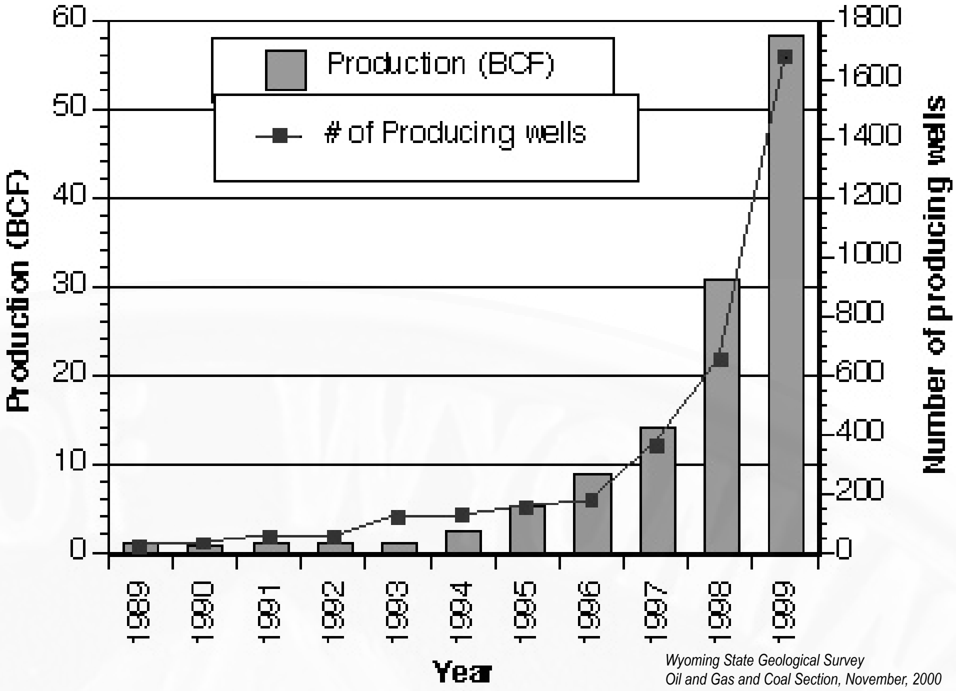

Figure 16. Wyoming coalbed methane production and number of producing wells (1989 through 1999).

Dudley & Associates, LLC. staked three new wildcat wells for coalbed methane in an area about 18 miles northeast of Rawlins and 20 miles northwest of Sinclair in section 3, T23N, R85W, and in section 33, T24N, R85W (**location C, Figure 9**). The tests are all expected to reach total depth in the Fox Hills Sandstone. Dudley could potentially develop 19 wells and construct a pipeline to Sinclair. The area covers 8320 acres, of which 4240 acres are federal surface and mineral estate. The BLM will prepare an EA on the proposal; however, the analysis may require an environmental impact statement (EIS) if the EA concludes that significant issues or impacts are present.

ESTIMATES OF COAL VOLUMES AND COALBED METHANE IN PLACE, POWDER RIVER BASIN, WYOMING

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This study estimates the potential gas resource in coal beds of the Powder River Basin (PRB), Wyoming based on an extensive database developed by Goolsby & Associates, LLC. A previously published estimate of approximately 12 trillion cubic feet (TCF) of coalbed methane gas in place was based on work by the U.S. Geological Survey. A new estimate presented here indicates that there are approximately 587 billion tons of coal and 38.2 TCF of coalbed methane gas in place in coal beds that are thicker than 20 feet and deeper than 200 feet. Using a recovery factor of 67% results in an estimate of 25.6 TCF of recoverable gas reserves.

Publication of the study was requested by the Wyoming State Geological Survey (WSGS) and the Wyoming Oil and Gas Conservation Commission (WOGCC). This report is provided as documentation for the new resource and reserve numbers now being used.

The authors and Goolsby & Associates, LLC., are solely responsible for the conclusions and results of this study. The State of Wyoming, including the WSGS and WOGCC, assumes no responsibility or liability for the opinions, results, or conclusions presented herein.

Methodology

Resources and reserves of coalbed methane can be calculated by determining the tonnage of coal in place, applying known or estimated gas contents to the coal tonnage to obtain gas resources in place, and then applying a recovery factor to determine reserves. Coal tonnage is determined by first calculating the volume of coal, which is the area (usually in acres) underlain by a coal bed (or beds) multiplied by its thickness (usually in feet, as determined from geophysical logs of drill holes). The lateral extent (area) of a coal bed can be determined by correlating numerous well logs in the vicinity and making maps of its thickness. The volume of coal is then converted to a tonnage (weight) by factoring in the density of the coal (expressed as tons per acre-foot of coal), which has been determined empirically for the rank of the coal.

Gas content of the coal, usually expressed as standard cubic feet per ton of coal, is taken from empirical measurements of coal cores, possibly from mud logging methods, and estimates from production data. This value, especially for coal beds in the PRB, is probably the most variable and poorest known part of the resource estimation procedure. The gas in place is then converted to reserves by estimating the recovery factor (a percentage). This factor is related to production and economics, usually obtained from companies that have been producing the coalbed methane. The sections below describe in more detail how this methodology was applied to coalbed methane occurrences in the PRB, Wyoming.

Coal tonnage estimate

The estimated volume (converted to tonnage) of coal that may contain coalbed methane in the area of this gas play is based on a coal database generated by Goolsby & Associates, LLC. Much of this database was prepared and completed at the request of Devon Energy Production, Inc. This database contains coal data from more than 8500 drill holes and covers over 4 million acres in the Wyoming part of the PRB (**Figure 17**). The coal correlations and mapping program used for this study are from Goolsby and Finley (2000). Currently, coal beds 20 feet thick or more are generally accepted by industry as necessary for the economic production of coalbed methane in the area. Also, it is generally accepted that coal beds less than 200 feet deep have already been de-pressured and much of the gas has escaped to the atmosphere. After excluding drill holes with no coal bed greater than 20 feet thick in a single seam and coal beds less than 200 feet deep, the analysis was completed using data from more than 6500 drill holes.

This data was used to generate three sets of maps for estimating coal volume and resultant tonnage: one set for coal beds over 20 feet thick at different depths, one set for coal beds over 20 feet thick found only in wells that penetrated the entire coal section, and one set for all coal beds of any thickness found only in wells that penetrated the entire coal section. The first set of maps consists of coal beds over 20 feet thick lying at depths between 200 and 500 feet, 500 and 1000 feet, 1000 and 1500 feet, and deeper than 1500 feet, respectively. This breakdown by depth intervals is necessary to apply varying gas contents, which are controlled by pressure. Coal volumes and tonnages were then calculated for each interval. Utilization of this data set resulted in a total calculated coal tonnage of 479.45 billion short tons (**Table 19**). Coal tonnage is underestimated because many of the drill holes used in this data set only logged a part of the coal interval. Many drill holes, especially those for oil wells, were only logged over the lower part of the coal section (below surface casing) while most drill holes exploring for coal or coalbed methane only drilled and logged through the upper part of the coal section (**Figure 18**). This results in a conservative estimate of tonnage because of the exclusion of coal.

The second map set uses only drill holes that logged the entire coal section (**Figure 18**). Only 1900 drill holes were logged through the entire coal section and contain coal beds over 20 feet thick. Although this data set has less than one-third of the wells in the previous set, the tonnage estimates are much more accurate because the entire section was logged and no coal was artificially excluded in coal tonnage calculations. The total coal tonnage calculated using this method is 587.03 billion short tons (**Table 19**).

The third map set consists of total coal regardless of coal bed thickness and depth and represents upside potential tonnage. These maps were also constructed from drill holes that logged the entire section (1900 wells). Because no economic limits were placed on coal thicknesses, the total potential in-place coal tonnage from this data set is 885.38 billion short tons (**Table 19**).

The various map sets for the different assumptions above were then constructed using Geographix Version 97.6. The maps were gridded using a minimum curvature algorithm, a convergence of 3%, and a grid spacing of 1500 feet, yielding the ability to map features as small as 13 acres. These maps were then contoured using Geographix and the resulting maps checked for ac-

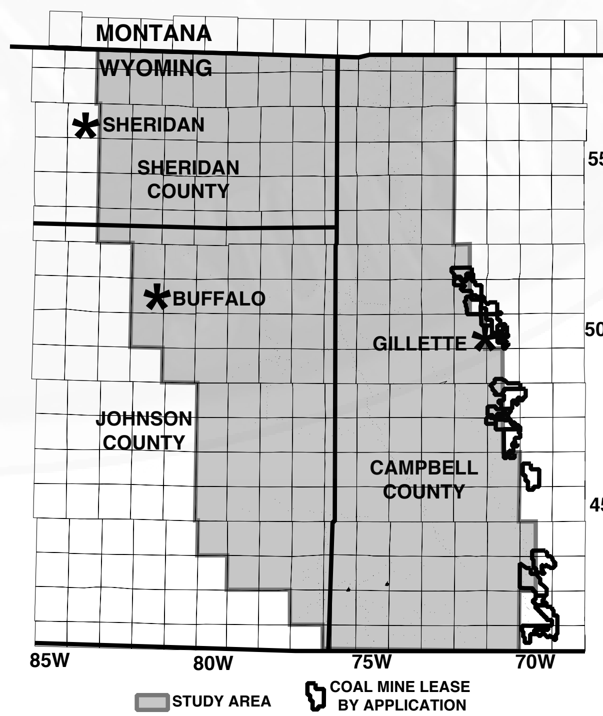

Figure 17. Study area of 4+ million acres for estimating coalbed methane resources in the Powder River Basin, northeastern Wyoming.

Table 19. Estimates of coal volumes, tonnages, and coalbed methane in place determined by three different methods for the Powder River Basin, Wyoming.

	Acre-feet	Tons (1770 tons/acre-foot)	Gas content (SCF/ton)	Gas in place (SCF)
		VOLUME OF COAL > 20' THICK BY DEPTH		
200-500'	28,880,442	51,118,382,340	20	1,022,367,646,800
500-1000'	48,721,045	86,236,249,650	45	3,880,631,234,250
1000-1500'	108,811,674	192,596,662,980	70	13,481,766,408,600
>1500'	84,462,594	149,498,791,380	90	13,454,891,224,200
TOTAL	**270,875,755**	**479,450,086,350**		**31,839,656,513,850**
		VOLUME OF TOTAL COAL > 20' THICK		
TOTAL	**331,656,190**	**587,031,456,300**	**65**	**38,157,044,659,500**
		TOTAL COAL VOLUME		
TOTAL	**500,217,225**	**885,384,488,250**	**65**	**57,549,991,736,250**

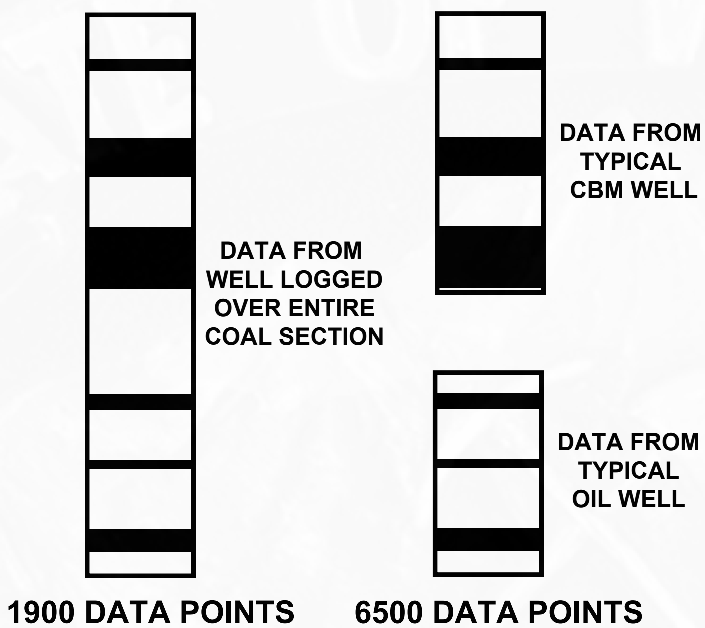

Figure 18. Data bias (underestimation of coal) in coalbed methane data sets due to drilling and well logging practices.

curacy. Although some data problems existed, these were corrected and the resulting gridded data very closely matched the actual thickness data. At this point, coal volumes for each map were generated using the Geographix volumetrics package and converted to coal tonnage using 1770 tons per acre-foot for subbituminous coal. The results of the calculations are summarized in **Table 19**.

Gas in place estimate

In order to use reasonable gas content values for this estimate, the U.S. Bureau of Land Management provided Goolsby & Associates, LLC. with all of the currently available public (non-proprietary) gas content data. However, the amount of this data is very limited and the accuracy of the gas content values are suspect. Instead, we used what appears to be reasonable gas content estimates for different depth intervals based on currently accepted values within the industry (**Table 19**). Using these gas content numbers and coal volumes in each depth interval, a weighted average gas content of 65 standard cubic feet per ton (SCF/ton) was calculated for coal beds at all depths and all thicknesses. After reviewing the gas contents with a number of operators active in the play, it appears the gas contents used in this estimate are somewhat conservative although reasonable. Using the three coal tonnages determined in the previous section, the gas in place was then determined (**Table 19**).

