Wyoming Geo-notes

Number 73

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HAZUS for Wyoming

The Wolf Mountain Slide and debris flow

Wyoming State Geological Survey
Lance Cook, State Geologist

Laramie, Wyoming
April, 2002

Featured Articles

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Richard W. Jones, PG-2972
Editor

Jaime R. Moulton
Layout and design

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Front cover: Boar's Tusk, the prominent feature in the middle of the slide, is a volcanic neck of wyomingite (phlogopite-leucite-lamproite). Located about 26 miles north of Rock Springs, this area is in the southwestern part of the Jack Morrow Hills oil and gas project area (see **OVERVIEW** article, p. 1-3) as well as part of the Leucite Hills volcanic field (see **METALS AND PRECIOUS STONES UPDATE**, p. 27) discussed in this issue. Boar's Tusk rises some 300 feet above the valley floor in the western part of the Killpecker sand dune field and like North and South Table Mountain (on left skyline), is composed of 1.1-million-year-old volcanic rocks known as lamproites. View is to southeast from north end of White Mountain. Photograph by Richard W. Jones, November, 1981.

MINERALS UPDATE

Overview

Lance Cook, PG-2577

State Geologist, Wyoming State Geological Survey

The latest mineral production numbers for 2001 have now been compiled (**Table 1**). Wyoming methane set a new production record at 1.4306 trillion cubic feet (TCF), along with coal at 368.7 million short tons. Production of helium and CO_2 increased, as did trona, but uranium and oil production continued to decline. The two major revenue producers from minerals in Wyoming, natural gas (methane) and coal, recorded price increases in 2001 (**Table 2**). Oil prices declined, but not as much as we had predicted, and mined trona increased slightly in price. The individual mineral updates provide more details on production, prices, and forecasts. Also in this issue of *Wyoming Geo-notes* is an article on the HAZUS program being run by the Geologic Hazards Section of the Wyoming State Geological Survey (WSGS) and another installment describing the Wyoming Department of Transportation's geotechnical and engineering work on landslides in Snake River Canyon.

In this overview section of *Wyoming Geo-notes*, we have included some highlights from a recently released paper, *Oil and gas resources of the Jack Morrow Hills and surrounding areas, southwestern Wyoming*, Open File Report 2002-1 (Cook and others, 2002). This paper is a systematic analysis of the expected-case oil and gas resource in the U.S. Bureau of Land Management's (BLM's) Jack Morrow Hills planning area. Electronic copies of the full paper and a press release summarizing our findings can be accessed on our website, or copies can be ordered from our sales desk. This effort occupied personnel in several of the WSGS sections for the better part of a month and delayed publication of this issue of *Wyoming Geo-notes* and several other pending reports.

Resource management plans

Federal land access and resource issues will continue to dominate the news for Wyoming minerals. Resource management plans for the Jack Morrow Hills, the Pinedale District, and the Continental Divide areas are being updated by the BLM. Forest plans for the Bridger-Teton, Medicine Bow, and Bighorn national forests are all due for revision by the U.S. Forest Service. As all of these federal land use planning efforts will be underway soon or are already underway, we hope to assist the federal agencies by ensuring the use of accurate and scientific resource data. This will be a challenging task for our small agency.

Oil and gas resources of the Jack Morrow Hills area

The Jack Morrow Hills (JMH) area of southwestern Wyoming is located between the Rock Springs uplift in the Greater Green River Basin (GGRB) and the southern end of the Wind River Range (**Figure 1**). The area includes 574,800 acres of federal land and 51,134 acres of state land within BLM's Jack Morrow Hills Coordinated Activity Plan and has a high potential for oil and gas resources.

The area contains a 20,000-foot-thick sedimentary rock succession with a large number of potential hydrocarbon source and reservoir rocks. The necessary elements for commercial oil and gas production are present within the JMH. Those elements are: 1) hydrocarbon source rocks and

Table 1. Wyoming mineral production (1985 through 2001) with forecasts to 2006[1].

Calendar Year	Oil[2,3]	Methane[3,4]	Carbon Dioxide[3,4]	Helium[4,5]	Coal[6]	Trona[7]	*In situ* Uranium[8]	Sulfur[3,9]
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	1023.4	149.0	1.10	278.4	18.6	1.9	1.22
1997	70.2	1040.7	151.0	1.10	281.5	19.4	2.2	1.23
1998	65.7	1072.6	151.0	1.10	315.0	18.6	2.3	1.20
1999	61.3	1133.1	161.0	1.10	336.5	17.8	2.8	1.20
2000	60.6	1292.9	161.0	1.10	338.9	17.8	2.1	1.20
2001	57.4	1430.6	174.0	1.20	368.8	18.0	2.0	1.20
2002	54.0	1504.8	174.0	1.20	361.0	18.0	2.0	1.20
2003	51.0	1562.8	196.0	1.20	372.0	18.5	2.0	1.20
2004	48.2	1642.8	196.0	1.20	375.7	18.5	2.0	1.20
2005	45.6	1722.8	196.0	1.20	379.5	18.5	2.0	1.20
2006	43.1	1802.8	196.0	1.20	383.3	18.5	2.0	1.20

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

Table 2. Average prices paid for Wyoming oil, methane, coal, and trona (1985 through 2001) with forecasts to 2006[1].

Calendar Year	Oil[2]	Methane[3]	Coal[4]	Trona[5]
1985	24.67	3.03	11.36	35.18
1986	12.94	2.33	10.85	34.80
1987	16.42	1.78	9.80	36.56
1988	13.43	1.43	9.16	36.88
1989	16.71	1.58	8.63	40.76
1990	21.08	1.59	8.43	43.70
1991	17.33	1.46	8.06	44.18
1992	16.38	1.49	8.13	43.81
1993	14.50	1.81	7.12	40.08
1994	13.67	1.63	6.62	38.96
1995	15.50	1.13	6.38	40.93
1996	19.56	1.46	6.15	45.86
1997	17.41	1.94	5.68	42.29
1998	10.67	1.81	5.41	41.29
1999	16.44	2.06	5.19	38.49
2000	26.87	3.42	5.40	37.28
2001	21.00	3.15	5.70	38.00
2002	18.00	2.35	5.75	38.00
2003	18.00	2.35	5.82	38.00
2004	18.00	2.35	5.85	38.00
2005	18.00	2.35	5.88	38.00
2006	18.00	2.35	5.90	38.00

[1]Modified 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, 1989-2000 (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, 1991-2000; [5]Dollars per ton of trona, not soda ash. Source Wyoming Department of Revenue, 1985-1999.

timing of maturation, i.e., "charge," 2) trap or other appropriate configuration to retain hydrocarbons, 3) seal or top barrier to hydrocarbon migration, and 4) presence of reservoir-quality rocks. Evidence for the existence of hydrocarbons in these rocks has been proven indirectly by oil and gas discoveries and production from the same rocks in nearby fields and directly from hydrocarbons recovered during tests of wells drilled in the area.

Based on knowledge of the regional geology along with an analysis and interpretation of pertinent geologic data available within the project boundaries, oil and gas resources were estimated using play concepts. An oil and gas play is defined as a group of reservoirs in a geographic area that have similar geologic parameters, such as a common stratigraphic unit, reservoir lithology, depositional environment, structural setting, and trapping mechanism. The play concept is a government- and industry-accepted approach to resource estimates in oil and gas provinces that uses analogs from successful (producing) or known (discovered) hydrocarbon occurrences to predict resources that may exist in unexplored or undeveloped areas.

The oil and gas play concepts considered as analogs for plays in the JMH included conventional development in nearby producing fields, turbidite sands in the Lewis Shale, deep mountain-front structures, deep-seated thrust structures, coalbed methane (restricted to the most accessible and thickest coal beds), and overpressured, low-permeability sandstones in four different formations. For these six play concepts (in nine different formations), in-place (unrisked) resources were calculated. Risk factors related to chance of success (COS) or chance of occurrence (COO) were applied and recoverable (risked) resources were calculated for each play (**Table 3**).

Additional resources that might be available in the future from advances in technology were also assessed in **Table 3** ("Incremental Future Technology" column). These resources may be especially significant and technological advances may have a major impact on future production from JMH. A few years ago, huge gas resources in the Jonah Field and on the Pinedale anticline were essentially written off as unrecoverable, but the recent advances in technology have made literally trillions of cubic feet of gas available today.

The present value (in terms of tax revenues) to the State of Wyoming and the affected counties if the oil and gas resources were to be produced in the JMH is about $1.88 billion.

Advances in technology include: special cement formulations or techniques to avoid damaging tight gas sands; improved fracturing methods that can liberate gas from tight gas sands; application of new drilling technology (either mud chemistry improvements or advances in air drilling techniques) to avoid damage to sensitive reservoirs caused by drilling fluids; or cost effective application of multiple horizontal lateral wells in tight formations to enhance recovery. Exploration aided by new seismic techniques, which can identify subtle details key to stratigraphic traps and pressure compartments, may yield additional discoveries.

As shown in **Table 3**, the total hydrocarbon resource potential of the

Table 3. Oil and gas potential, by play, for the Jack Morrow Hills area, southwestern Wyoming.

Play Name	Target Formation	Unrisked Resource	Discount Factor (Risk/Recovery)	Present Technology Risked/Recoverable Resource	Potential # Wells	Incremental Future Technology
Conventional Development	Frontier, Dakota	0.100 TCFG	95% COS	95.00 BCFG	38	50 BCFG
Lewis Shale Turbidites	Lewis	0.137 TCFG	10% COO	13.70 BCFG	49	130 BCFG
		2.300 MMBO	2% COO	230.00 MBO		
Deep Mountain-Front Structures	Phosphoria, Madison	4.000 TCFG	2% COO	80.00 BCFG	4	400 BCFG
Deep-Seated Thrust Structures	Frontier, Dakota,	0.621 TCFG	5% COO	31.00 BCFG	88	31 BCFG
	Phosphoria, Weber	6.100 MMBO	5% COO	305.00 MBO		305 MBO
Coalbed Methane	Fort Union, Lance	13.400 TCFG	20% RF	2,680.00 BCFG	710	1,340 BCFG
Overpressured Low-perm. Sands	Frontier	40.300 TCFG	0.25% RF	100.75 BCFG	20	705 BCFG
Overpressured Low-perm. Sands	Mesaverde	354.800 TCFG	0.25% RF	887.00 BCFG	100	6,209 BCFG
Overpressured Low-perm. Sands	Lewis	2.400 TCFG	0.5% RF	12.00 BCFG	8	132 BCFG
Overpressured Low-perm. Sands	Fox Hills/Lance	14.400 TCFG	0.25% RF	36.00 BCFG	15	252 BCFG
Totals		**430.158 TCFG**		**3,935.45 BCFG**	**1,032**	**9,249 BCFG**
		8.400 MMBO		**535.00 MBO**		**305 MBO**

Abbreviations include COS = chance of success, COO = chance of occurrence, RF = recovery factor, BCFG = billion cubic feet of gas, MMBO = million barrels of oil, MBO = thousand barrels of oil, TCFG = trillion cubic feet of gas. *Wyoming State Geological Survey, March, 2002.*

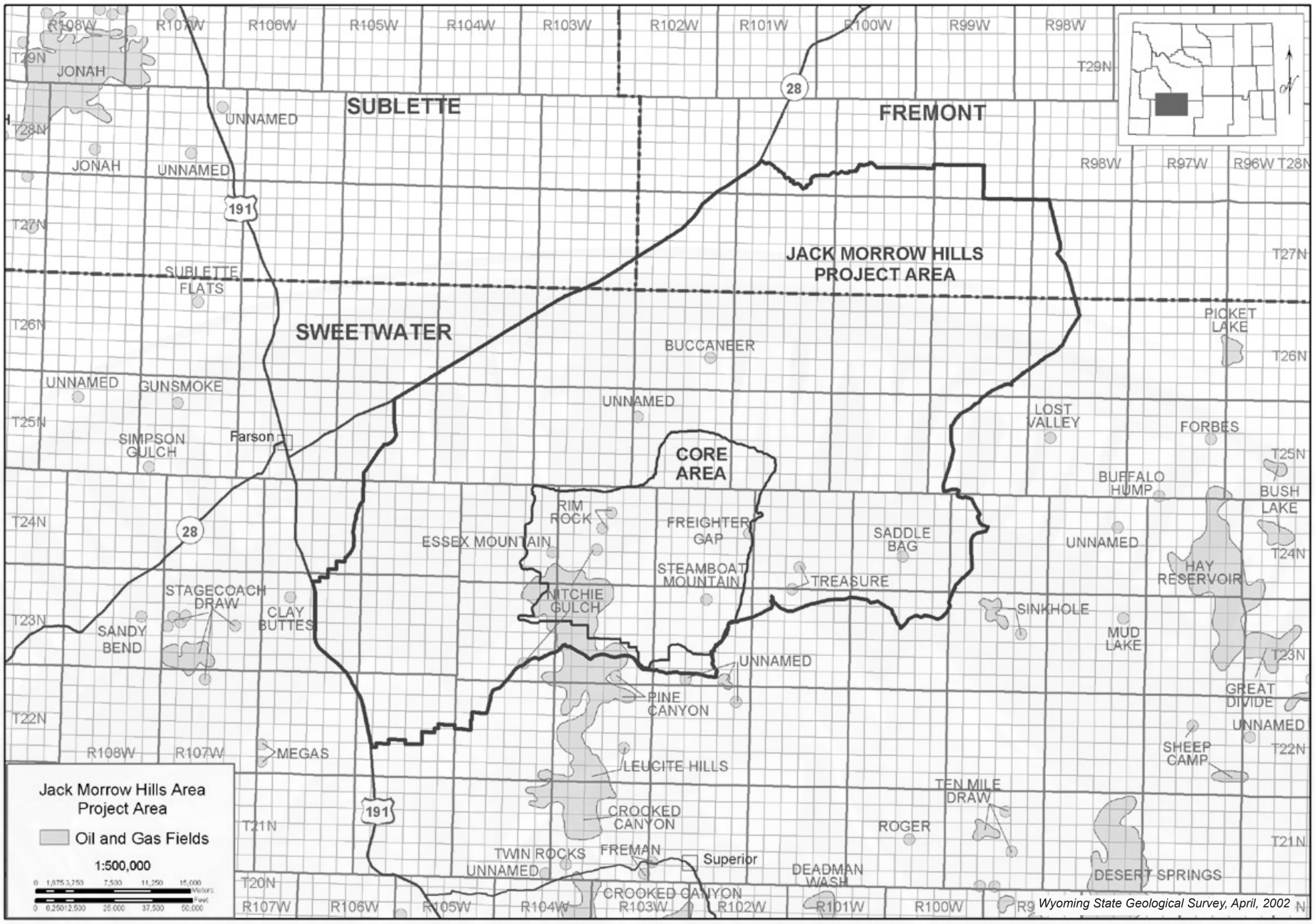

Figure 1. Location map of the Jack Morrow Hills and surrounding area, southwestern Wyoming.

JMH planning area is estimated to be 430.2 TCF of gas and 8.4 million barrels of oil (MMBO). On a risked basis, we believe there is a strong potential for up to 3935 billion cubic feet of gas (BCFG) and 535 thousand barrels of oil (MBO) to be successfully discovered and developed with present technology and an incremental 9249 BCFG and 305 MBO to be successfully discovered and developed with future technology.

The direct economic value of the JMH resource to the state and county governments, aside from indirect benefits such as increased employment and sales tax revenues, is estimated (**Table 4**). The estimate uses the "moderate" price scenario [see the full report for details] and assumes flat prices: oil price of $22.50 per barrel; gas price of $2.50 per thousand cubic feet; county ad-valorum tax rate of approximately 6%; land ownership is 8.2% state, 91.6% federal, and approximately 0.2% private; state royalty rate is 16.667%; federal royalty rate is 12.5%; and severance tax rate is 6%. The present value (in terms of tax revenues) to the State of Wyoming and the affected counties if the oil and gas resources were to be produced in the JMH is about $1.88 billion. Incremental (additional) revenues for future oil and gas resources produced from advances in technology are projected at $4.41 billion.

Reference cited

Cook, L., De Bruin, R.H., Boyd, C.S., and Jones, R.W., 2002, Oil and gas resources of the Jack Morrow Hills and surrounding areas, southwestern Wyoming: Wyoming State Geological Survey Open File Report 2002-1, 41 p., 3 oversize sheets.

Table 4. Direct value (from tax revenues) of oil and gas production from Jack Morrow Hills to the State of Wyoming and affected counties.

			Present net value*		Future net value*	
Revenue stream	Revenue rate	Percent of lands	Gas (millions)	Oil (thousands)	Gas (millions)	Oil (thousands)
County ad-valorum tax	6%	100%	$590.25	$722.00	$1,387.00	$412.00
Severance tax	6%	100%	$590.25	$722.00	$1,387.00	$412.00
1/2 Federal royalty	6.25%	91.60%	$563.19	$689.00	$1,323.00	$393.00
State royalty	16.67%	8.20%	$134.47	$165.00	$316.00	$94.00
Totals			$1,878.00	$2,298.00	$4,413.00	$1,311.00
Present value oil and gas			**$1.88 billion**			
Future value oil and gas					**$4.41 billion**	

* Net value = (revenue rate) x (% land) x (gross value); Present gross gas value = 3,935,000,000 mcf x $2.50/mcf =$9.8375 billion; Incremental gross future gas = 9,249,000,000 mcf x $2.50/mcf = $23.1225 billion; Present gross oil value = 535,000 bbl oil x $22.50/bbl = $12.037 million; Incremental gross future oil = 305,000 bbl oil x $22.50/bbl = $6.862 million. *Wyoming State Geological Survey, March, 2002.*

CALENDAR OF UPCOMING EVENTS

Talks

COALBED METHANE RESOURCES OF WYOMING– *Rodney H. De Bruin*, Rocky Mountain Energy Technology Conference, Independent Petroleum Association of Mountain States (IPAMS): Denver, Colorado, April 24-25, 2002.

RECENT DEVELOPMENTS IN WYOMING'S INDUSTRIAL MINERALS (POSTER)–*Ray E. Harris*, 38th Annual Forum on the Geology of Industrial Minerals: St. Louis, Missouri, April 28-May 2, 2002.