Conclusions

The PRB coalbed methane play has become an extremely important gas resource over the past several years. Because of the large number of oil, gas, and coalbed methane wells drilled in the basin, a reasonable estimate for the amount of producible coal can be made. Using the most accurate estimate of coal in place (from 1900 data points), a gas content of 65 SCF/ton over the entire coal interval, an economic cutoff considering only coal beds with over 20 feet of producible thickness, and an overburden thickness of at least 200 feet, the play appears to have probable reserves of approximately 38.2 TCF of gas in place (**Table 19**). Recovery factors may vary greatly, but assuming that a recovery factor of 67% can be achieved, we estimate that more than 25 TCF of recoverable coalbed methane exists in the Wyoming part of the PRB. Government decisions will probably have the greatest effect on ultimate gas recovered.

Acknowledgements

The authors and Goolsby & Associates, LLC. thank Devon Energy Production, Inc. for allowing us to use the data we originally gathered for Devon in the preparation of this estimate. We also thank Wally Reaves for countless hours spent at the WOGCC picking coal tops and bases and Gary Winter of Associated Energy Consultants for his input while completing these estimates.

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SUBSIDENCE POTENTIAL RELATED TO WATER WITHDRAWAL IN THE POWDER RIVER BASIN

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Recent concerns have been raised about the potential of coalbed-methane-related water withdrawal in the Powder River Basin (PRB) to induce ground surface subsidence. While it is true that withdrawal of water or oil from the subsurface can cause the surface to subside, the amount of subsidence and the time over which it occurs are the most important factors in determining if measurable damage will occur.

Documented cases

A number of documented cases exist where fluid withdrawal has caused ground subsidence. One of the most famous cases is Mexico City. The city is directly underlain by unconsolidated and saturated lacustrine (fresh water lake) clays. Beneath the clays are thick saturated deposits of unconsolidated sand and gravel beds interbedded with clayey silts. The primary water for the city is derived from the sands and gravels, and when water is pumped from them, the overlying clays are slowly dewatered (Figueroa Vega, 1984). The porosity (volume of voids divided by the total unit volume of soil or rock) in the unconsolidated clays is high, and when water is removed they can compress significantly. There had been so much water pumped from the sand and gravel beds that between 1940 and 1960, the resulting dewatering and compression of the overlying clays led to as much as 27 feet of ground surface subsidence (Poland, 1984).

In the United States, ground surface subsidence related to fluid withdrawal has been documented at a number of localities. The best known localities include the San Joaquin Valley in California; Las Vegas, Nevada; New Orleans, Louisiana; and Houston, Texas. The common geological tie between the sites is that all are underlain by saturated, unconsolidated sands and gravels with interbeds and/or overlying beds of saturated clays. Water or oil is being removed (pumped) from the sands and gravels, and effects similar to those in Mexico City have been observed.

To date, no surface subsidence has been associated with other equally significant water withdrawals in the Gillette area.

Powder River Basin conditions

The geologic conditions in the PRB are not the same as those observed in the cases cited above. The bedrock underlying the surface is compacted and consolidated. Instead of loose sand, sandstone is present; instead of unconsolidated clay, shale is present. The porosity of saturated, unconsolidated clay can be as high as 88% (Poland, 1984), whereas the porosity of shale is usually in the 0 to 10% range. The porosity of unconsolidated sand is usually in the 25 to 50% range, whereas the porosity of sandstone is usually between 5 and 30% (Freeze and Cherry, 1979). As sedimentary rocks are formed and compressed, the void space, which can hold water, is decreased.

Even saturated bedrock, such as sandstone, can compress if water is removed under certain conditions. If an aquifer is buried and overlain by relatively tight shale, the aquifer is said to be confined. The weight of the overlying rock and the fluids it contains is supported by both the water in the aquifer and the bedrock itself. In the case of a buried and confined sandstone aquifer, if water under pressure is removed from the sandstone, then the sandstone could be further compressed by the weight of the overlying rock and water. The degree of compression depends upon the amount of water removed (and the resultant decrease in water pressure) and upon the strength and elasticity of the bedrock (Poland, 1984). Removing the water will decrease its hydrostatic head, which is the level to which the water will rise if a well were drilled into the confined aquifer. In reality, if an aquifer is confined, the water released from storage when the hydrostatic head declines comes primarily from compression of the aquifer and to a minor extent, from expansion of the water.

Coal beds can also serve as aquifers because water can flow through fractures or cleats as well as along bedding or depositional planes within the coal. If the coal is buried, confined, and saturated, it will also compress when water is removed. Some (but not all) water is being pumped from specific coal beds in the PRB to allow for the release of coalbed methane. The water pressure in the coals has to drop below a certain level to bring about the release of the gas. If all the water were pumped from the coal, the micropores in the coal would probably close, which would stop most of the flow of methane through the coal. Coalbed methane producers try to keep enough water in the coal beds to prevent this from happening.

Compression calculations for aquifers

Hydrologists can use a relatively simple formula to estimate how much a confined aquifer may compress when water is removed. The analysis starts with an understanding of certain hydrologic parameters. The storage coefficient, S, is defined as the volume of water that an aquifer releases from storage per unit surface area of the aquifer per unit change in head (Heath, 1987). The volume of water released is for the entire thickness of the aquifer under the unit surface area. In other terms, S= (volume of water) / (unit area x unit head change).

The actual formula for calculating the amount of aquifer compression that occurs when water is withdrawn from an aquifer has been derived by Edgar and Case (2000). The change in aquifer thickness or compression (ΔB), is equal to the storage coefficient (S) times the change in head ($\Delta\phi$). In other words, $\Delta B = S \times \Delta\phi$. The storage coefficient is determined through a well monitored pump test, and the change in head is obtained by monitoring declines in water level over time. The compressibility of an aquifer decreases with increasing depth (Edgar and Case, 2000).

To summarize, in order to calculate the amount of aquifer compression that may occur, it is necessary to have data on both the storage coefficient and the head decline for the aquifer or system under investigation.

Subsidence potential for the Powder River Basin

In the coalbed methane producing areas of the PRB, a widely used storage coefficient figure for both the coals producing coalbed methane and for underlying sands providing water for the town of Gillette is 1.0×10^{-4} (Larry Wester, Wester-Wetstein & Associates Consulting Engineers, personal communication, 2000). The proposed head declines for coal beds that may be or already are being produced for coalbed methane will vary from area to area.

The Bureau of Land Management (1999) presented a series of maps that showed modeled drawdown (head decline) for a number of scenarios. In the Gillette area, the maximum modeled coalbed-methane-related drawdown for the upper Wyodak coal is approximately 150 feet. The modeled drawdown for the lower Wyodak coal is approximately 250 feet. Applying the formula above, the aquifer compression for the upper Wyodak coal would then be 0.015 feet, and the aquifer compression for the lower Wyodak coal would then be 0.0250 feet. The sum of the two compressions would equal 0.04 feet, or slightly less than 1/2 inch.

Because of the strength of materials above the coals, it is thought that only a part, if any, of the compression would be observed at the surface. It is expected that such subsidence would be uniform over the area, and would not result in significant damage. Significant quantities of water have already been pumped from sandstones underlying the Wyodak coal zone for the Gillette water supply. To date, no surface subsidence has been observed or associated with this water withdrawal. The storage coefficient of those sandstones is 1.0×10^{-4}, and the measured drawdown is approximately 400 feet (Larry Wester, Wester-Wetstein & Associates Consulting Engineers, personal communication, 2000). These data have the same values as those projected for the Wyodak coal in the Gillette area.

Summary

It appears that minor aquifer compression up to 1/2 inch may occur in the coal beds that are being developed for coalbed methane in the Gillette area. That entire compression, however, may not be transmitted to the surface. To date, no surface subsidence has been associated with other equally significant water withdrawals in the Gillette area.

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INDUSTRIAL MINERALS AND URANIUM UPDATE

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Several new quarries for construction aggregate were opened in Wyoming in the third quarter and the largest aggregate quarry in Wyoming changed hands. Two new quarries are being developed for decorative aggregate and production of dimensional stone continues. Trona production is forecast to increase, but prices continue to drop. Uranium production will increase because of closure of mills in other states but low uranium prices continue.

Internet site

Some Industrial Minerals and Uranium Section pages on the Wyoming State Geological Survey (WSGS) internet site have been revised. Pages entitled *About the Industrial Minerals and Uranium Section*, *Production Statistics*, *Uranium*, and *Decorative Stone* are revised and one new page, *Limestone and dolomite* has been added. Information on new potential dimensional stone quarry sites is also being posted (see the *Decorative Stone* page). Visit the Section's pages at: http:// www. wsgsweb.uwyo.edu/minerals/about.htm.

Construction aggregate

Construction aggregate includes sand and gravel, scoria (also known as clinker or baked and fused shale), crushed stone, shale, and other material used in construction. In the summer of 2000, several new sources of construction material were used in Wyoming. The sources included a limestone aggregate quarry opened at Plumbago Creek in Albany County and a granite aggregate quarry opened on the Khaun property in Niobrara County. The Plumbago Creek site in Albany County is described in Harris (1988). Rissler-McMurry opened the quarry and transported the material to a stockpile near State Highway 34 (**Figures 19** and **20**). Rissler-McMurry anticipates using material from this stockpile for future highway construction projects.

Nygaard Construction opened the granite aggregate quarry on the Khaun property north of Bald Butte in southern Niobrara County in mid-2000 (**Figure 19**). Material from this quarry was used in the reconstruction of the Union Pacific rail line from Van Tassel, Wyoming to Morrill, Nebraska.

On September 6, 2000, Martin Marietta Materials, Inc., of Raleigh, North Carolina, announced the purchase of Meridian Aggregates, of Englewood, Colorado. Meridian Aggregates operated the largest aggregate quarry in Wyoming, the Granite Cañon quarry west of Cheyenne in Laramie County (**Figures 19** and **21**). The granitic aggregate produced at this quarry is used for railroad ballast and general construction purposes. Geologically, the rock quarried here is quartzofeldspathic gneiss. About 10% of the aggregate used in the construction of Denver International Airport came from this quarry. Meridian Aggregates was the 10th largest producer of crushed stone in the U. S. before the sale, while Martin Marietta Materials is the second largest producer of construction aggregate in the U. S. Production of aggregate from the Granite Cañon quarry is expected to continue at current rates.

Decorative and dimensional stone

The development of a new decorative aggregate quarry continued in the third quarter of 2000. Slate Creek Stone conducted a close-spaced drilling program on the Grant Ranch property in the Richeau Hills, southwestern Platte County (**Figures 19** and **22**). The aggregate is a bluish-white to light bluish-gray marble and production is planned to begin in the fourth quarter of this year. Slate Creek Stone in cooperation with other parties is also considering opening a dimensional stone quarry in this marble on the same property.

To supply stone for the construction of a pocket park (a small area between downtown buildings) in Wheatland, a quarry was opened in a blocky quartzite at George Creek, southwest of Wheatland (**Figure 19**). The quarry site was shown to the local producer by the WSGS.

Raven Quarries (Raven), in Albany County west of Wheatland, continues to produce a pink dimensional granite called

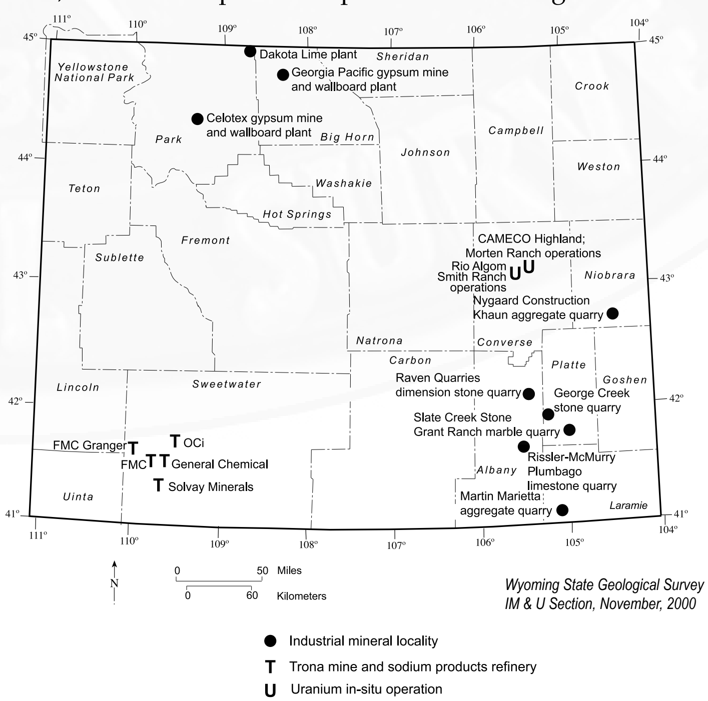

Figure 19. Index map of Wyoming showing the location of industrial mineral and uranium sites mentioned in the text.

Figure 20. Stockpile of limestone from the Plumbago Creek quarry being processed along State Highway 34, October 12, 2000.

Figure 21. Martin Marietta Materials (formerly Meridian Aggregates) granitic aggregate quarry, Granite Cañon, Wyoming, September 28, 2000. Train above benches, upper left center, for scale.

"Mirage Granite." Raven has installed a cutting facility at their quarry site on the Kennedy Ranch (**Figure 19**). In addition to shipping some blocks to Western Granite in Tijuana, Mexico and processing some slab at Strid Marble and Granite in Cheyenne (see *Wyoming Geo-notes No. 67*, September, 2000), Raven is also processing some materials on site (**Figure 23**).