WYOMING GEMSTONES, and **GEOLOGY OF THE IRON MOUNTAIN KIMBERLITE DISTRICT, EASTERN WYOMING–***W. Dan Hausel*, talks for theme session "Gemstones and Semiprecious Minerals and Host Rocks in the Western U.S.," 54th Annual Meeting, Rocky Mountain Section, Geological Society of America: Cedar City, Utah, May 7-8, 2002.

THE HEALTH BENEFITS OF CARATS–*W. Dan Hausel*, Wyoming Geological Association: Petroleum Club, Casper, Wyoming, May 24, 2002.

MINING DISTRICTS OF THE MEDICINE BOW MOUNTAINS–*W. Dan Hausel*, Rocky Mountain Prospectors and Treasure Hunters Club: Fort Collins, Colorado, June 5, 2002.

PROSPECTING FOR GEMSTONES–*W. Dan Hausel*, Rocky Mountain Prospectors and Treasure Hunters Club: Fort Collins, Colorado, July 3, 2002.

PROSPECTING WYOMING–*W. Dan Hausel*, Rocky Mountain Prospectors and Treasure Hunters Club: Fort Collins, Colorado, August 7, 2002.

WYOMING GEMSTONES, and **THE GREAT 1872 DIAMOND HOAX–***W. Dan Hausel*, Colorado Friends of Mineralogy-USGS-Colorado School of Mines Mineral Symposium: September 6-8, 2002.

Field trips

CENTENNIAL RIDGE-DOUGLAS CREEK GOLD DISTRICT–*W. Dan Hausel*, Rocky Mountain Prospectors and Treasure Hunters Club: Centennial, Wyoming, June 14, 2002.

ENCAMPMENT MINING DISTRICT–*W. Dan Hausel*, Rocky Mountain Prospectors and Treasure Hunters Club: Encampment Museum, Encampment, Wyoming, July 12, 2002.

GEOLOGY, GOLD, AND MINING HISTORY OF SOUTH PASS–*W. Dan Hausel*, public field trip: Atlantic City iron ore mine turnout on State Highway 28, 8:30 am, July 20, 2002.

CHICKEN PARK DIAMONDIFEROUS KIMBERLITES– *W. Dan Hausel*, Rocky Mountain Association of Geologists "On the Rocks" program: Cherokee Park, Colorado parking lot along U.S. Highway 287, 9:30 am, August 10, 2002.

GOLD AND MINING HISTORY OF THE SOUTH PASS MINING DISTRICT–*W. Dan Hausel*, Rocky Mountain Prospectors and Treasure Hunters Club: Atlantic City iron ore mine turnout on State Highway 28, August 16, 2002.

TIN CUP DISTRICT–*W. Dan Hausel*, Rocky Mountain Prospectors and Treasure Hunters Club: Ore House cafe, Jeffrey City, Wyoming, August 30, 2002.

Meetings, conferences, exhibits, etc.

38TH ANNUAL FORUM ON THE GEOLOGY OF INDUSTRIAL MINERALS–*Ray E. Harris*: St. Louis, Missouri, April 28-May 2, 2002.

WYOMING STATE GEM AND MINERAL SHOW–*various WSGS staff*, Wyoming Gem and Mineral Society: Holiday Inn, Cheyenne, Wyoming, May 25-26, 2002.

COALBED METHANE FAIR–*various WSGS staff*: The Camplex, Gillette, Wyoming, June 6-7, 2002.

NATRONA COUNTY GEM AND MINERAL SHOW– *Richard W. Jones*: Natrona County Fairgrounds, Casper, Wyoming, June 22-23, 2002.

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS (AAPG), ROCKY MOUNTAIN SECTION, in conjunction with the **WYOMING GEOLOGICAL ASSOCIATION (WGA)–**hosted by Department of Geology and Geophysics, University of Wyoming and WSGS: University of Wyoming, Laramie, Wyoming, September 8-11, 2002.

DENVER GEM AND MINERAL SHOW–*various WSGS staff*: Denver Merchandise Mart, Denver, Colorado, September 13-15, 2002.

ASSOCIATION OF EARTH SCIENCE EDITORS (AESE) 2002 ANNUAL MEETING–*Richard W. Jones*: Halifax, Nova Scotia, Canada, September 14-18, 2002.

WESTERN STATES SEISMIC POLICY COUNCIL (WSPCC) MEETING–*James C. Case, Lance Cook*: Denver, Colorado, September 15-18, 2002.

WYOMING GAS FAIR–*various WSGS staff*: Snow King Resort, Jackson, Wyoming, September 26-27, 2002.

GEOLOGICAL SOCIETY OF AMERICA (GSA) 2002 ANNUAL MEETING–*various WSGS staff*: Colorado Convention Center, Denver, Colorado, October 27-30, 2002.

Oil and Gas Update

Rodney H. De Bruin, PG-3045

Staff Geologist–Oil and Gas, Wyoming State Geological Survey

Wyoming oil and gas producers received much lower prices for oil and natural gas in the fourth quarter of 2001 when compared to prices received earlier in the year and in 2000. The overall average prices for 2001 were lower than in 2000 for oil, but higher for natural gas. Oil production declined by 5.3%, while natural gas production increased 10.3% during 2001. Natural gas production was boosted by a large increase in coalbed methane production in the Powder River Basin, which made up 15.6% of Wyoming's total gas production in 2001. The Energy Information Administration (EIA) published its year-end 2000 reserves for crude oil, natural gas, and natural gas liquids. Almost two trillion cubic feet was added to Wyoming's dry natural gas reserves and 235 million barrels to its natural gas liquids reserves, but the state lost almost 30 million barrels of crude oil reserves. In the fourth quarter, two federal lease sales brought in over $3.1 million; the six federal sales for the year brought in almost $34 million, the highest yearly total since 1998. One state sale during the fourth quarter brought in over $679,000. Revenue from state sales was down slightly compared to recent years, mainly because no sale was held in December, 2001 due to a shortage of desirable parcels. The number of applications for permit to drill, geophysical activity, and rig counts remained healthy in the fourth quarter and for the year.

Wyoming had the largest increase of any state in proved reserves of dry natural gas with nearly two trillion cubic feet (TCF) of gas added.

Prices and production

Prices paid to Wyoming oil producers during the fourth quarter of 2001 averaged $16.39 per barrel (**Table 5**), which is the lowest quarterly average price since the second quarter of 1999. The average price for the quarter is $10.94 lower than for the fourth quarter of 2000, and $5.42 lower than for the fourth quarter of 1999. Overall oil price for 2001 was $21.59 per barrel (**Tables 2** and **5**) which is somewhat more than projected in the October, 2001 estimate by the State of Wyoming's Consensus Revenue Estimating Group (CREG). We expect future oil prices to stabilize around $18.00 per barrel (**Figure 2**). A graph of the posted sweet and sour crude oil prices and first purchase prices for Wyoming oil averaged by month (**Figure 3**) shows the continued decrease in oil prices during the year.

Oil production reported by the Wyoming Oil and Gas Conservation Commission (WOGCC) for 2001 was 57.4 million barrels (**Tables 1** and **6**). This production is a drop of 5.3% from 2000 and near what we predicted earlier (see *Wyoming Geo-notes No. 72*, December, 2001). Annual oil production from Wyoming will continue to decrease (**Figure 4**).

Spot prices for natural gas at Opal, Wyoming averaged $2.00 per thousand cubic feet (MCF) during the fourth quarter of 2001. This is $2.88 per MCF lower than the average price for the fourth quarter of 2000, and $0.13 lower than for the third quarter of 2001 (**Table 7** and **Figure 5**). The overall price of natural gas for 2001 was $3.66 per MCF, $0.51 more than we predicted earlier (see *Wyoming Geo-notes No. 72*, December, 2001). This is encouraging because it marks a third year of annual gas price increases (**Figure 6**) instead of the two years we predicted.

Natural gas production in Wyoming for 2001 was 1605.8 billion cubic feet (BCF) according to production figures from the WOGCC. This production is up 10.3% from 2000 (**Tables 1** and **8**). Coalbed methane production from the Powder River Basin accounted for 250.6 BCF of that total and was

Table 5. Monthly average price of a barrel of oil produced in Wyoming (1998 through February, 2002).

	1998		1999		2000		2001		2002	
	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative
January	$12.79	$12.79	$9.30	$9.30	$24.01	$24.01	$24.62	$24.62	**$15.30**	**$15.30**
February	$12.16	$12.47	$9.09	$9.20	$26.48	$25.25	$24.82	$24.72	**$16.50**	**$15.90**
March	$10.97	$11.97	$11.77	$10.05	$27.24	$25.91	$22.71	$24.05		
April	$11.54	$11.87	$14.34	$11.12	$22.92	$25.16	$22.85	$23.75		
May	$11.19	$11.73	$15.16	$11.93	$26.06	$25.34	$23.68	$23.74		
June	$9.63	$11.38	$15.36	$12.50	$28.31	$25.84	$22.99	$23.61		
July	$10.20	$11.21	$17.39	$13.20	$27.12	$26.02	$22.55	$23.46		
August	$9.58	$11.01	$18.43	$13.86	$28.18	$26.29	$23.67	$23.49		
September	$11.19	$11.03	$20.97	$14.65	$30.22	$26.73	$22.02	$23.32		
October	$11.04	$11.03	$20.01	$15.18	$28.75	$26.93	$17.71	$22.76		
November	$9.64	$10.90	$22.20	$15.82	$29.63	$27.17	$16.44	$22.19		
December	$8.05	$10.66	$23.22	$16.44	$23.60	$26.88	$15.03	$21.59		
Average yearly price		**$10.66**		**$16.44**		**$26.88**		**$21.59**		

All averages are derived from published monthly reports by the Energy Information Administration, except that averages in bold print in 2002 are estimated from various unpublished bulletins listing posted prices. *Wyoming State Geological Survey, Oil and Gas Section, March, 2002.*

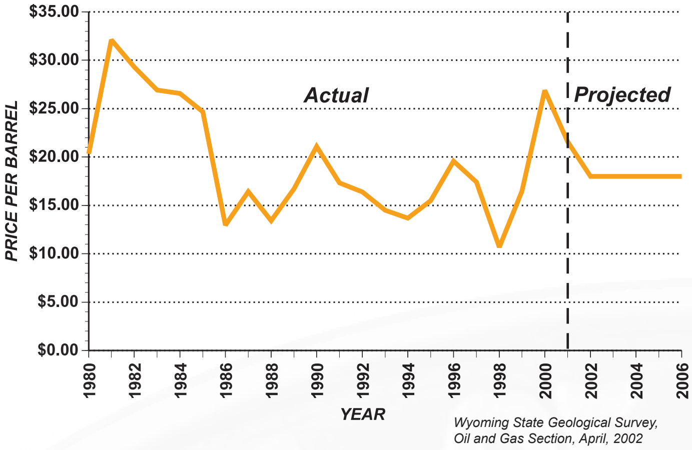

Figure 2. Average prices paid for Wyoming crude oil (1980 through 2001) with forecasts to 2006.

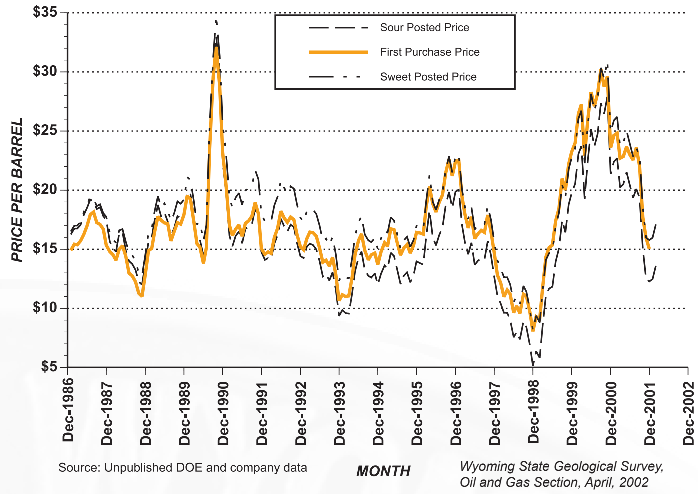

Figure 3. Wyoming posted sweet and sour crude oil prices and first purchase prices, averaged by month (January, 1987 through February, 2002).

15.6% of Wyoming's natural gas production in 2001 (see **COALBED METHANE UPDATE** for details). Both helium and carbon dioxide production also increased in 2001 (**Figure 7**), as ExxonMobil's LaBarge plant increased the amount of gas processed.

Reports, projects, and transactions

In the last quarter of 2001, the EIA released its new reserve estimates for crude oil, natural gas, and natural gas liquids in the U.S. Among the top ten states at the end of 2000, Wyoming ranked third in dry natural gas reserves, third in natural gas liquids reserves, and sixth in crude oil reserves (**Table 9**). Wyoming had the largest increase of any state in proved reserves of dry natural gas with nearly two trillion cubic feet (TCF) of gas added (**Table 10**). Most of that increase came from the 1.54 TCF of coalbed methane added from the Powder River Basin. This is EIA's first addition of coalbed methane to Wyoming's total for dry gas reserves. The increase in reserves came despite production of over 1.4 TCF in 2000. Wyoming's dry natural gas reserves are at their highest level ever and are approaching reserves of

Table 6. Monthly oil production from Wyoming in barrels (1997 through Dember, 2001).

	1997		1998		1999		2000		2001	
	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative
January	5,964,848	5,964,848	5,846,364	5,846,364	5,333,257	5,333,257	5,185,683	5,185,683	5,001,928	5,001,928
February	5,459,518	11,424,366	5,233,502	11,079,866	4,744,527	10,077,784	4,871,733	10,057,416	4,493,565	9,495,493
March	6,014,780	17,439,146	5,759,176	16,839,042	5,297,674	15,375,458	5,202,533	15,259,949	4,969,821	14,465,314
April	5,729,869	23,169,015	5,534,568	22,373,610	5,065,591	20,441,049	5,003,812	20,263,761	4,802,352	19,267,666
May	6,050,971	29,219,986	5,626,125	27,999,735	5,200,031	25,641,080	5,201,564	25,465,325	4,930,856	24,198,522
June	5,761,549	34,981,535	5,335,463	33,335,198	5,000,039	30,641,119	5,001,932	30,467,257	4,664,829	28,863,351
July	5,964,005	40,945,540	5,464,514	38,799,712	5,164,705	35,805,824	5,077,548	35,544,805	4,846,220	33,709,571
August	5,868,789	46,814,329	5,287,415	44,087,127	5,190,052	40,995,876	5,093,558	40,638,363	4,761,492	38,471,063
September	5,710,557	52,524,886	5,109,053	49,196,180	5,081,384	46,077,260	4,983,126	45,621,489	4,718,493	43,189,556
October	5,949,974	58,474,860	5,274,269	54,470,449	5,163,165	51,240,425	5,156,755	50,778,244	4,821,224	48,010,780
November	5,800,811	64,275,671	5,232,287	59,702,736	5,010,985	56,251,410	4,877,512	55,655,756	4,645,045	52,655,825
December	5,900,791	70,176,462	5,078,909	64,781,645	5,090,959	61,342,369	4,970,686	60,626,442	4,744,316	57,400,141
Total Barrels Reported[1]		**70,176,462**		**64,781,645**		**61,342,369**		**60,626,442**		**57,400,141**
Total Barrels not Reported[2]		**52,364**		**897,131**						
Total Barrels Produced[3]		**70,228,826**		**65,678,776**						

[1]Monthly production reports from Petroleum Information/Dwights LLC. Except for 1999, 2000, and 2001 which is from Wyoming Oil and Gas Conservation Commission; [2](Total barrels produced) minus (total barrels reported by Petroleum Information/Dwights LLC.); [3]Wyoming Oil and Gas Conservation Commission. *Wyoming State Geological Survey, Oil and Gas Section, March, 2002.*

Table 7. Monthly average spot sale price for a thousand cubic feet (MCF) of natural gas at Opal, Wyoming (1998 through March, 2002).

	1998		1999		2000		2001		2002	
	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative
January	$2.05	$2.05	$1.80	$1.80	$2.20	$2.20	$8.75	$8.75	$2.35	$2.35
February	$1.70	$1.88	$1.65	$1.73	$2.40	$2.30	$6.60	$7.68	$1.75	$2.05
March	$1.90	$1.88	$1.50	$1.65	$2.35	$2.32	$4.90	$6.75	$2.00	$2.03
April	$1.90	$1.89	$1.60	$1.64	$2.70	$2.41	$4.55	$6.20		
May	$1.95	$1.90	$2.00	$1.71	$2.70	$2.47	$4.10	$5.78		
June	$1.65	$1.86	$2.00	$1.76	$3.65	$2.67	$2.60	$5.25		
July	$1.60	$1.82	$2.00	$1.79	$3.90	$2.84	$2.05	$4.79		
August	$1.75	$1.81	$2.20	$1.84	$3.10	$2.88	$2.25	$4.48		
September	$1.60	$1.79	$2.60	$1.93	$3.40	$2.93	$2.10	$4.21		
October	$1.65	$1.78	$2.40	$1.98	$4.30	$3.07	$1.25	$3.92		
November	$2.00	$1.80	$2.85	$2.05	$4.35	$3.19	$2.60	$3.80		
December	$2.00	$1.81	$2.10	$2.06	$6.00	$3.42	$2.15	$3.66		
Average yearly price		**$1.81**		**$2.06**		**$3.42**		**$3.66**		

Source: American Gas Association's monthly reports. *Wyoming State Geological Survey, Oil and Gas Section, March, 2002.*

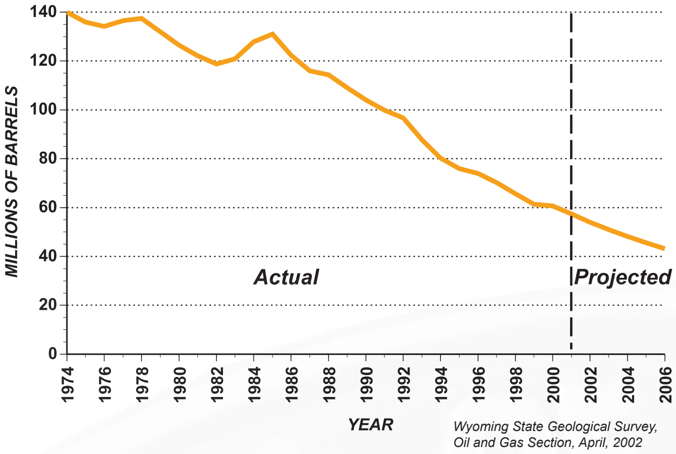

Figure 4. Annual crude oil production from Wyoming (1974 through 2001) with forecasts to 2006.