Gypsum

Gypsum production in Wyoming continues, with the two wallboard plants in the Bighorn Basin, Celotex and Georgia Pacific (**Figure 19**), operating at peak capacity. There has been increased interest in Wyoming's gypsum resources during the summer of 2000. There are several areas of gypsum resources in Wyoming and the potential exists for increased production through the construction of new gypsum mines and calcining, prelling, and wallboard plants at or near the potential mine sites.

Limestone

Wyoming contains large resources of limestone. Much of the resource is chemical grade (95% $CaCO_3$ or greater). Chemical grade limestone is used as the main ingredient in cement manufacturing, as a clarifying agent in the process of refining sugar from sugar beets, and in emissions control in coal-fired power plants.

Lime (CaO) is manufactured from limestone by heating ($CaCO_3$ + heat > CaO + CO_2). Lime is used in a variety of chemical processes and is manufactured in Wyoming at Frannie (**Figure 19**) by Dakota Lime from limestone at the Warren quarry six miles northeast of the plant in Montana.

Limestone is also used as crushed stone for aggregate. Most of the limestone quarried in Wyoming is used for this purpose, primarily in highway construction for road base and as an aggregate in surfacing material.

Limestone is an underdeveloped resource in Wyoming. None of the sugar beet refining plants in Wyoming or western Nebraska currently use Wyoming limestone. The plants in the Bighorn Basin use limestone from the Warren quarry; Holly Sugar in Torrington, which is 30 miles from the Hartville quarry, uses limestone from Pringle in the Black Hills of South Dakota; and the Western Sugar plants in western Nebraska use limestone transported by

Figure 22. Reserve drilling by Slate Creek Stone at the Grant Ranch marble quarry site, Platte County, Wyoming, September, 2000.

Figure 23. Slabs processed by Raven Quarries at the quarry site in Albany County. Wireline saw (with ladder and circular drive shield) in background, October 13, 2000.

rail almost 400 miles through Wyoming from Warren, Montana.

Areas of Wyoming that contain limestone resources are shown on WSGS Map Series MS-47 (Harris, 1996). For information about this and other publications on Wyoming's mineral resources see the WSGS publications page at: http://www.wsgsweb.uwyo.edu.

Trona

The Consensus Revenue Estimating Group (CREG) revised their estimates of mined trona production upward for the years 2001 through 2006 (**Table 1**). These revisions take into account recently announced capacity increases by Solvay Minerals. Prices estimated by CREG for mined trona have been revised downward for 2000 through 2006 (**Table 2**), and in fact reverse the trend from increasing prices during those years to decreasing prices. The CREG trona prices are based on Wyoming Department of Revenue (DOR) projections. According to the DOR, the new price projections more closely reflect the forecasts made by the trona/soda ash industry.

Trona is mined by four companies at five locations in Sweetwater County, Wyoming (**Figure 19**) and processed into soda ash and other sodium-based chemicals at plants near the mines (**Figure 24**). FMC also recovers trona from water that has flooded abandoned underground mine workings. Soda ash is the ninth most widely used chemical in the United States, according to OCi Chemical Corp., one of the Wyoming producers.

Domestically, 48% of soda ash is used in making glass; 26% is used in other chemicals including sodium silicate, sodium phosphate, and sodium cyanide; 12% in cleaning agents like detergents; 3% in the pulp and paper industry; 3% in water treatment; and 8% in various other uses.

Uranium

Uranium production in Wyoming in 1999 increased almost 22% over the amount produced in 1998, according to figures released by the Wyoming State Inspector of Mines. The 1999 production was 2,760,255 pounds of yellowcake. All of Wyoming's uranium is produced by *in situ* methods at two localities in Converse County (**Figure 19**). Wyoming remains the nation's leader in uranium production.

Figure 24. Solvay Minerals soda ash refining plant west of Green River. The strucure at the right of the photograph is the headframe that provides access to the mine workings 1600 feet below the surface. (Photograph by Solvay Minerals, 1998.)

There are only four localities that produce yellowcake in the U.S. Besides the two Wyoming sites, yellowcake is produced by *in situ* processes at Crow Butte in western Nebraska and by conventional milling at Cañon City, Colorado. Uranium production has recently ceased in New Mexico and southern Texas.

Because the uranium mills in New Mexico and Texas are now closed, uranium production at Wyoming's two remaining *in situ* recovery plants should be higher than previously estimated. Although domestic uranium production is on the decline, these closures shift some of the total domestic production to the remaining plants, particularly the two Wyoming operations and the Crow Butte operation in western Nebraska. CREG raised projected Wyoming uranium production by 0.7 million pounds in 2000 and by 0.4 million pounds annually from 2001 through 2006 (**Table 1**).

The spot market price of yellowcake continued to fall during the second quarter of 2000. At the end of the quarter, the price according to the Uranium Exchange web site (http://www. uxc.com/top_review.html) was $7.45 (**Figure 25**), the lowest since September, 1995. The price drop is due to international purchases of Russian uranium from stockpiles and the decommissioning of uranium-based weapons. Russia and other countries of the former Soviet Union continue to sell yellowcake on the world market at US$6.75 per pound, according to the Uranium Exchange.

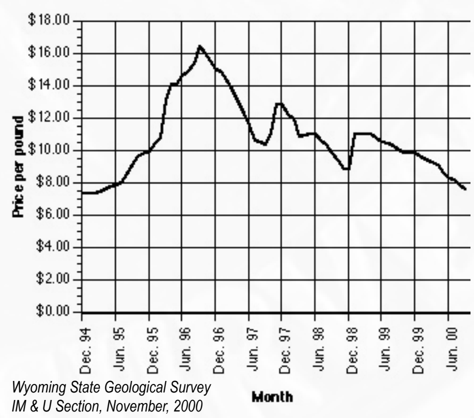

Figure 25. Spot market yellowcake prices, as of September, 2000. Source: Uranium Exchange weekly reports.

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METALS AND PRECIOUS STONES UPDATE

W. Dan Hausel
Senior Economic Geologist-Metals and Precious Stones, Wyoming State Geological Survey

Exploration for platinum group metals (PGMs) in Wyoming is the most significant activity in metals, with a major PGM province located in southeastern and south-central Wyoming. The **ROCK HOUNDS CORNER** describes PGM mineralogy and occurrences in this province and throughout the world. An iolite occurrence in the Laramie Mountains is attracting some interest and diamond research has slowed in the Iron Mountain district.

Platinum group mineralization

The rush for PGMs continued throughout the third quarter, with many new mining claims being staked for platinum-group mineralization. The activity will undoubtedly continue all winter long.

During the past few months, the Metals and Precious Stones Section responded to several requests for information from companies, consultants, and prospectors related to PGM occurrences. A summary of the Wyoming platinum-palladium-nickel province was recently published by Hausel (2000a), and an abstracted summary of this paper is located on the Section's web site at http://www.wsgsweb.uwyo.edu/metals/platinum/index.html.

Nearly 2000 mining claims were reportedly staked during the past year for platinum-group mineralization in Wyoming. Exploration activity included stream sediment sampling, soil and rock sampling, and some airborne geophysical surveys. Companies with interest in the region include Cowboy Exploration, Donnybrook Resources, Encampment Resources, General Minerals, Trend Mining Company, and Ursa Major International, as well as some consultants and prospectors. Also, some major mining companies and investors have been showing interest in the activity.

A potentially significant discovery was recently announced by Ursa Major International near the historical New

Continued on next page.

ROCK HOUND'S CORNER: PROSPECTING FOR PLATINUM

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Several prospectors and rock hounds have recently contacted the Metals and Precious Stones Section of the Wyoming State Geological Survey (WSGS) about where to find platinum-group metals (PGMs). PGMs are the most precious of the precious metals, and the geology of Wyoming suggests that significant amounts of these metals may be found in the state.

The PGMs (platinum, palladium, rhodium, ruthenium, osmium, and iridium) are important precious metals. Their value resides in the fact that they are rare. Prices on October 26, 2000 were $585 per ounce for platinum (Pt), $763 per ounce for palladium (Pd), and $1775 per ounce for rhodium (Rh)–all considerably higher than silver (Ag) or gold (Au). More than 90% of the PGMs worldwide are currently mined in South Africa and Russia. Some are also mined in Canada and the U.S.

PGMs are closely associated with dark, ultramafic rocks with high magnesium content, particularly those that are enriched in olivine, such as peridotites. A peridotite is a greenish rock composed almost entirely of olivine with small amounts of pyroxene. Peridotites alter to serpentine; thus, when prospecting for platinum, the prospector should investigate all rocks described as "ultramafic," "peridotite," "pyroxenite," or "serpentinite" as well as rock groups described as "mafic complexes" or "gabbroic complexes" on geologic maps.

Like Au, PGMs are heavy, and are often found as flakes or nuggets in streams. PGM placers have been found at Goodnews Bay, Alaska; Tulameen, British Columbia; Douglas Creek, Wyoming; Trinity River, California; and Choco, Columbia. Periodically, a few mercury-coated gold nuggets are found in Douglas Creek that are mistaken for platinum. These nuggets are distinctly bright and shiny, unlike Pt. If you cut an amalgamated (mercury-coated) gold nugget, the core will be gold-colored, while the surface remains brightly silver.

In lodes, PGMs have been identified in sulfide minerals such as sperrylite or may occur as impurities in some copper-sulfide minerals such as covellite. Pure Pt is very heavy (21.5 times heavier than water). However, most natural Pt ranges from 14 to 17 due to impurities. One common impurity found in Pt is iron and when found in sufficient amounts, it may cause the Pt to be weakly magnetic.

Continued on page 27.

Rambler copper-palladium-silver-platinum-gold mine in the Medicine Bow Mountains. According to STOCKWATCH (September 13, 2000):

> *. . . significant palladium-platinum-copper was discovered in the Mullen Creek complex in the Medicine Bow Mountains by Ursa Major International. Eleven samples collected over a strike length of 1,500 feet, 1.8 miles west of the historic New Rambler Mine, assayed 10.97 gm/t to 89.22 gm/t (0.39-3.15 opt) palladium, 3.23 to 20.24 gm/t (0.11- 0.71 opt) platinum, and 2.92 to 32.5% copper.*

Although the source of the mineralization was apparently not identified, 1500 feet of high-grade mineralization along strike, even as float, is significant. This trend may be even longer when mineralization at nearby properties is also included (see McCallum and Orback, 1968).

The Centennial Ridge district is another area that we anticipate will receive some exploration activity in the near future. The Centennial Ridge district was initially developed as a gold district, but platinum-group mineralization was reportedly discovered later, which gave the district a short rebirth in the early 1900s (McCallum, 1968; Hausel, 2000b). Since then, very little work has occurred in the district. Also see material on this page of the Section's web site: http://www.wsgsweb.uwyo.edu/metals/cent/index.html.

This fall, the WSGS conducted field reconnaissance in the district and collected a group of anomalous samples. One of the samples, collected from the Golden Eagle prospect on Centennial Ridge, was highly anomalous and assayed 6.9 ounces per ton gold.

One of the samples, collected from the Golden Eagle prospect on Centennial Ridge, was highly anomalous and assayed 6.9 ounces per ton gold.

Trend Mining Company announced in an October 26, 2000 press release, that they had expanded their holdings in the province and had staked 42 lode claims on mafic rocks adjacent to their Lake Owen and Albany properties in the Medicine Bow Mountains. According to the press release:

> *. . . the Spruce Mountain project hosts highly anomalous PGM (platinum-group metals) mineralization interpreted to be geologically similar to areas which have produced platinum and palladium in the past. Spruce Mountain is situated near the northwestern margin of the Lake Owen layered mafic-ultramafic complex and is surrounded to the north by the New Rambler and Centennial mining districts, and to the west by the Mullen Creek mafic-ultramafic complex.*
>
> *The claim block is located on a reported PGM occurrence within mafic intrusives along an interpreted northwest to east-west trending structural zone. The area is characterized by intense shearing and hydrothermal alteration, which apparently concentrated the PGM's from the surrounding mafic host rocks.*
>
> *Geochemical samples collected in the past revealed highly anomalous PGM mineralization as reported by Loucks (1976). Loucks reported that near the eastward termination of the Albany-Cuprite fault, a gentle swerve in the fault trend is accompanied by broadening of the shear to form a lens of sub-mylonitic to mylonitic quartzo-feldspathic gneiss approximately 100 feet wide and a quarter mile long. In surface exposures, the sheared lens is developed entirely within quartzo-feldspathic gneiss. Prospect pits along the eastern end of the sheared lens have exposed several small, weakly mineralized quartz seams. A few samples comprised mainly of secondary Cu sulfides, malachite, limonite, and a little pyrite were collected from on the prospect pits. Two samples were assayed and yielded extraordinary concentrations of platinum and palladium, silver, and significant amounts of gold and nickel. The combined average of the two samples assayed, as reported by Loucks, returned values of 23 ppm Pt, 16 ppm Pd, 56 ppm Ag, 1.6 ppm Au, 11% Cu, and 250 ppm Ni. The company believes Spruce Mountain is situated in one of the most prospective PGM-bearing districts in North America with the potential to discover high-grade, economic PGM mineralization within this broad, geologically favorable zone.*
>
> *Last month Trend Mining Company announced that it has substantially increased its land position at the Lake Owen Platinum Group Metal Project in Albany County, Wyoming. Trend located 407 additional claims between March and June 2000, bringing the total number to 606 unpatented lode claims covering over 12,000 acres.*

The reference to Loucks (1976) is included in the ***References cited*** at the end of this article.