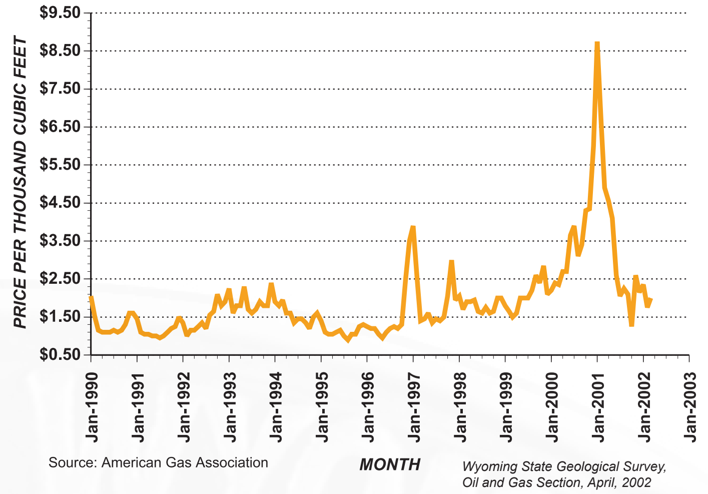

Figure 5. Spot sale prices for methane at Opal, Wyoming, averaged by month (January, 1990 through March, 2002).

second-place New Mexico. The EIA also revised Wyoming's natural gas liquids upward to their highest level since 1988 (**Table 10**). Crude oil reserves were revised downward, but Wyoming still managed to move past Louisiana into sixth place in crude oil reserves among the states (**Table 9**).

Quantum Geophysical proposed a seismic survey on or adjacent to existing federal oil and gas leases located within the Adobe Town Wilderness Study Area in Sweetwater County. Lands involved in the proposal are in T14N, R98W; T15N, R98W; and T15N, R97W.

WesternGeco proposed a seismic survey on federal, state, and private lands in Sweetwater and Fremont counties. The area covered by the proposed project is approximately bounded by the Sweetwater River on the north, South Pass on the west, Cyclone Rim on the south, and Bison Basin Road on the east. The project would include about 102 miles of linear seismic lines. Approximately 15 miles of one of the lines would be located in the area covered by the Jack Morrow Hills Coordinated Activity Plan currently being revised by the U.S. Bureau of Land Management (BLM). An environmental assessment will be prepared for the seismic project.

The BLM has approved the Horse Trap natural gas project proposed by Condor Exploration, LLC. The project involves the development of 24 natural gas wells in a 13,680-acre area about 13 miles northeast of Kemmereer. Condor expects the

Table 8. Monthly natural gas production from Wyoming in thousands of cubic feet (MCF) (1997 through December, 2001).

	1997		1998		1999		2000		2001	
	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative
January	99,579,818	99,579,818	103,640,214	103,640,214	108,524,793	108,524,793	122,078,095	122,078,095	135,968,875	135,968,875
February	91,766,159	191,345,977	94,501,819	198,142,033	94,288,888	202,813,681	114,204,669	236,282,764	123,372,642	259,341,517
March	104,157,578	295,503,555	103,906,999	302,049,032	111,012,987	313,826,668	121,104,908	357,387,672	138,969,778	398,311,295
April	99,459,039	394,962,594	98,201,007	400,250,039	102,363,550	416,190,218	118,775,280	476,162,952	132,559,769	530,871,064
May	101,070,371	496,032,965	96,741,237	496,991,276	104,746,697	520,936,915	118,462,106	594,623,058	138,100,005	668,971,069
June	91,905,308	587,938,273	98,413,520	595,404,796	102,717,295	623,654,210	116,887,377	711,512,435	126,733,129	795,704,198
July	100,129,497	688,067,770	102,055,968	697,460,764	106,733,493	730,387,703	120,690,168	832,202,603	131,151,216	926,855,414
August	97,673,622	785,741,392	105,378,334	802,839,098	107,536,099	837,923,802	122,412,623	954,615,226	132,329,266	1,059,184,680
September	100,028,888	885,770,280	98,474,782	901,313,880	108,200,542	946,124,344	119,730,975	1,074,346,201	130,725,850	1,189,910,530
October	102,206,875	987,977,155	96,470,624	997,784,504	118,545,893	1,064,670,237	127,507,997	1,201,854,198	136,704,129	1,326,614,659
November	100,752,128	1,088,729,283	103,445,859	1,101,230,363	110,904,046	1,175,574,283	122,846,630	1,324,700,828	136,260,720	1,462,875,379
December	103,415,430	1,192,144,713	99,339,043	1,200,569,406	119,648,215	1,295,222,498	130,711,331	1,455,412,159	142,912,497	1,605,787,876
Total MCF Reported[1]		**1,192,144,713**		**1,200,569,406**		**1,295,222,498**		**1,455,412,159**		**1,605,787,876**
Total MCF not Reported[2]		**683,432**		**22,955,142**						
Total MCF Produced[3]		**1,192,828,145**		**1,223,524,548**						

[1]Monthly production reports from Petroleum Information/Dwights LLC. Except for 1999, 2000, and 2001 which is from Wyoming Oil and Gas Conservation Commission; [2](Total MCF produced) minus (total MCF reported by Petroleum Information/Dwights LLC.); [3]Wyoming Oil and Gas Conservation Commission. *Wyoming State Geological Survey, Oil and Gas Section, March, 2002.*

Table 9. 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 begining of 2001.

State	Crude oil	State	Dry natural gas	State	Natural gas liquids
Texas	5.273	Texas	42.082	Texas	2.819
Alaska	4.861	New Mexico	17.322	New Mexico	0.896
California	3.813	**Wyoming**	**16.158**	**Wyoming**	**0.750**
New Mexico	0.719	Oklahoma	13.699	Oklahoma	0.734
Oklahoma	0.610	Colorado	10.428	Louisiana	0.436
Wyoming	**0.561**	Louisiana	9.239	Colorado	0.316
Louisiana	0.529	Alaska	9.237	Kansas	0.306
Utah	0.283	Kansas	5.299	Alaska	0.277
North Dakota	0.270	Utah	4.235	Utah	0.197
Montana	0.235	Alabama	4.149	Alabama	0.150

Source: U.S. Department of Energy, 2001. *Wyoming State Geological Survey, Oil and Gas Section, March, 2002.*

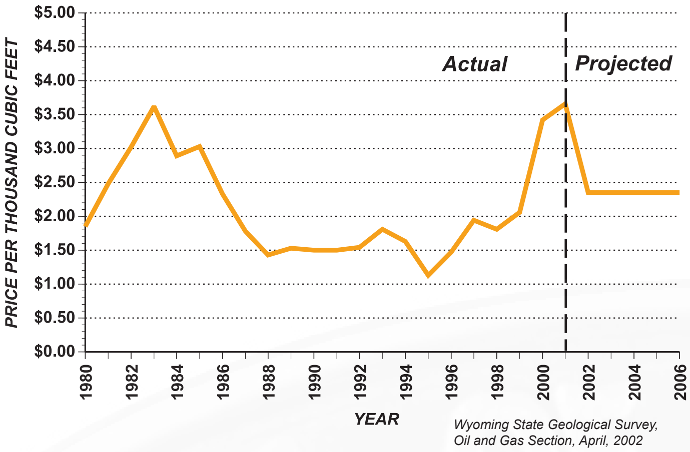

Figure 6. Average prices paid for Wyoming methane (1980 through 2001) with forecasts to 2006.

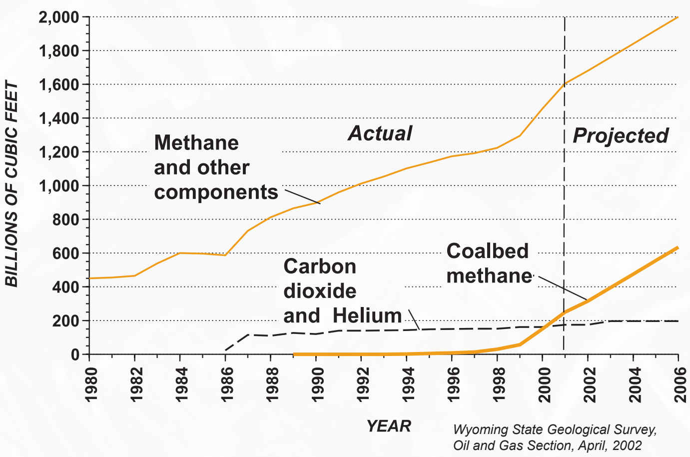

Figure 7. Annual natural gas production from Wyoming (1980 through 2001) with forecasts to 2006.

drilling to take about two years. Two producing subthrust Amsden Formation wells in T23N, R115W are already located in the project area, and Condor has drilled three other subthrust Amsden wells in the project area.

Howell Corp. purchased Conoco's interest in Elk Basin Field in the Bighorn Basin for $26 million. The purchase will more than double Howell's reserves in Elk Basin, will increase Howell's net production by about 2150 barrels of liquid hydrocarbons per day, and will result in the company owning approximately 64% of the working interest in the field.

Kinder Morgan Energy Partners, L.P. signed a definitive agreement to increase its ownership in Trailblazer Pipeline Co. to 100% by acquiring a 33.3% interest from Enron Trailblazer Co. for $68 million. Kinder Morgan already operates the 436-mile natural gas interstate pipeline that transports gas from Rockport, Colorado (just south of the Wyoming-Colorado line) to Beatrice, Nebraska.

Williams Energy Services was the company of choice by five natural gas producing companies to process natural gas

Table 10. Comparison of Wyoming'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 2000.

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
2000	0.561	16.158	0.750

Source: U.S. Department of Energy, 2001. [1] Estimated from U.S. Department of Energy figures. *Wyoming State Geological Survey, Oil and Gas Section, March, 2002.*

from Jonah and Pinedale anticline fields. AEC Oil & Gas, Amoco Production Co., McMurry Energy Co., Nerd Energy Inc., and Williams' own production unit have dedicated about 575 million cubic feet (MMCF) of gas per day to the Williams processing plant in Opal, Wyoming. The Opal plant was expanded in early 2000 and can now process 1.1 BCF of gas per day. Williams also operates a plant near Wamsutter, Wyoming that is being expanded from 250 to 400 MMCF of gas per day.

TEPPCO Partners, L.P. acquired Jonah Gas Gathering Co. for $360 million from Green River Pipeline, LLC. and McMurry Oil Co., both subsidiaries of Alberta Energy Co. (AEC). The 300-mile Jonah system gathers and transports natural gas from Jonah Field to processing plants. The processed gas is then delivered to several interstate pipelines. The Jonah system will be managed and operated by Duke Energy Field Services, L.P.

Western Gas Resources and Questa Market Resources formed a joint venture to provide gas gathering and compression services to the Pinedale anticline and Jonah Field areas. The companies have formed Rendezvous Gas Services, LLC. that will construct and operate gas pipeline and compression facilities having the capacity to transport 275 MMCF of gas per day. Rendezvous will deliver natural gas for blending and processing services to Mountain Gas Resource's (subsidiary of Western Gas Resources) Granger plant and to the Blacks Fork plant (50% owned by Questar).

The U.S. Department of Energy has awarded a contract to Advanced Resources International to accomplish three goals: 1) Build a regional database on surface water composition and chemistry for key Rocky Mountain gas basins; 2) Identify water sources and waterways in close proximity to natural gas formations; and 3) Verify regional water storage, flow models, and field tests to avoid or mitigate large amounts of produced water. The effort is aimed at the major northern Rocky Mountain gas basins, with an emphasis on the Green River and Wind River basins of Wyoming and the Waltman/Cave Gulch field area on the northeastern side of the Wind River Basin. The $678,316 contract will last 27 months.

Lease sales

Leasing activity at the October, 2001 sale held by the Wyoming Office of State Lands and Investments (State Lands) was distributed throughout Wyoming (**Figure 8**). Shama Zoe, L.P. made the sale's top per-acre bid of $120 for a 640-acre tract that covers all of section 36, T32N, R111W (**location A, Figure 8**). The lease is about three miles east of Ultra Resources 32-33 Cottonwood-Federal discovery well, which was completed in 1998 from the Lance Formation, the Mesaverde Formation, and the Ericson Sandstone. There were only nine leases at this sale that received bids of $50 or more per acre. The sale generated revenue of over $679,000 and the average per-acre bid was $12.72 (**Table 11**).

For the year 2001, over 203,000 acres were leased from the State of Wyoming and revenues generated for the state were about $4.7 million, less than the previous three years (**Table 11**). Fewer parcels were leased in comparison with previous years, but the average price per acre leased was higher.

The Oil and Gas and the Publications sections at the WSGS have completed revising four oil and gas maps of Wyoming basins. . .

Leasing activity at the October, 2001 BLM sale was heaviest in the Powder River Basin and in southwestern Wyoming (**Figure 9**). Hanson & Strahn, Inc. made the high per-acre bid of $160 for a 38.34-acre lease that covers parts of section 2, T48N, R70W (**location A, Figure 9**). The lease is in the vicinity of Fourche Field, a Minnelusa oil producer. There were only seven parcels at this sale that received bids of $50 or more per acre. The sale generated revenue of just under $1 million and the average per-acre bid was $9.25 (**Table 11**).

Leasing activity at the December BLM sale was heaviest in southwestern Wyoming (**Figure 9**). Baseline Minerals, Inc. made the high per-acre bid of $550 for a 71.44-acre lease that covers parts of section 6, T47N, R75W (**location A, Figure 9**). The lease is in the vicinity of shallow coalbed methane production from the Fort Union Formation. There were 22 parcels at this sale that received bids of $50 or more per acre. The sale generated revenue of over $2.1 million and the average per-acre bid was $19.28 (**Table 11**).

For the year 2001, federal lease sales generated revenues from bonus bids of almost $34 million (of which the State

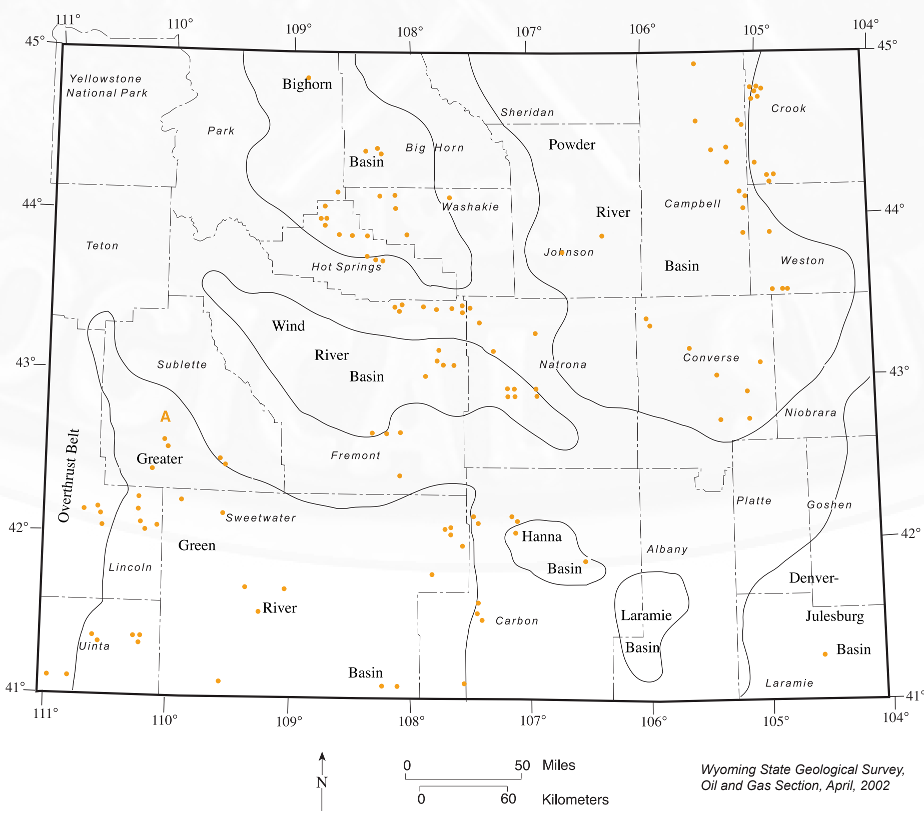

Figure 8. Locations of state oil and gas tracts leased by the Office of State Lands and Investments at its October, 2001 sale. Locations are approximate and may represent more than one tract.

Table 11. Federal and State competitive oil and gas lease sales in Wyoming (1996 through December, 2001).

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
October	$5,028,610	147	129	149,934	124,724	$40.32	$510.00
December	$6,352,525	185	179	182,935	180,380	$35.22	$725.00
TOTAL	$31,537,729	1183	1055	1,058,204	898,612	$35.09	$725.00
				2001			
February	$9,138,921	202	159	224,225	148,972	$61.35	$1,475.00
April	$10,976,580	185	184	221,147	221,067	$49.65	$530.00
June	$3,088,796	158	149	144,738	138,088	$22.37	$360.00
August	$7,626,362	204	190	260,409	245,116	$31.11	$525.00
October	$998,308	119	105	127,396	107,880	$9.25	$160.00
December	$2,162,599	155	146	125,830	112,159	$9.28	$550.00
TOTAL	$33,991,566	1023	933	1,103,745	973,282	$34.92	$1475.00

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
October	$1,660,315	300	216	117,598	81,603	$20.35	$268.00
December	$1,240,442	300	192	109,375	62,636	$19.80	$210.00
TOTAL	$6,495,616	1199	796	475,090	295,915	$21.95	$775.00
			2001				
April	$2,250,353	300	212	112,379	82,834	$27.16	$450.00
June	$1,754,320	300	192	111,507	66,829	$26.25	$650.00
October	$679,343	300	129	112,255	53,396	$12.72	$120.00
TOTAL	$4,684,016	900	533	336,141	203,059	$23.07	$650.00

Sources: Wyoming Office of State Lands and Investments, Petroleum Information/Dwights LLC - Rocky Mountain Region Report, and U.S. Bureau of Land Management. *Wyoming State Geological Survey, Oil and Gas Section, March, 2002.*

of Wyoming receives half). This is more than the last two years but less than the $63.8 million recorded in 1998 (**Table 11**). In total, 933 parcels containing 973,282 acres were leased for an average price per acre of $34.92.