Gemstones

The Section continued to investigate the iolite-gneiss deposit it discovered in 1995 (Hausel and Sutherland, 2000). Mapping by Hausel showed the iolite gneiss cropping out over a strike length of 200 feet, and disappearing along trend to the west and east. However, the discovery of detrital iolite grains 300 feet upslope suggests that the deposit is probably more extensive. Based on the discovery, a Colorado company recently filed claims on the occurrence.

Iolite (also known as dichroite) is a transparent, sapphire-blue, cordierite. This alumino-silicate is rarely found as a gemstone, but when it is of gem quality, the stone forms transparent blue gems with distinct pleochroism. The pleochroism results in iolite gems appearing to change color depending on the angle from which they are viewed. In one direction, the iolite will appear sapphire-blue; when rotated, it will change to a light grayish-blue.

Several iolite grains were recently recovered from the deposit by the WSGS. These weighed 1.5, 6, 11.5, 13.5, 14, 63.5, 109.5, 308.5, 887, and 2948 carats respectively. The larger stone required the use of a postal scale to weigh. Samples of iolite gneiss containing as much as 20% iolite were also found on the deposit.

The iolite deposit also has the added attraction of corundum-bearing kyanite schist. This schist continues along trend for 1000 feet. Corundum is abundant, and includes translucent and transparent white and pink sapphire and red translucent ruby, as well as deep blue kyanite crystals.

Research in the Iron Mountain kimberlite district continued at a slow rate due to funding cuts for this project. Several hundred pounds of material collected last summer are still being processed as time permits. Other sample concentrates are scheduled for examination when possible. A preliminary report on the district was recently published (Hausel and others, 2000). The data collected so far suggests that the district should contain low ore-grade diamond resources (Hausel, 2000c).

Section notes

Following the loss of funding for the Section's diamond project, Wayne M. Sutherland went to work as a part-time consultant on a diamond project north of Laramie; Woody Motten, former contract geologist, was working out of his home in Casper and plans to travel to Yemen for work in the spring; and Rachael Toner secured employment with Western Research Institute in Laramie.

Robert W. Gregory, Laboratory Technician for the WSGS, has continued his research on samples collected during the diamond project. Samples of diamond indicator minerals are being chemically tested on an electron microprobe in the Department of Geology and Geophysics at the University of Wyoming. As time is available, he is also processing samples of kimberlite on the Survey's grease table in an attempt to extract diamonds (see the Section's web site for more information and updates: http://www.wsgsweb.uwyo.edu/metals/metals.htm).

The author continued to compile data on the diamond project for a summary report on the state's diamond potential. The Wyoming craton apparently has the highest potential in the U.S. for the discovery of significant diamond deposits associated with kimberlite and possibly with lamproite. The Section is working with the U.S. Forest Service on a summary of mineral potential in the Medicine Bow National Forest. Other projects include a study of international diamond deposits, a study of Wyoming's PGM occurrences and the geology favorable for them, a prospector's guide to the Medicine Bow National Forest, and a report on the Leucite Hills lamproite field. This field was mapped a few years ago, along with controlling fractures that trend perpendicular to the axis of the Rock Springs uplift. The report on this rare field of volcanics will include the Section's mapping, geochemical, and petrologic work.

The Wyoming craton apparently has the highest potential in the U.S. for the discovery of significant diamond deposits associated with kimberlite and possibly with lamproite.

The author was recently notified that his work in geoscience will be highlighted in the 55th edition of *Who's Who in America* scheduled for publication in 2001. Earlier this year, he was included in *Who's Who in Science and Engineering*, *Who's Who in the West*, and *Who's Who in the World*.

Book review

Wyoming State Geological Survey Report of Investigations 53, "Diamonds and mantle source rocks in the Wyoming Craton with a discussion of other U.S. occurrences" received a very favorable review in the Fall, 2000 (vol. 36, no. 3) issue of *Gems and Gemology*, A.A. Levinson summarized, "*....this is the most complete compilation of its kind.*"

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Rock Hound's Corner, continued from page 24.

Platinum is malleable, tough, and bluish-gray (steel-colored). It has a very high melting point, and is not affected by an ordinary blowtorch. It has a hardness of 4 to 4.5, and produces a shining silver streak when scratched by a knife. Pt and Pd may also occur as impurities in Au, producing what is known as white Au. Unlike amalgamated Au, white Au will have a consistent color throughout the nugget.

Layered mafic complexes

Major PGM deposits are found in layered mafic complexes. The better-known deposits are the Bushveld of South Africa and the Stillwater of Montana. These complexes have cyclic layers that are difficult to recognize. Many of the layers display cumulate texture, which gives the rock a bedded, granular appearance (similar to sandstone). However, unlike sandstone, the rock has no primary quartz.

Cumulate layers are thin but may be persistent for several miles. They are thought to have formed when minerals crystallized in a cooling magma and settled out under gravity, accumulating on the floor of a magma chamber. The initial mineral to crystallize from the magma is olivine, which will produce an olivine-rich peridotite layer. Sometimes PGM sulfides will settle with the olivine. In other layers, chromite or titaniferous magnetite may occur.

The Bushveld complex, South Africa, hosts world-class deposits of PGMs. It probably formed as the result of a meteor impact 2.1 billion years ago, which melted Earth's crust and tapped magmas from Earth's upper mantle. Such deposits are rare, since most major impacts occurred prior to 600 million years ago, and most have been obliterated by erosion through time. The Bushveld complex is enormous (26,000 mi^2) and is a source for PGMs as well as cobalt, copper (Cu), Au, nickel (Ni), and Ag. It is also a potential source for titanium (Ti), vanadium (V), and chromium (Cr).

PGMs are mined from layers that have been named the Merensky Reef, UG2 Chromite layer, and Platreef. The Merensky is a few feet to several feet thick, and the ore averages 0.19 ounce per ton (opt) combined Pt+Pd+Au. In contrast, Pt and Pd in the J-M Reef at Stillwater, Montana, occurs in a 3- to 15-foot-thick zone that extends 20 to 25 miles. The ore in the J-M Reef may average 0.7 opt Pt+Pd+Au.

Several Pt, Pd, and Ni anomalies have been recognized in southeastern Wyoming, in a region that covers three mountain ranges, paralleling a major fault zone known as the Mullen Creek-Nash Fork shear zone (also known as the Cheyenne belt) (**Figure 26**). Other possible host rocks have been found to the north. These include the Trailside complex in the Bighorn Mountains and some peridotites in the Laramie Mountains that are essentially unexplored. However, the better deposits have been identified to the south (**Figure 27**), and include Lake Owen, Mullen Creek, Puzzler Hill, Centennial Ridge, the Elkhorn gabbro, Woods Mountain peridotite, and the Laramie anorthosite.

Mullen Creek

This complex is about 60 mi^2 in area and lies along the edge of the Douglas Creek district in the Medicine Bow Mountains. This complex was probably the main source of Pt and Pd recovered during some of the early placer gold mining operations in Douglas Creek. The New Rambler mine, along the northeastern edge of the complex, produced some Pt and Pd during the early 1900s. Much of the complex was enclosed in the Savage Run and Platte River Wilderness Areas several years ago.

In the early 1900s, some Cu, Au, Ag, Pt, and Pd were mined along the northeastern edge of this complex at New Rambler. More than 5000 feet of drifts and crosscuts were developed from the mine shaft. The ore was covered by gossan at the surface. At depth, a Cu-rich zone was found. Beneath this, Pt-bearing covellite and chalcocite were intersected in an arsenic-rich sulfide zone. Below 100 feet, quartz veins containing sperrylite ($PtAs_2$) were intersected.

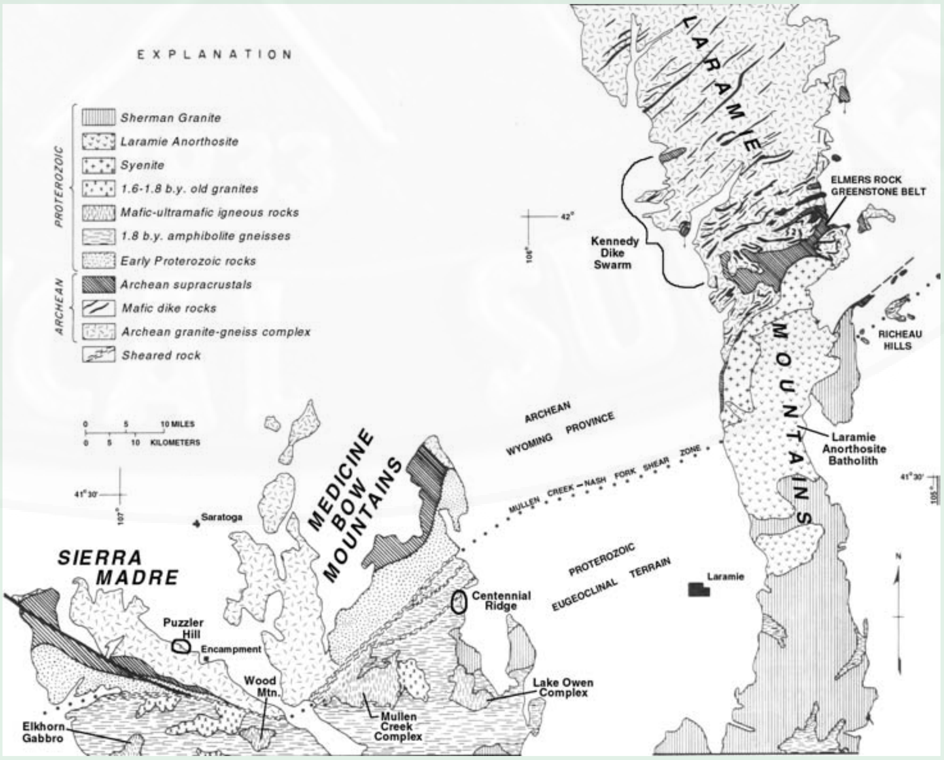

Figure 26. Location map showing the Mullen Creek-Nash Fork shear zone and the Wyoming platinum-palladium-nickel province.

Continued on page 28.

Rock Hound's Corner, continued from page 27.

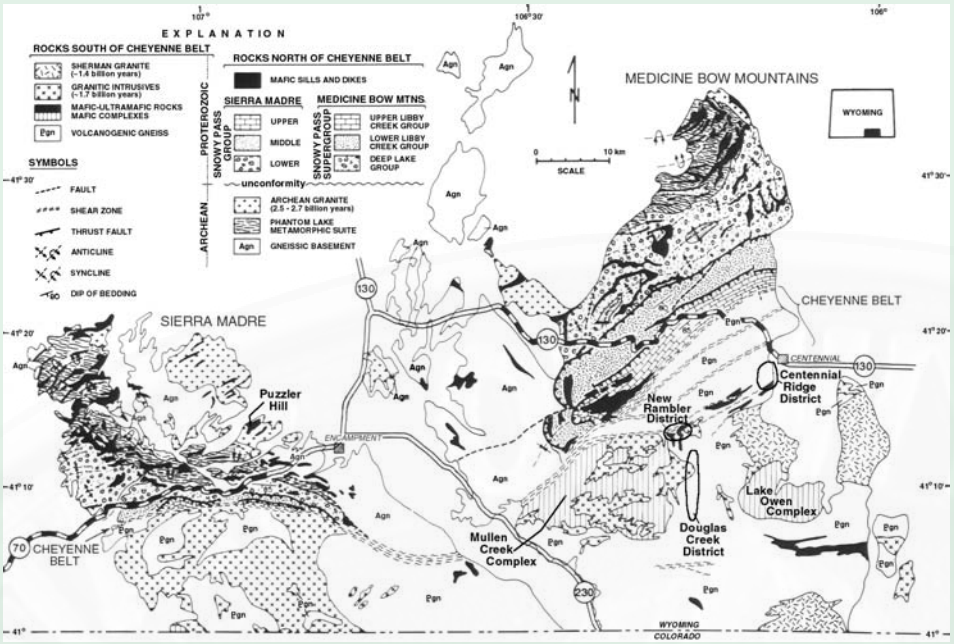

Figure 27. Generalized geologic map of the western part of the Wyoming platinum-palladium-nickel province (modified form Karlstrom and others, 1983).

The mine operated from 1900 to 1918. Operations ceased following a fire that destroyed the mine buildings. The last concentrates shipped from the mine contained 3.24 to 61.37% Cu, a trace to 1.4 opt Au, 1.01 to 7.5 opt Ag, 0.047 to 3.2 opt Pt, and 0.33 to 12.3 opt Pd. It is apparent that the deposit was not mined out. A search of nearby properties resulted in other PGM discoveries. Two samples collected from the Blanche mine to the west assayed 6 and 17 ppm (parts per million) Pt, 30 and 20 ppm Pd, and 20 and 17% Cu, respectively.

Lake Owen

The Lake Owen complex east of Mullen Creek crops out over 25 mi^2. The lowermost layer in the complex was followed for 1.8 miles; the uppermost layer was followed for 7.5 miles. Based on some early research by Robert Loucks, sulfide-bearing zones were identified in 12 layers, some reportedly containing anomalous Au with Pt ± Pd. Four layers were described as having PGMs + Au at grades greater than (>)1 ppm in the olivine-rich rocks. The mineralization was spotty but included zones up to 15 feet thick with strike lengths of more than 1 mile.