Permitting and drilling

The WOGCC approved 2718 Applications for Permit to Drill (APDs) in the fourth quarter of 2001. The total for the fourth quarter of 2001 is more than the number of APDs approved in all of 1995, 1996, 1997, or 1998 (**Table 12**). Campbell County again led with 56.5% of the total APDs that were approved in the fourth quarter. Sheridan and Johnson counties combined for another 31.3% of the total APDs that were approved. Nearly all of the approved APDs in these three counties were for coalbed methane tests. The total approved APDs in 2001 was 3114 more than were approved in 2000 and the highest total ever for one year.

The WOGCC permitted 11 seismic projects in the fourth quarter of 2001 (**Table 13**). The number of permits is the same as for the fourth quarter of 2000; however, the number of conventional miles permitted is higher than for 2000 and the total square miles of 3-D seismic is only slightly lower. Geophysical activity is a good indicator of future exploration and production drilling.

The average daily rig count for the fourth quarter of 2001 was 49. This average is two less than for the fourth quarter of 2000. The rig count does not include rigs drilling for coalbed methane. **Figure 10** shows the Wyoming daily rig count averaged by month and by year. The average rig count for 2001 was 55 compared to only 41 in 2000 and 32 in 1999.

Publication and maps of interest

The March 4, 2002 issue of the Oil and Gas Journal contains an insert in poster format with type logs of the Bighorn, Powder River, and Wind River basins. The poster was a joint effort of the Oil and Gas Section of the WSGS, the WOGCC, and strataGRAPHIX.

The Oil and Gas and the Publications sections at the WSGS have completed revising four oil and gas maps of Wyoming basins, Map Series 51, 52, 53, and 54. The maps are now completed using true Geographic Information Systems (GIS)-based data via ESRI's ArcGIS® software. Users can now obtain the GIS databases from the WSGS for each quadrant of Wyoming on CD-ROM, as well as viewable/plottable versions of the maps. In addition, we are developing a new, large format oil and gas map of the entire state using these data. Color, plotted hard copies of each map will also be available.

Exploration and development

Company data, news releases, and information compiled and published by Petroleum Information/Dwights, LLC. are used to track oil and gas exploration and development activity in Wyoming. **Table 14** reports the most significant activities exclusive of coalbed methane (see the **COALBED METHANE UPDATE** for development in the industry) during the fourth quarter of 2001. The numbers correspond to locations on **Figure 11**.

References cited

Energy Information Administration, 2001, U.S. crude oil, natural gas, and natural gas liquids reserves: Annual Report 2000: Washington, D.C., 160 p.

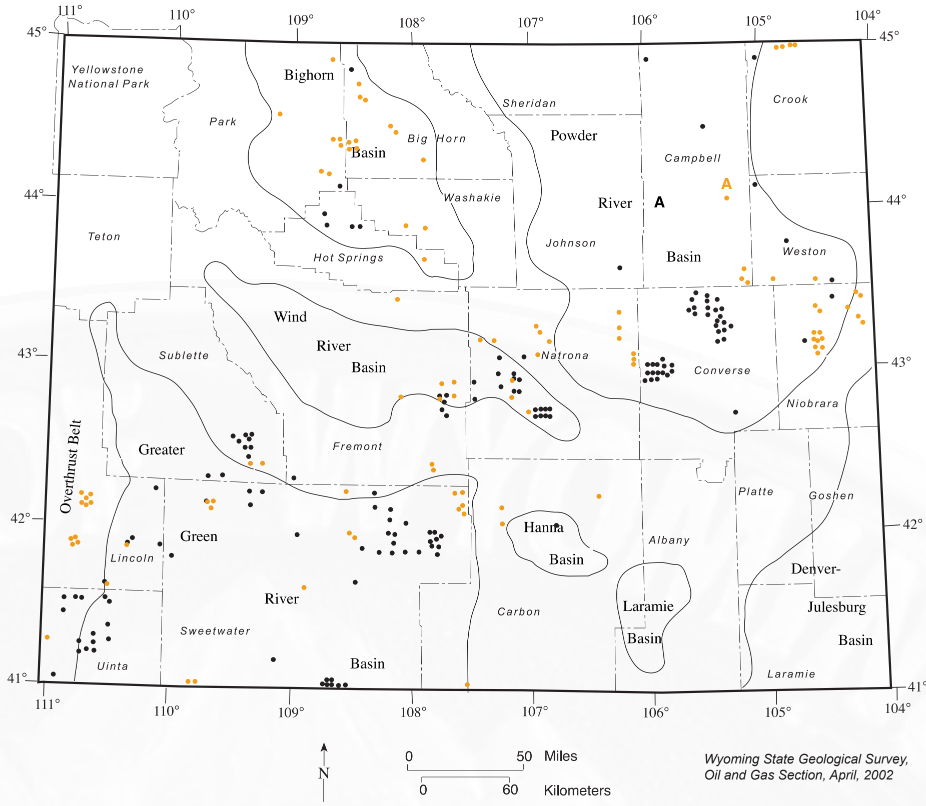

Figure 9. Locations of federal oil and gas tracts leased by the U.S. Bureau of Land Management at its October, 2001 sale (locations in yellow) and its December, 2001 sale (locations in black). Locations are approximate and may represent more than one tract.

Table 12. Number of Applications for Permit to Drill (APDs) approved by the Wyoming Oil and Gas Conservation Commission (1995 through December, 2001).

County	1995 APDs	1996 APDs	1997 APDs	1998 APDs	1999 APDs	2000 APDs	2001 APDs
Albany	1	1	0	0	0	0	1
Big Horn	16	53	59	13	6	11	23
Campbell	151	554	941	1586	4461	5580	6204
Carbon	50	77	84	96	127	174	261
Converse	29	20	16	6	19	70	25
Crook	15	37	26	29	30	47	20
Fremont	30	26	58	76	67	136	149
Goshen	0	0	0	0	0	0	0
Hot Springs	13	24	42	1	8	6	2
Johnson	6	16	6	49	304	769	805
Laramie	10	2	3	2	0	2	3
Lincoln	64	55	122	105	51	70	87
Natrona	80	74	59	36	51	53	45
Niobrara	4	7	8	8	5	18	15
Park	20	30	25	11	12	18	45
Platte	0	0	0	0	0	0	0
Sheridan	0	0	2	35	416	891	1811
Sublette	61	118	179	230	189	338	435
Sweetwater	153	136	210	181	124	335	534
Teton	0	0	0	0	0	0	0
Uinta	11	10	27	26	26	53	35
Washakie	31	30	36	9	0	7	10
Weston	10	10	5	6	4	20	7
Totals	**755**	**1280**	**1908**	**2505**	**5900**	**8598**	**10,517**

Source: All data are from the Wyoming Oil and Gas Conservation Commission. *Wyoming State Geological Survey, Oil and Gas Section, March, 2002.*

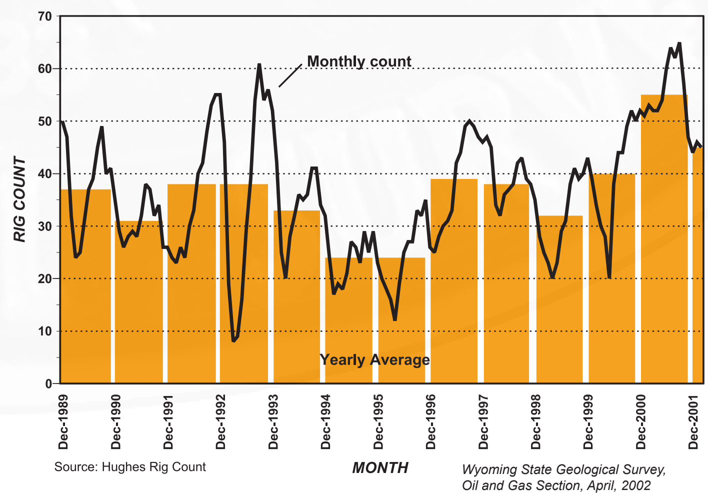

Figure 10. Wyoming daily rig count, exclusive of coalbed methane rigs, averaged by month and year (December, 1989 through December, 2001).

Table 13. Number of seismic projects and miles permitted by the Wyoming Oil and Gas Conservation Commission (1997 through December, 2001).