Two layers contained bornite, chalcopyrite, carrollite ($CuCo_2S_4$), millerite (NiS), Ti-poor magnetite ± PGMs. In one layer, bornite with PGMs was reported to be continuous for 1.2 miles. In another layer, the mineralization extended over an interval of 6 miles. Sixteen vanadium-bearing layers were described to have lateral persistence of 3 to 7.5 miles. The layers were estimated to have 1.4 billion tons of vanadium valued at $33 billion (1988 prices).

Centennial Ridge district

North of Lake Owen, Pt was reported in some Au mines in the Centennial Ridge district. The richest Au ores were found in sulfide-rich zones in mylonites, graphitic fault gouge, and in strongly altered shear zones in mafic amphibolite. The mineralization was spotty. (For more information, see our web site addition at http://www.wsgsweb.uwyo.edu/metals/cent/index.html.)

Puzzler Hill

Puzzler Hill is a relatively new Pt-Pd-Ni discovery made by the WSGS in 1995. The area lies 6.5 miles north of Encampment. Samples from historical prospects and mines yielded 0.01 to 4.43% Cu, 66 ppm to 3.72% Ni, a trace to 0.29 opt Au, a trace to 828 ppb Pt, a trace to 0.12 opt Pd, a trace to 0.19 opt Ag, and 21 to 831 ppm Co.

Prospecting hints

Prospectors may find it profitable to search old mine dumps looking for gossans (iron-stained rock outcrops) in regions where Pt has been reported in the past. Pt and Pd are often found in placers in some of these areas. In Wyoming, Douglas Creek, a well-known Au placer, periodically produces some Pt nuggets and flakes. The Middle Fork of the Little Laramie River, and other drainages in the Centennial Ridge district, as well as many drainages originating from the Mullen Creek and Lake Owen complexes, remain essentially unprospected.

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MAPPING AND HAZARDS UPDATE

GEOLOGIC MAPPING, PALEONTOLOGY, AND STRATIGRAPHY UPDATE

Alan J. Ver Ploeg
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A color geologic map of the Laramie 1:100,000-scale Quadrangle is now available from the Wyoming State Geological Survey. Funding from the STATEMAP project helped finance detailed mapping components for this quadrangle. A proposal for STATEMAP 2001 includes 1:100,000-scale bedrock geologic maps of the Rattlesnake Hills, Casper, and Buffalo quadrangles and surficial geologic maps of the Basin and Midwest quadrangles.

Color digital geologic map of the Laramie area published

A new color digital geologic map of the Laramie area is now available. Preliminary compilation and mapping of the geology for the Laramie 1:100,000-scale Quadrangle was completed in August, 1999 as Preliminary Geologic Map PGM 99-1. Following additional structural mapping on the crest of the Laramie Mountains and the Boulder Ridge/Tie Siding area in the fall of 1999, the preliminary map was updated, then scanned and digitized. Funding from the STATEMAP Program assisted both the Geologic Mapping Section and the Hazards Section at the Wyoming State Geological Survey (WSGS) in completing the maps.

The "Digital geologic map of the Laramie 30' X 60' Quadrangle, Albany and Laramie Counties, southeastern Wyoming" by A.J. Ver Ploeg and C.M. Boyd is available as Geologic Hazards Section Digital Map HSDM 00-1. The color map contains a pamphlet with a detailed description of map units and map symbols and the sources of geologic data used in compilation. The map is available as a plotted color map or on CD-ROM, which includes a viewable file of the map as well as the ArcView and ArcInfo files.

The Laramie 1:100,000-scale Quadrangle is located in southeastern Wyoming, on the Colorado/Wyoming border (**Figure 28**). Bedrock exposed on the quadrangle ranges from Precambrian to Upper Miocene in age. The Laramie structural basin occurs in the western half of the quadrangle; the Laramie Mountains and west flank of the Cheyenne-Denver (or Denver-Julesburg) Basin occurs on the east side of the quadrangle. High angle reverse faults bound the west side of both the Laramie and Cheyenne-Denver basins. A northwest trending line of anticlines lies east of and parallel to the reverse faults on the west side of the Laramie Basin. A previously unidentified fault zone with indications of lateral motion was identified in 1994 on the east flank of the Laramie Basin. Mapping in 1995 and 1999 further clarified and substantiated the existence of this fault trend. Unique geomorphic features such as Big Hollow (an eolian blowout) in the Laramie Basin and the Gangplank (a late Tertiary depositional/erosional surface) on the east side of the Laramie Mountains also occur on the quadrangle.

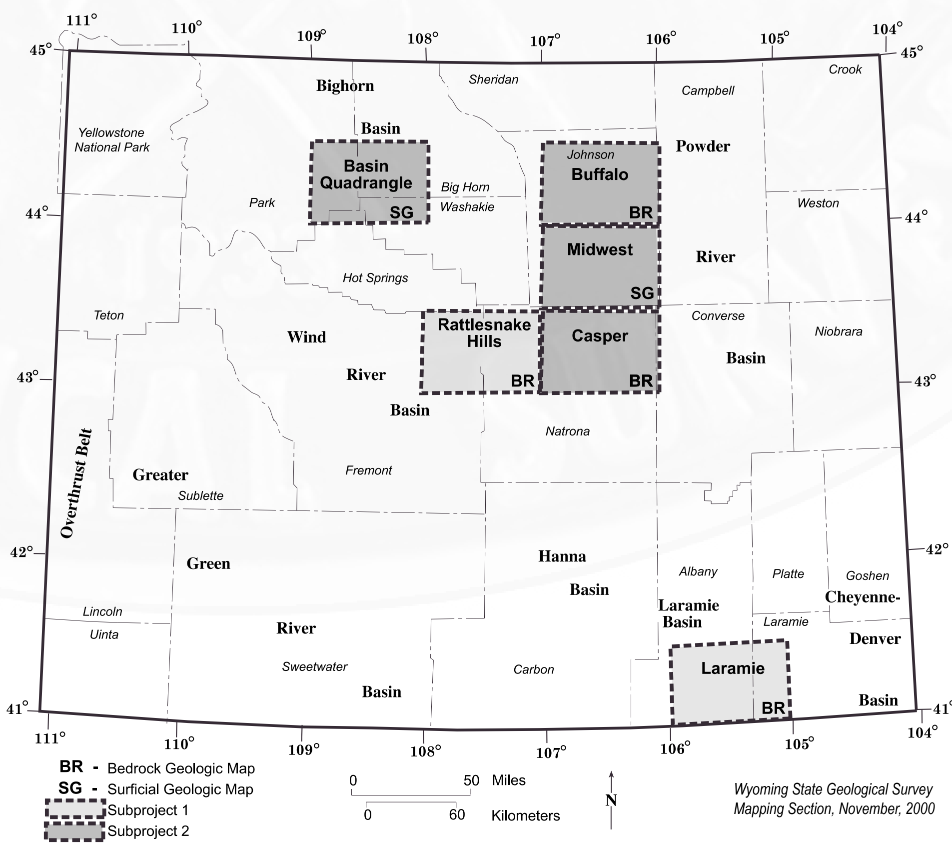

Figure 28. Index map to a recently completed geologic mapping project and to the proposed STATEMAP FY2001 projects.

In addition to the existing published and unpublished geologic maps used to compile the color digital map of the Laramie 30′ x 60′ Quadrangle, the Geologic Mapping Section created some new 1:24,000-scale geologic maps to fill gaps in existing mapping and correct outdated mapping. The Laramie 7 1/2-minute Quadrangle (funded by STATEMAP 94) and Red Buttes 7 1/2-minute Quadrangle (funded by the WSGS) were mapped and field checked during the 1994 field season. The Laramie 7 1/2-minute Quadrangle was originally published as Preliminary Geologic Map PGM 95-1 and published as a printed map, Map Series MS-50. Red Buttes Quadrangle was published as a Preliminary Geologic Map PGM 95-2. The Howell 7 1/2-minute Quadrangle was completed in 1996 with funding from STATEMAP 95 and published as Preliminary Geologic Map PGM 96-1.

The Section completed eight 7 1/2-minute reconnaissance photogeologic maps in 1998 and 1999 under STATEMAP 98. These unpublished maps include the Best Ranch, Dale Creek, Downey Lakes, Hutton Lake, Johnson Ranch, King Mountain, Pilot Hill, and Sherman Mountains West quadrangles. Copies of the unpublished maps are available for viewing in the Geologic Mapping Section's files.

STATEMAP 2001 proposal

The WSGS recently proposed two mapping projects for the STATEMAP 2001 Program. The first project is to map the Rattlesnake Hills 1:100,000-scale Quadrangle; the second project is to digitize four existing 1:100,000-scale maps–two surficial and two bedrock geologic maps. Current mapping priorities established by the WSGS in consultation and cooperation with the Wyoming Geologic Mapping Advisory Committee include: 1) producing geologic maps to support coalbed methane exploration/production activities and associated ground and surface water protection needs in the Powder River Basin, and 2) mapping the more populated areas to provide assistance to city and county planners in siting and land-use planning, as well as to provide information supporting mineral and water resource development.

The Rattlesnake Hills 1:100,000-scale Quadrangle (**Figure 28**) is in part a re-submittal. The Barlow Gap 1:24,000-scale Quadrangle was completed as the first part (STATEMAP 1998) of the Rattlesnake Hills mapping project. The second phase of the project was not funded. Completion of this mapping project by the Metals and Precious Stones Section will encourage and support mineral development in this area. Section personnel will evaluate and compile existing mapping to the 100,000-scale and use limited new mapping from aerial photography and field checking to fill gaps in existing mapping and to correct outdated mapping. If funded, the Rattlesnake Hills 1:100,000-scale geologic map will be completed in 2002.

The four existing maps proposed for digitizing were chosen because each falls under one or both of the established priorities. Bedrock geologic maps of the Casper and Buffalo 1:100,000-scale quadrangles and surficial geologic maps of the Basin and Midwest quadrangles (**Figure 28**) will provide needed information to planning, mineral, and water development entities in those areas. The surficial maps will be digitized from unpublished section reports and the bedrock geologic maps will be digitized from maps currently being compiled and mapped by the Geologic Mapping Section under STATEMAP 2000. Some field checking and final compilation of the two bedrock maps is included with the STATEMAP 2001 proposal.

The Publications Section, with assistance from the Geologic Mapping Section and the Hazards Section of the WSGS, will be involved with this project. For each proposed map, the geology layer will be scanned, converted from a raster image to a vector image, and edited to be consistent with National Digital Mapping Standards. Funding will enable the WSGS to acquire digital topography and public land survey data from the EROS Data Center, it will fund salary for one geological assistant, and will cover map scanning costs.

Last year (FY2000) the U.S. Geological Survey's STATEMAP Program received proposals from 44 states asking for $5,233,567. Some $4,033,821 was awarded, which funded 77% of the amount asked for. This year (FY2001) the STATEMAP Program will be distributing $6,660,550 in awards. This is a significant increase and it appears that about the same number of states will be submitting proposals.

Funds from this cooperative program from 1992 through 2000 have already helped the WSGS accelerate geologic mapping efforts in Wyoming. The WSGS has completed 21 maps using funding from this program since it began in 1992; an additional 11 maps were completed independent of the program's funding. Six additional maps are in progress with STATEMAP 2000 funding.

The first project is to map the Rattlesnake Hills 1:100,000-scale Quadrangle; the second project is to digitize four existing 1:100,000-scale maps–two surficial and two bedrock geologic maps.

PROBABILISTIC SPECTRAL ACCELERATION MAPS AND THEIR APPLICATIONS

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

The probability of having earthquake-induced ground accelerations in Wyoming was addressed in Wyoming Geo-notes No. 67 (September, 2000). A series of maps showed the probability of having certain levels of ground motion, in terms of acceleration as a percent of gravity (g), during various periods of time. These maps have been used for many years, and are periodically updated and revised. Over the last ten years, however, another type of map, the probabilistic spectral acceleration map, has been generated. These maps have become so widely accepted that they now form the basis of seismic design in the new International Building Code for 2000.

Harmonic vibrations and buildings

When an earthquake occurs, seismic waves are generated just as when a tuning fork is hit, it vibrates and generates sound waves. The following paragraphs make reference to various aspects of seismic waves and vibrations. Frequencies of waves are expressed in terms of cycles per second (hertz or Hz). A less familiar but related term is called the wave period which is equal to 1/frequency, and is usually expressed in terms of seconds or part of a second. A wave frequency of 5 Hz is equivalent to a wave period of 0.2 second (i.e., [1/(5cycles/second)= 0.2 seconds]). The frequency thus defines the number of complete waveforms that pass a given point in a second, while the period is the time it takes one complete waveform to pass a given point. Using the example above, if a wave has a frequency of 5 cycles per second, then one cycle of the wave would pass a given point in 0.2 second, the wave period.

Many objects have a natural frequency or period, at which they naturally want to oscillate. Harmonic vibration is the same as a natural frequency or a natural period. Buildings, metal rods, tuning forks, drinking glasses, and even out-of-balance tires all have a natural frequency or period. During an earthquake some buildings may collapse while others are only slightly damaged. This can be due in part to the age of the buildings involved and their type of construction, but the natural frequencies or periods (harmonics) of the buildings are also a factor. Taller buildings (greater than seven stories or so) usually have natural frequencies near 1 Hz and natural periods near 1 second. Shorter buildings usually have natural frequencies near 5 Hz and natural periods near 0.2 second, although they can have natural periods up to 0.6 second (Perkins, 2000). If the buildings are vibrated (like in an earthquake) at a frequency near their natural frequency, they will have a tendency to sway more than if subjected to a vibration at a significantly different frequency. Of course building type and seismic design can affect the natural frequency and period of a building, so the tendencies mentioned above cannot be applied to all buildings.

Higher frequency waves, on the order of 5 Hz, have a tendency to be more damaging to shorter buildings. Lower frequency seismic waves, on the order of 1 Hz, have a tendency to be more damaging to taller buildings. In effect, if buildings are subjected to a vibration that matches their natural frequency (or period), the buildings will be subjected to accelerations that may be significantly greater than those experienced by the ground surface. These all result from the harmonic vibrations that are induced in the buildings.

Seismic waves

When an earthquake occurs, seismic waves of various frequencies or periods are generated. In fact, there are four different types of seismic waves: P waves, S waves, Rayleigh waves, and Love waves. P waves are longitudinal waves, also called primary waves or push-pull waves. Imagine holding a springlike toy called a "slinky" in a straight line and alternately pushing and pulling one end of it. A pulse made of a compression and an expansion would travel down the "slinky." P waves are the fastest of all seismic waves, and as a result are the first to be felt.

S waves are transverse waves, also called secondary waves. These waves are similar to what would be observed if one end of a rope was tied to a stationary object and the free end was given a series of side-to-side jerks. S waves are the second fastest of all seismic waves and are the second waves to be felt. They are usually more damaging than P waves because they cause structures to move from side to side. Compared to other seismic waves, P and S waves are high-frequency, low-period waves and they have a tendency to damage low structures. Harmonic vibrations in short buildings are more likely to be created by the periods associated with these waves.

Rayleigh waves are confined to Earth's surface layers. The particle motion is in a vertical plane, and the motion is elliptical and retrograde with respect to the direction of wave propagation. Rayleigh waves are considered to be the principal component of ground roll.

Love waves are transverse waves restricted to Earth's surface layers. They induce a particle motion that is horizontal and transverse to the direction of wave propagation. Both Rayleigh and Love waves are low-frequency, higher-period waves that have a tendency to induce harmonic vibrations in taller buildings.

Not all earthquakes damage buildings or other structures. Of course the larger the earthquake magnitude, the greater the chance that a building or other structure will be damaged. If two earthquakes had the same magnitude, however, and one generated more high-frequency, low-period seismic waves, it is likely that more short buildings or structures would be damaged by that event.

Seismologists or engineers sometimes examine just parts of the seismic record to better determine why certain buildings were affected by an earthquake. They examine seismic waves or the parts of seismic waves with the frequencies or periods that closely match those of the structures or buildings in question. This is called a spectral analysis.

Spectral acceleration

While the natural frequency of a building is sometimes used in seismic design, it is more common to use the natural period. Because of the relationship between frequency and period, buildings with a larger natural frequency have a smaller natural period and vice versa. A spectral acceleration is approximately the acceleration experienced by a building with a specific natural period, when it is subjected to seismic waves with a similar period.

Through complex mathematical modeling, the U.S. Geological Survey (USGS) has generated a series of spectral acceleration maps for various periods of seismic waves and the corresponding periods of buildings. Maximum ground motions and their associated spectral accelerations with various periods are considered for various time frames. Like the probabilistic peak ground acceleration maps (see *Wyoming Geo-notes No. 67*, September, 2000), probabilistic spectral acceleration maps are usually generated for accelerations (as % of gravity, g) that have a 2%, 5%, or 10% probability of being exceeded in 50 years. **Figures 29** through **34** are spectral acceleration maps for periods of 0.2 second and 1.0 second with a 2%, 5%, or 10% probability of being exceeded in 50 years. The maps, which were generated by the USGS, can be generated and downloaded from the following USGS web site: http://geohazards.cr.usgs.gov/eqint/html/custom.shtml.

The spectral acceleration maps were generated for a publication by the Building Seismic Safety Council (1997), and were based upon accelerations that may be felt in buildings sited on rock. This publication is hereafter referred to as the 1997 NEHRP Recommended Provisions. The accelerations derived from the maps must be modified for different site conditions, and spectral

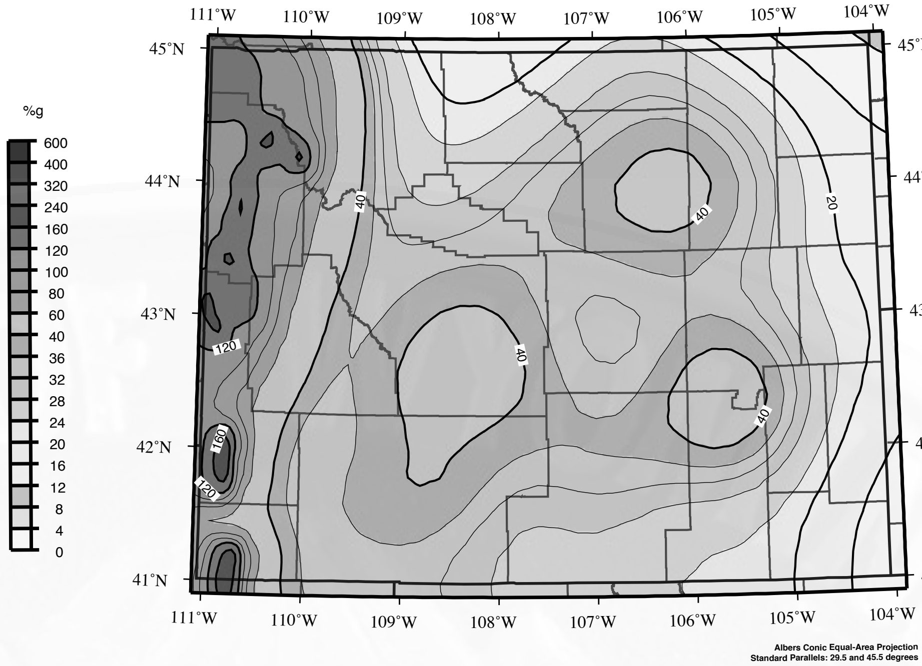

Figure 29. Spectral acceleration map of Wyoming, in percent of gravitational force (g), for structures with a 0.2-second period, with a 2% probability of being exceeded in 50 years. Data for NEHRP B-C boundary site from the U.S. Geological Survey National Seismic Hazard Mapping Project.

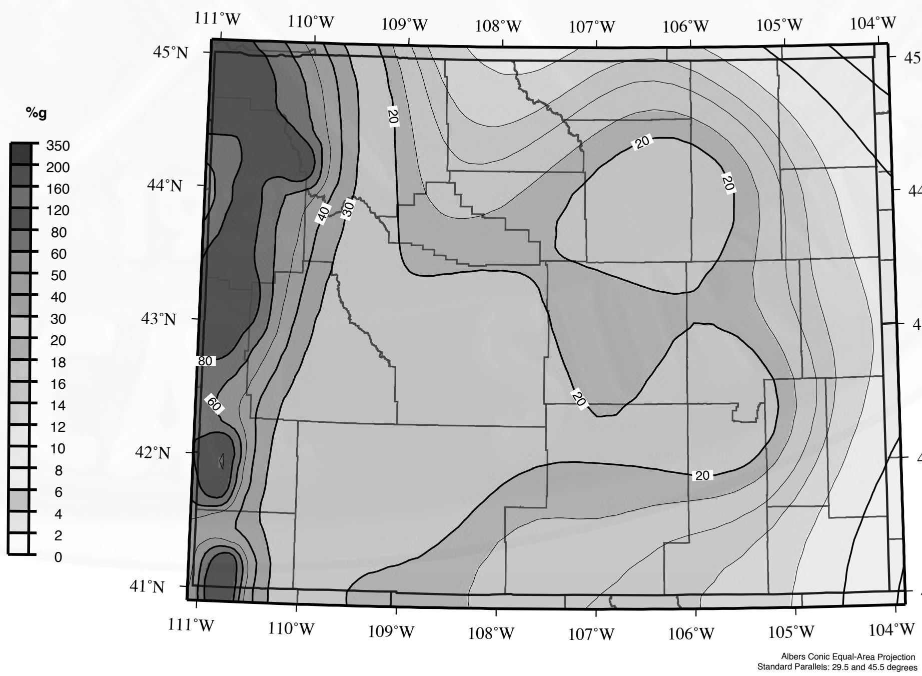

Figure 30. Spectral acceleration map of Wyoming, in percent of gravitational force (g), for structures with a 0.2-second period, with a 5% probability of being exceeded in 50 years. Data for NEHRP B-C boundary site from the U.S. Geological Survey National Seismic Hazard Mapping Project.

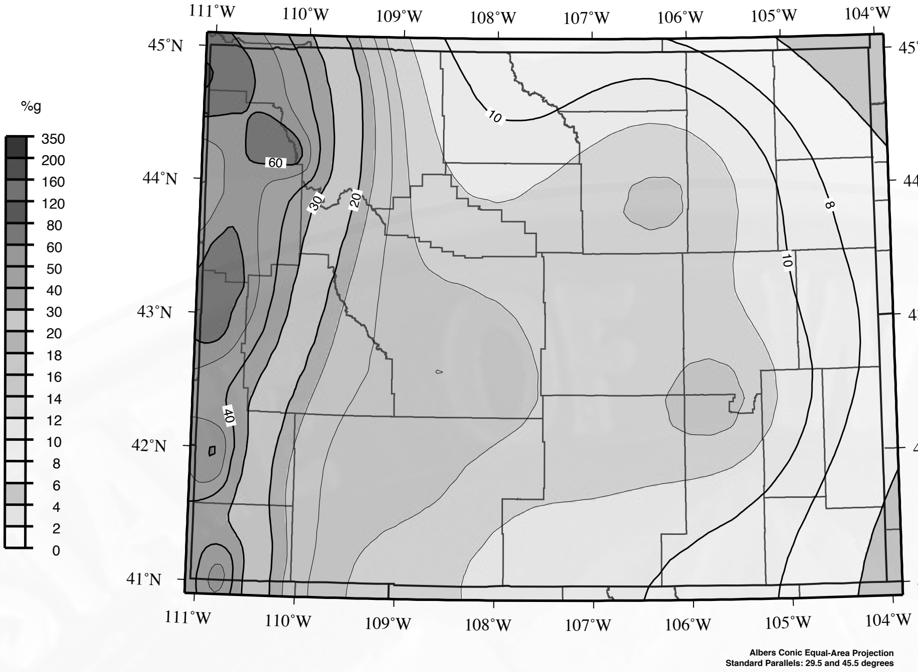

Figure 31. Spectral acceleration map of Wyoming, in percent of gravitational force (g), for structures with a 0.2-second period, with a 10% probability of being exceeded in 50 years. Data for NEHRP B-C boundary site from the U.S. Geological Survey National Seismic Hazard Mapping Project.

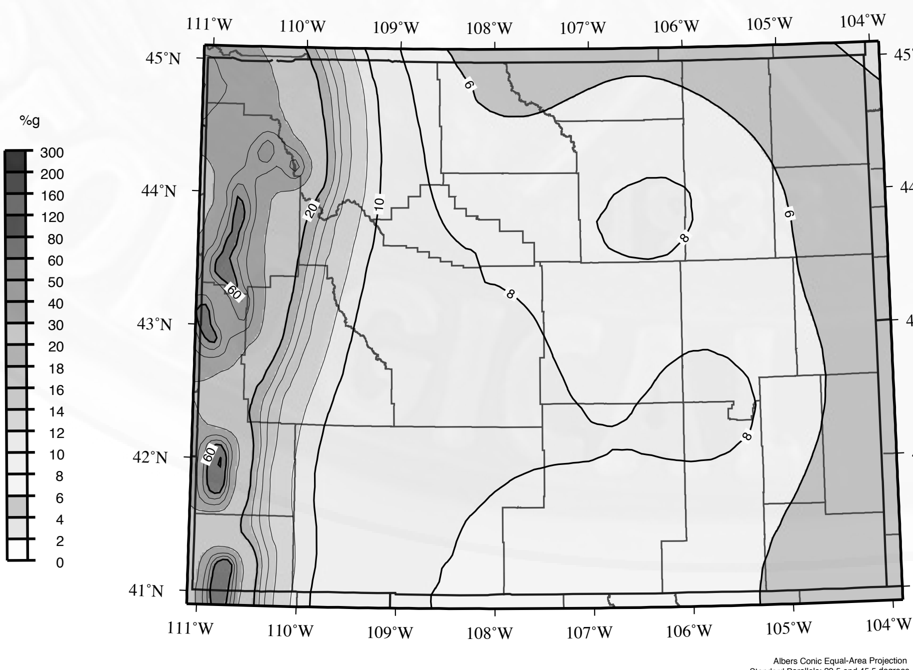

Figure 32. Spectral acceleration map of Wyoming, in percent of gravitational force (g), for structures with a 1.0-second period, with a 2% probability of being exceeded in 50 years. Data for NEHRP B-C boundary site from the U.S. Geological Survey National Seismic Hazard Mapping Project.

accelerations for buildings with natural periods other than 0.2 second and 1.0 second must be calculated (Leyendecker and others, 2000). An approximate response spectrum, which shows the approximate spectral acceleration values for all periods, can be generated for any specific site in the United States, as explained by Leyendecker and others (2000). In essence, the approximate response spectrum for a site is based upon the 0.2-second period and 1.0-second period spectral accelerations derived from **Figures 29** through **34**, and then adjusted for site conditions. **Figure 35** shows a simplified approximate response spectrum.

Spectral acceleration maps represent the types of accelerations that may occur in a building subjected to seismic waves with a period similar to the natural period of the building. The maps are a good starting point for this type of analysis. For example, if an engineer or building official wanted to know what peak acceleration a building with a natural period of 0.2 second would be subjected to, with a 2% probability of being exceeded in 50 years, a good starting point would be **Figure 29**. The map indicates that if the building was located just west of Jackson, it could be subjected to a spectral acceleration near 160%g. This is considerably greater than the peak ground acceleration for the same location, which would be near 60%g (*Wyoming Geo-notes No. 67*, September, 2000). Local site conditions and specific types of construction or strengthening, however, will all have to be factored into a final analysis.

A few recent articles explain the spectral acceleration and ground acceleration maps in greater detail. An overview of all maps is presented in Frankel and others (2000). A more detailed discussion of the spectral acceleration maps is presented in Leyendecker and others (2000). Other articles or reports can be observed or downloaded through the following web site: http://geohazards.cr.usgs.gov/eq/.

Building codes

The seismic provisions of the new 2000 International Building Code (IBC) are largely based upon two of the spectral acceleration maps presented above. The IBC uses Maximum Considered Earthquake (MCE) spectral acceleration maps for periods of 0.2 second and 1.0

second, which are equivalent to the 2% in 50 years probabilistic acceleration maps presented above (**Figures 29** and **32**, respectively). Ground accelerations that exceed those in **Figures 29** and **32** may occur, but those are not considered in the IBC. The MCE maps are a change from previous building codes that represented five seismic zones (Case, 1995). Although the seismic provisions of the 2000 IBC appear to be much more complex than previous building codes, they should be more defensible scientifically.

The 2000 IBC and the 1997 NEHRP Recommended Provisions contain considerably more information, data, and formulas needed to properly design and site a building than given here. The discussion that follows is designed to serve as an introduction to the seismic design parts of both publications.

The MCE maps in the IBC are designed to be used for a specific site condition or class, which is rock (Site Class B). If a structure is to be sited on material other than rock, the spectral accelerations must be adjusted using a formula and site class factors presented in the IBC and in the 1997 NEHRP Recommended Provisions (Building Seismic Safety Council, 1997). There are six site classes, ranging from Site Class A (hard rock) to Site Class F (soil prone to liquefaction or collapse, peat, and highly plastic clay). For example, if a building is sited in a stiff soil profile (Site Class D) instead of rock (Site Class B), and the 0.2-second period spectral acceleration for the site (derived from the 0.2-second period MCE map – Site Class B) is 0.75g, then the spectral acceleration would have to be multiplied by 1.2 in order to adjust it for site conditions. The result is an adjusted 0.2-second period spectral acceleration of 0.90g, based upon a chart generated by the Building Seismic Safety Council (1997).

The IBC and the 1997 NEHRP Recommended Provisions are to be used to determine how a structure should be designed. Although the MCE maps show the maximum considered accelerations to which a building could be subjected, buildings are not usually designed to withstand these forces. The IBC and the 1997 NEHRP

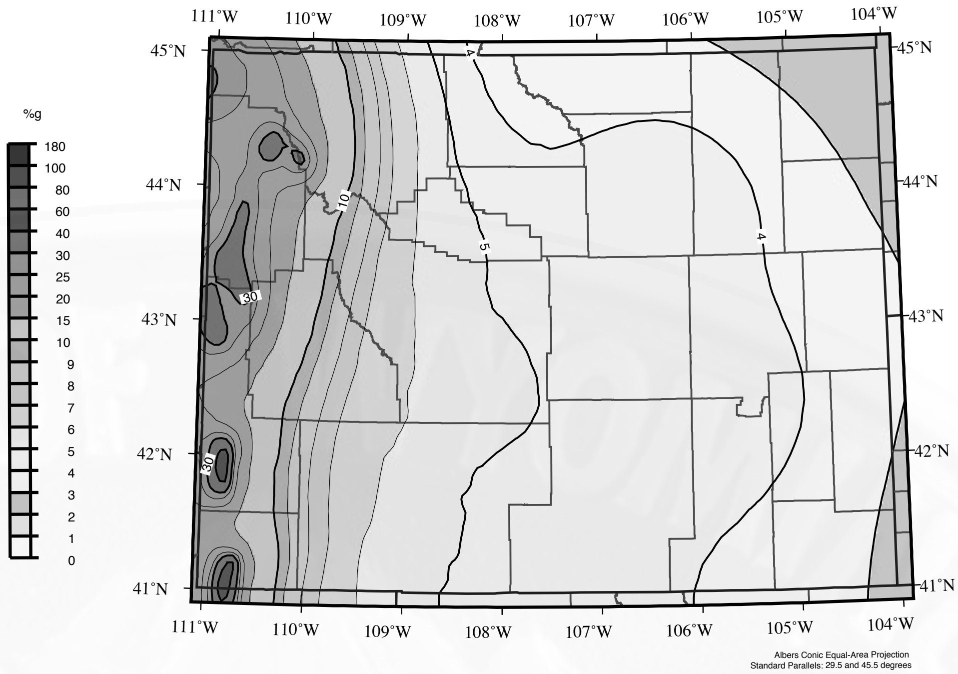

Figure 33. Spectral acceleration map of Wyoming, in percent of gravitational force (g), for structures with a 1.0-second period, with a 5% probability of being exceeded in 50 years. Data for NEHRP B-C boundary site from the U.S. Geological Survey National Seismic Hazard Mapping Project.

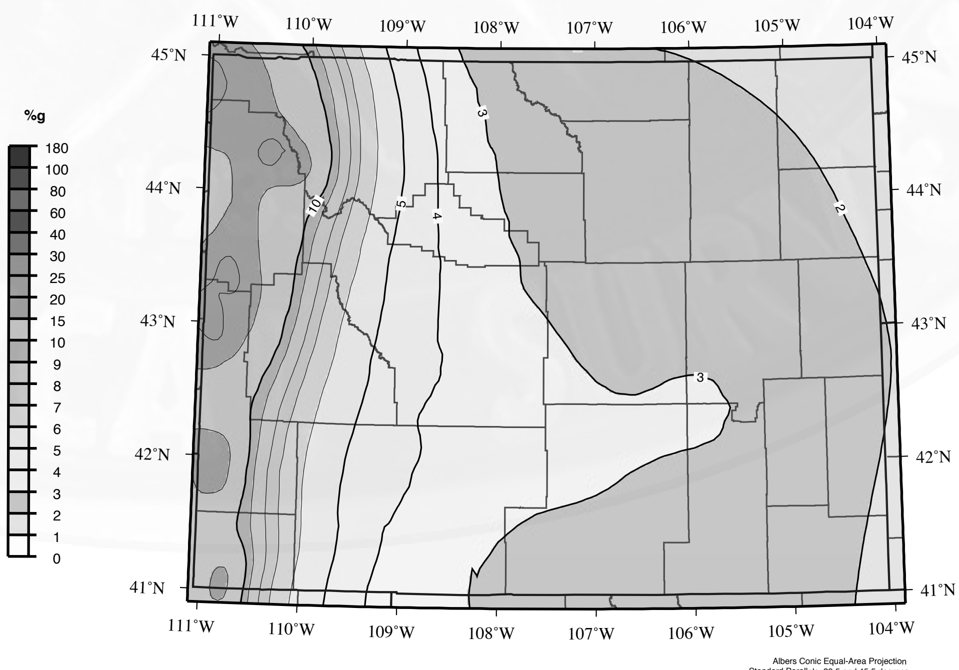

Figure 34. Spectral acceleration map of Wyoming, in percent of gravitational force (g), for structures with a 1.0-second period, with a 10% probability of being exceeded in 50 years. Data for NEHRP B-C boundary site from the U.S. Geological Survey National Seismic Hazard Mapping Project.

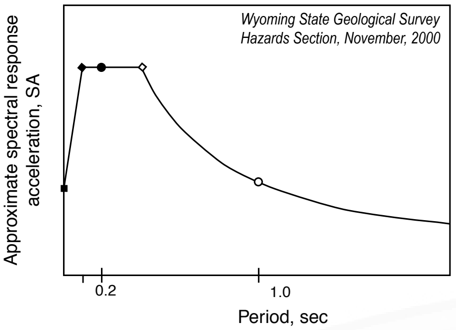

Figure 35. Generalized approximate response spectrum (modified from Leyendecker and others, 2000).

Recommended Provisions suggest that a building be designed to two-thirds of the MCE spectral accelerations (adjusted for site conditions). A design response spectrum can be developed for a specific site, in a manner similar to that used for the approximate response spectrum described above (Leyendecker and others, 2000). The difference between the maximum and the design spectra is that the 0.2-second period and 1.0-second period spectral accelerations used to generate the approximate response spectrum are multiplied by two-thirds before they are used to generate a design response spectrum.

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Case, J.C., 1995, Relationship between Wyoming's seismic hazards and the Uniform Building Code: Wyoming State Geological Survey Wyoming Geo-notes No. 47, p. 51-55.

Frankel, A.D., Mueller, C.S., Barnhard, T.P., Leyendecker, E.V., Wesson, R.L., Harmsen, S.C., Klein, F.W., Perkins, D.M., Dickman, N.C., Hanson, S.L., and Hopper, M.G., 2000, USGS National Seismic Hazard Maps: Earthquake Spectra, vol. 16, no. 1, February, 2000, p. 1-19.

Leyendecker, E.V., Hunt, R.J., Frankel, A.D., and Rukstales, K.S., 2000, Development of maximum considered earthquake ground motion maps: Earthquake Spectra, vol. 16, no. 1, February, 2000, p. 21-40.

Perkins, D., 2000, How do I use these maps: U.S. Geological Survey National Seismic Hazard Mapping Project web page, http://geohazards.cr.usgs.gov/eq/faq/psha02.shtml, 2 p.

PUBLICATIONS UPDATE

NEW PUBLICATIONS BY THE WYOMING STATE GEOLOGICAL SURVEY

Gemstones and other unique minerals and rocks of Wyoming— A field guide for collectors, by W.D. Hausel and W.M. Sutherland, 2000: Bulletin 71 - $20.00.

Stream classification and drainage systems map of the northeast Wyoming coal bed methane development area, by Wyoming Department of Environmental Quality, 2000: Coalbed Methane Map CMM 00-3, on demand plotted color map, rolled only - $15.00; a digital version (ArcInfo/ArcView format) of this map is now included with the CD-ROM versions of Coalbed Methane Maps CMM 00-1 and 00-2 or as a separate CD-ROM - $10.00.

*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.

* Preliminary surficial geologic map of the Cody 30′ x 60′ Quadrangle, Park County, Wyoming, by L.L. Hallberg, J.C. Case, and A.L. Kirkaldie, 2000, scale 1:100,000: Hazards Section Digital Map HSDM 00-3, 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 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 Maps 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.

* Construction aggregate in Wyoming, by R.E. Harris, 2000: Industrial Mineral Report IMR 00-1, 9 p. copied report - $2.00.

* Pumping induced settlement of aquifers, by T.V. Edgar and J.C. Case, 2000: Preliminary Hazards Report PHR 00-1, 9 p. copied report - $2.00.

Geologic map of the Cache Creek Quadrangle, Teton County, Wyoming, by J.D. Love and C.M. Love, 2000, scale 1:24,000: J. David Love Map Series, Geology of the Teton-Jackson Hole area, Wyoming, LMS-1, on demand plotted color map, rolled only - $20.00; CD-ROM of digital map coverages in ArcInfo format plus viewable, printable version in Mr. Sid - $10.00.

Geologic map of the Teton Village Quadrangle, Teton County, Wyoming, by J.D. Love and J.C. Reed, Jr., 2000, scale 1:24,000: J. David Love Map Series, Geology of the Teton-Jackson Hole area, Wyoming, LMS-2, on demand plotted color map, rolled only - $20.00; CD-ROM of digital map coverages in ArcInfo format plus viewable, printable version in Mr. Sid - $10.00.

Preliminary geologic map of the Sheridan 30′ x 60′ Quadrangle, Sheridan, Johnson, and Campbell Counties, Wyoming and southern Montana, by A.J. Ver Ploeg and C.S. Boyd, 2000, scale 1:100,000: Preliminary Geologic Map PGM 00-1, on demand plotted 3-color map, rolled only - $15.00 .

Each geologic section of the Survey now prepares and releases some of its own numbered reports and maps. Please contact the Staff Geologists for coverage, availability, prices, or further information on specific commodities or topics [Phone: (307) 766-2286; FAX: (307) 766-2605; or use the Email addresses included in the **SURVEY DIRECTORY** on back cover].

*New releases since the last issue of *Wyoming Geo-notes*.

STAFF PROFILE–RICHARD W. JONES

Jaime R. Bogaard
Editorial Assistant-Publications, Wyoming State Geological Survey

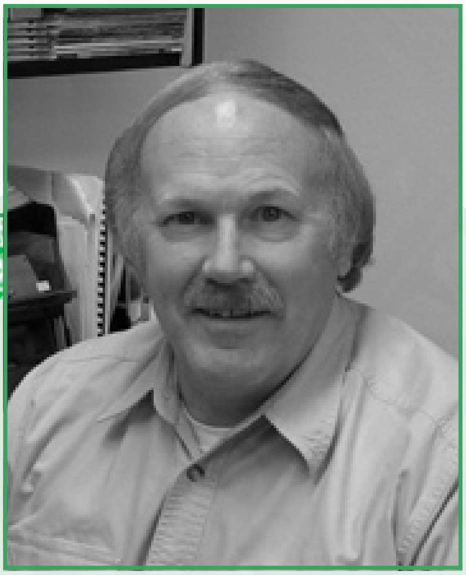

Figure 36. Richard W. Jones is the Editor and Head of the Publications Section at the Wyoming State Geological Survey.

Richard W. "Dick" Jones (**Figure 36**) is the Editor and Head of the Publications Section at the Wyoming State Geological Survey (WSGS). As the editor and section head, he is responsible for review and editing, production, printing, sales, and distributing WSGS's reports and maps. He supervises four people including two cartographers, an editorial assistant, and a publications salesperson.

Dick works with staff geologists in all phases of preparing and releasing geologic information. He prepares specifications for printing numerous Survey publications, works with preproduction contractors and printing companies, and attends press runs to ensure quality of printing. He also reviews and prepares press releases, represents the agency in publication-related matters, and assists in public outreach, education, and public relations.

Dick was born in Watertown, South Dakota, but has lived in Wyoming most of his life. His family moved to Midwest, Wyoming, where his father was employed by Amoco Production Company. After attending grade school in Midwest and later Powell, he graduated from Powell High School. In 1967 Dick received an A.A. degree in pre-engineering and business from Northwest Community College, also in Powell. After an unsuccessful and somewhat lengthy career as an engineering student, he finally saw the light in a geology course, and instead earned a B.S. degree in geology at the University of Wyoming (UW) in 1972. Dick started work toward a M.S. degree in geology at UW, completing his course and field work, but never returning to complete the thesis.

Dick began his career as a geologist with the U.S. Geological Survey (USGS) in Casper, Wyoming, working

Continued on next page.

Other publications now available from the Wyoming State Geological Survey

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

*New item since the last issue of *Wyoming Geo-notes*

State Explorer ®, BLM Edition

In addition to the All Topos: Wyoming set of CD-ROMs published by iGage available for $140.00 (or upgrade your old versions), we are now offering an additional product.

State Explorer®, BLM Edition, Wyoming is topographic mapping software that contains all the 1:100,000-scale Bureau of Land Management (BLM) Surface Management Quadrangles in Wyoming. Published by MapTrails, Inc., these maps are contained on a CD-ROM and include the following features:

- Public and private land status, BLM administrative lands, national parks and monuments, Indian lands or reservations, national grasslands, national forests, route markers, and state lands.
- County roads, BLM roads, roads with public access; recreational sites, trails, and areas; state, county, city, wildlife, park, and outdoor recreation areas; and other features found on the BLM series maps.
- Map interaction tools, including zoom levels, distance calculators, elevation profiling, and display of latitude, longitude, and elevation for any point.
- Map customization tools, including Waypoint Manager, capability to create custom trip databases, and capability to organize trip data.
- Navigational tools , including comprehensive search lists, printing capabilities (can print high-resolution custom maps of any area), and full GPS utility (can upload or download coordinates with GPS interface).

The entire package sells for $49.95 and can be purchased over the counter or by mail from the address below. Orders must be prepaid; we cannot invoice with shipment. Add $5.00 shipping and handling; Wyoming residents add 6% sales tax.

Order these and other publications from: Wyoming State Geological Survey, P.O. Box 3008, Laramie, Wyoming 82071-3008. Phone: (307) 766-2286; Fax: (307) 766-2605; and Email: sales@wsgs.uwyo.edu. An order form is also included at the back of this issue of *Wyoming Geo-notes*. Many of these publications are also available over-the-counter at the Wyoming Oil and Gas Conservation Commission (Basko Building) in Casper, Wyoming. A free list of publications is available on request.

Staff profile, continued.

on coal deposits in the Powder River Basin and other parts of Wyoming. After a brief stint with the Survey in Salt Lake City and with the Bureau of Land Management in Worland, he returned to the USGS in Casper, and in 1981 was promoted to District Supervisor for Resource Evaluation with the USGS in Rock Springs. When the Conservation Division of the USGS was dissolved a year later, Dick ended federal service and accepted a position with the WSGS.

Dick joined the WSGS in 1982, originally as Staff Geologist–Coal and Head of the Coal Section. Coincidentally, Dick's interest in coal had started in Laramie some 10 years earlier, when he worked part-time for the WSGS on Wyoming geology and coal deposits while he was a UW geology student. In 1992 he became the Editor and Head of the Publications Section, still maintaining his duties as coal geologist for a year while that position was being filled. After years of having his work as a geologist hacked to pieces by editors, he still enjoys the challenge of working with geologists from the editor's point of view.

Throughout his employment, Dick has authored more than 140 papers, articles, reports, and maps. He has also prepared and given numerous presentations, lectures, and workshops, mostly related to coal and coal geology of Wyoming. Dick says that the biggest challenge for an editor in a geological survey is editing highly technical subjects and writing so they can be understood by the non-geologist and the layman.

Dick is a member of the American Association of Petroleum Geologists, the Geological Society of America, Wyoming Geological Association, Rocky Mountain Association of Geologists, the Association of Earth Science Editors (AESE), and is a Registered Professional Geologist in Wyoming (PG-2972). He is quite active in AESE, having hosted the 1995 annual meeting in Jackson Hole, served on several committees, was program chairman at the 1999 annual meeting and was field trip coordinator at the 2000 annual meeting. He was elected Vice President of AESE for 1999-2000 and recently became the President of AESE for the year 2000-2001.

Dick says he "enjoys fly fishing on streams and fishing for walleye on Wyoming's reservoirs, boating, photography, natural history, and geology-related subjects." He is active in the University Amateur Radio Club, currently serving as Vice President and Secretary of that group and is working on an advanced amateur radio operators license. "I listen to a lot of classical music and at times become addicted to interactive, role-playing computer games. I travel across the country every few years as a serious opera fan, especially to attend Wagnerian opera festivals such as *The Ring of the Niebelung*."

SECOND ANNUAL FIELD TRIP

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

The Wyoming State Geological Survey (WSGS) held its second annual field trip late this summer. The WSGS invited the public to a geologic tour of the Medicine Bow Mountains west of Laramie, a repeat of last year's trip which had sold out. The theme of the annual event is "Get to know your state's geologists, geology, and resources." Each summer the WSGS leads the public to a geologically interesting part of Wyoming. A road log/field guide to this field trip is available from the WSGS.

On the crisp morning of August 25, 2000, some 35 registered participants, 13 WSGS staff members, and an emeritus professor piled into four vans and one pickup truck and left the University of Wyoming (UW) campus, headed west. The first stop was at the WyomingTerritorial Prison parking lot. Jim Case (WSGS Geologic Hazards Section) introduced the field trip leaders and spoke on geologic processes and Dr. Brainerd Mears, Professor Emeritus at UW, talked on the geologic history of the Laramie River and the related surfaces and benches.

Proceeding west on State Highway 130, the caravan passed upward onto old floodplain surfaces that cover the Laramie Basin. Stop 2, on the Airport bench, was at the Laramie Regional Airport, where Jim discussed ground water, selenium, radon, and other geologic hazards and Dr. Mears related (in his own inimitable lecture style) some UW history during the early days of the atomic age (post World War II), which included the burial of a radioactive cow near the airport. Just west of the airport, we encountered Big Hollow, which the route paralleled for a number of miles.

Near the turnoff to Twin Buttes Lake and Lake Hattie, the group made its third stop. The tour guides by this time had explained the local and regional geology of the Laramie Basin, and Rod DeBruin (WSGS Oil and Gas Section) then discussed regional oil and gas activity and Big Hollow Oil Field. Dr. Mears presented the geomorphology and origin of Big Hollow, the Airport bench, and related Pleistocene/Quaternary features, especially those of eolian activity. Finally, Jim discussed the origin of caliche cups, as well as some environmental geology and geologic hazard issues in the Laramie Basin.

The trip continued westward, dropping off the Airport surface into the Little Laramie River valley. Excellent views of Sheep Mountain (which consists of Precambrain rocks thrust eastward over Cretaceous rocks in the Laramie Basin) and the structure of the western Centennial Valley could be seen from the road. At Porter Lake (Stop 4), Dan Hausel (WSGS Metals and Precious Stones Section) discussed Late Cretaceous titaniferous sandstones, Dr. Mears continued his discussion of local geomorphology, and Dick Jones (WSGS Publications Section) described the stratigraphic sequence and structural geology of Sheep Mountain, Laramie and Centennial valleys, and the Medicine Bow Mountains.

After crossing the Little Laramie River, we entered Centennial Valley. From here to Centennial, we drove across boulder fields of glacial outwash and observed the Centennial Valley syncline. Just east of Centennial was Stop 5 (**Figure 37**), where WSGS geologists and Dr. Mears explained various aspects of the geology. Dan talked about gold mining and other metal deposits of the Centennial mining district, Ray Harris (WSGS Industrial Minerals and Uranium Section) discussed industrial minerals in the area, namely aggregate and stone quarries, and Jim and Dr. Mears pointed out glacial features above Centennial and how to distinguish the different ages of moraines.

Figure 37. Centennial Ridge (on horizon) and the town of Centennial (right center, at base of ridge) at Stop 5 were the sites of several mining booms.

Just past the town of Centennial, we started into the Medicine Bow Mountains, crossing moraines left by mountain glaciers flowing off the subsummit surface at the base of the Snowy Range. We turned onto Barber Lake Road near Barber Lake, we left the pavement and drove up a steep road to a spectacular observation point (Stop 6). This provided an excellent view to the south of the entire Centennial Valley and the surrounding mountains (**Figure 38**). Here, with the help of descriptions from Dr. Mears and Jim, one could imagine glacial ice advancing and retreating in the valleys below at various times during the Ice Age, perhaps even overtopping our vantage point. The Precambrian rocks at this point were on the upper part of a thrust fault that bounds the north end of Centennial Valley.

Figure 38. From this observation point at Stop 6 the group learned about the glaciers that flowed into Centennial Valley. Sheep Mountain is visible on the skyline; the tree-covered areas above the group contain two ages of glacial moraines.

After passing through a group of highly metamorphosed granites/granite gneisses and schists on Barber Lake Road, the caravan eventually rejoined State Highway 130. Near the old S.H. Knight science camp (now the Snowy Mountain Lodge), the caravan passed the Cheyenne belt shear zone which separates younger metamorphic rocks on the south from the older Archean and Proterozoic rocks to the north. Part of the Proterozoic sequence contains very well exposed metasedimentary rocks seen at several subsequent stops.

Near Nash Fork campground at Stop 7, Dan led us to outcrops of French Slate where we saw spectacularly folded and crenulated slate and phyllite and at Stop 8, Dan, Ray, and Dr. Mears explained the beautifully preserved, 1.7-billion-year-old stromatolites of the Nash Fork Formation (**Figure 39**). The group had a chance to stand on an ancient shoreline, now turned on end, and imagine Earth containing only this primitive form of life.

Just past Snowy Range pass and Libby Flats overlook, the group viewed the various rock units along the steep mountain front of the Snowy Range, namely the Medicine Peak

Figure 39. The Nash Fork Formation at Stop 7 contains spectacular outcrops of 1.7-billion-year-old stromatolites. These are very accessible to the public, located right along the Forest Service road to Sugarloaf Recreation Area.

and Sugarloaf quartzites and the Lookout Schist. After an excellent lunch at Mirror Lake campground, Stop 9, Jim and Dr. Mears discussed more details of the glacial features, high level erosion surfaces (such as Libby Flats), and glaciation of the Snowy Range; Dr. Mears also described the plane crash into the mountain front that occurred in 1956.

The field trip turned around and headed back toward Centennial on State Highway 130, and at the U.S. Forest Service Information Center, turned south on the gravel road along the canyon of the Little Laramie River. At Stop 10, Dan led the group in a gold panning demonstration at the Mother Lode prospect (**Figure 40**). Several participants found gold flakes and some even recovered some small pyrope garnets, which are indicator minerals for kimberlites (some of which are diamond host rocks). From here, the field trip route backtracked to State Highway 130, continued east past Centennial, and turned south on County Road 416.

Figure 40. Intrepid prospectors panning for gold on the Little Laramie River at Stop 10. Several panners actually found flakes of gold along with some small pyrope

After crossing Centennial Valley on this road (which must hold the world's record number of washboards) and reaching State Highway 11, the caravan made two stops (11 and 12) to examine Jurassic and Cretaceous rocks on the east flank of Centennial Valley syncline. Ray led the group through the local stratigraphic sequence and described the major formations in the area. The group located some fish scales in the Mowry Shale and some invertebrate fossils in the Sundance Formation and got a chance to see the rocks up close.

The vans turned back north on State Highway 11 then east on State Highway 130, arriving back in Laramie about 5:00 PM to end the trip. The participants and the WSGS staff enjoyed an excellent day in the field and had many opportunities to exchange knowledge and ideas. It was a good educational experience and nearly everyone agreed that these field trips should continue into the future.

Plans for the 2001 field trip are still being formulated. The WSGS would entertain suggestions from the public on the general theme or the area to be visited on future trips.

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