	1997			1998			1999			2000			2001		
County	Permits	Conventional Miles	3-D Square Miles	Permits	Conventional Miles	3-D Square Miles	Permits	Conventional Miles	3-D Square Miles	Permits	Conventional Miles	3-D Square Miles	Permits	Conventional Miles	3-D Square Miles
Albany	0	0	0	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	1	0	4
Campbell	20	52	79	14	18	182	4	4	10	14	64	132	5	38	3
Carbon	3	7	190	4	0	318	5	77	57	0	0	0	1	500	0
Converse	1	5	0	4	12	239	1	0	50	1	15	0	0	0	0
Crook	7	8	18	2	2	4	1	0	10	7	16	22	4	32	0
Fremont	6	43	126	2	100	0	1	0	88	4	25	116	2	70	15
Goshen	2	227	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot Springs	1	8	0	4	19	0	0	0	0	0	0	0	0	0	0
Johnson	2	7	17	1	4	0	0	0	0	4	35	0	2	4	4
Laramie	0	0	0	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	1	0	25
Natrona	5	14	101	6	12	214	2	0	230	5	36	135	2	19	63
Niobrara	0	0	0	0	0	0	5	16	31	1	0	25	1	0	16
Park	4	56	58	3	16	132	3	25	32	1	13	0	4	21	20
Platte	0	0	0	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	2	0	81
Sublette	1	0	61	2	1	115	3	0	308	4	77	44	10	261	374
Sweetwater	4	66	296	6	214	66	9	0	530	13	54	1004	11	129	802
Teton	0	0	0	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	1	259	0
Washakie	3	36	0	4	41	35	1	0	8	0	0	0	0	0	0
Weston	1	0	17	1	0	35	1	40	0	0	0	0	0	0	0
Totals	**65**	**536**	**1124**	**58**	**463**	**1503**	**38**	**162**	**1412**	**55**	**722**	**1478**	**47**	**1333**	**1407**

Source: All data are from the Wyoming Oil and Gas Conservation Commission. *Wyoming State Geological Survey, Oil and Gas Section, March, 2002.*

Table 14. Significant exploration and development wells in Wyoming, fourth quarter of 2001[1]. Number corresponds to location on Figure 11.

	Company name	Well name/number	Location	Formation tested	Depth(s) interval(s) tested	Tested prod. (per day)	Remarks
1	Amoco Production	2AH Champlin-457-D	NW SE sec 13, T18N, R120W	Madison Ls.	13,914-16,920	33.0 MMCF 336 BBL H_2O	Directional redrill in Whitney Canyon-Carter Creek Field
2	Texaco Exploration & Production	11-13 Rim Rock	NW NW sec 13, T23N, R113W	Frontier Fm.	10,741-10,812	4.9 MMCF 59 BBL H_2O	New producer in Shute Creek Field
3	Ultra Resources	5-19 Pinedale	SW NW sec 19, T30N, R108W	Lance Fm.	17 intervals 8265-12,345	12.5 MMCF	Pinedale anticline well
	Ultra Resources	1-4 Pinedale	NE NE sec 31, T31N, R109W	Lance Fm.	13 intervals N/R	13 MMCF	Pinedale anticline well
	Petrogulf Corp.	36-1 Petrogulf-State	SW NE sec 36, T31N, R109W	Lance Fm./ Mesaverde Fm.	6 intervals 11,460-13,050	3.3 MMCF 35 BBL Cond 95 BBL H_2O	Pinedale anticline well
	Questar Exploration & Production	3-7V Mesa	NE NW sec 7, T32N, R109W	Lance Fm.	several intervals 8753-12,883	7.8 MMCF 48 BBL Cond 72 BBL H_2O	Pinedale anticline well
	Wexpro	3-16D Mesa Unit	SE NW sec 16, T32N, R109W	Lance Fm.	13 intervals 9175-13,330	10.4 MMCF 72 BBL Cond 96 BBL H_2O	Pinedale anticline well
	Wexpro	7-16D Mesa Unit	SE NW sec 16, T32N, R109W	Lance Fm.	11 intervals 9255-13,340	9.9 MMCF 60 BBL Cond 84 BBL H_2O	Pinedale anticline well, drilled from same drillpad as 3-16D Mesa Unit well
	Questar Exploration & Production	11-17 Mesa Unit	NE SW sec 17, T32N, R109W	Lance Fm.	14 intervals 8638-13,100	9.2 MMCF 86 BBL Cond 48 BBL H_2O	Pinedale anticline well
	Questar Exploration & Production	11-20V Mesa	NE SW sec 20, T32N, R109W	Lance Fm.	several intervals 9030-13,233	11.5 MMCF 48 BBL Cond 72 BBL H_2O	Pinedale anticline well
	Anschutz Exploration	9-21d Mesa	NE SE sec 21, T32N, R109W	Lance Fm.	13 intervals 8953-12,735	5.5 MMCF	Pinedale anticline well

Table 14. Continued. Significant exploration and development wells in Wyoming, fourth quarter of 2001[1]. Number corresponds to location on Figure 11.

	Company name	Well name/number	Location	Formation tested	Depth(s) interval(s) tested	Tested prod. (per day)	Remarks
3	Questar Exploration & Production	5-21 Mesa Unit	SW NW sec 21, T32N, R109W	Lance Fm.	13 intervals 8546-12,670	9.4 MMCF 72 BBL Cond 48 BBL H_2O	Pinedale anticline well
	Anschutz Exploration	10-21d Mesa	NE SE sec 21, T32N, R109W	Lance Fm.	several intervals 10,272-13,214	5.5 MMCF 31 BBL Cond 94 BBL H_2O	Pinedale anticline well
	Anschutz Exploration	16-21d Mesa	NE NE sec 28, T32N, R109W	Lance Fm.	6 intervals 11,083-12,583	5.8 MMCF 43 BBL Cond 252 BBL H_2O	Pinedale anticline well
	Anschutz Exploration	2-28d Mesa	NE NE sec 28, T32N, R109W	Lance Fm.	11 intervals 10,655-12,917	7.6 MMCF 24 BBL Cond 240 BBL H_2O	Pinedale anticline well, drilled from same drillpad as 16-21d Mesa well
	Questar Exploration & Production	9-29 Stewart Point	SE SE sec 29, T33N, R109W	Mesaverde Fm.	2 intervals 13,154-13,396 13,563-13,796	5.0 MMCF 72 BBL Cond 12 BBl H_2O	Pinedale anticline well
	Questar Exploration & Production	4-32V Stewart Point	NW NW sec 32, T33N, R109W	Lance Fm.	7 intervals 9688-12,992	4.3 MMCF 36 BBL Cond 72 BBL H_2O	Pinedale anticline well
4	McMurry Oil	4-18 Jonah-Federal	NW NW sec 18, T28N, R108W	Lance Fm.	several intervals 7559-7829	2.4 MMCF 15 BBL Cond 42 BBL H_2O	Jonah Field well
5	Shell Western Exploration & Production	B3-33 Pacific Creek	SW NE sec 33, T27N, R103W	Lance Fm./ Mesaverde Fm.	production casing set to 13,032		1mile west of Pacific Creek well (1978-1979), which set Rocky Mtn. depth record of 25,764 feet
6	Amoco Production	23-2 Bitter Creek	NE NW sec 23, T16N, R99W	Mesaverde Gp.	3 intervals 10,885-11,348	1.8 MMCF	Stepout from Bitter Creek Field
7	Cabot Oil & Gas	40-30 Lookout Wash	NW SE sec 30, T15N, R93W	Almond Fm.	11,181-11,285	1.1 MMCF 2 BBL Cond	Stepout from Snowbank Field
8	Williams Production RMT	3-29 Cave Gulch-Federal	NW SW sec 29, T37N, R86W	Frontier Fm.	several intervals 16,750-17,376	9.1 MMCF 58 BBL H_2O	Reentry of a subthrust Muddy/ Lakota producer, recompleted in subthrust Frontier in Waltman Field
9	Double Eagle Petroleum & Mining	1 Allen Deep	SE NW sec 26, T39N, R90W	Fort Union Fm.	2 intervals 11,230-11,360	2.0 MMCF	Exploratory well with two new pay zones; flow rate is for two new zones plus original pay zone
10	Marathon Oil	45 Tribal "C"	SW SW sec 29, T4N, R1W	Tensleep Ss.	6875-6935	567 BBL oil 2921 BBL H_2O	Development well in Steamboat Butte Field
	Marathon Oil	47 Tribal "C"	NE NE sec 31, T4N, R1W	Tensleep Ss.	6870-6920	309 BBL oil 2334 BBL H_2O	Development well in Steamboat Butte Field
11	Marathon Oil	54 Spring Creek	SW SW sec 12, T49N, R102W	Phosphoria Fm./ Tensleep Ss.	3850-3888 4004-4141	334 BBL oil 654 BBL H_2O	Development well in Spring Creek South Field
	Marathon Oil	55 Spring Creek	SE NW sec 13, T49N, R102W	Phosphoria Fm./ Tensleep Ss.	3910-3926 4053-4245	151 BBL oil 38 BBL H_2O	Development well in Spring Creek South Field
12	Trend Exploration	28-1 Trend-Fee	SW NE sec 28, T55N, R72W	Minnelusa Fm.	8442-8444	347 BBL oil 236 BBL H_2O	Wildcat discovery
13	True Oil	21-31 McIntyre-State	NE NW sec 31, T49N, R68W	Minnelusa Fm.	7932-7936	204 BBL oil	Development well in Slattery Field
14	Ballard Petroleum	33-3H BPL-Iberlin Ranch	NW SE sec 3, T42N, R74W	Frontier Fm.	11,441-12,396	103 BBL oil	Recompletion of a vertical Frontier discovery that flowed 45 BBL oil; producing interval is horizontally drilled
15	EOG Resources	1-19 Crotalus	SE NW sec 19, T38N, R75W	Frontier Fm.	about 12,800	250 BBL oil	Wildcat discovery

[1]Abbreviations include: MMCF=millions of cubic feet of natural gas; BBL=barrels; Cond=condensate; H_2O=water; Gp.=Group; Ss.=Sandstone; Ls.=Limestone; Fm.=Formation; Sh.=Shale. *Wyoming State Geological Survey, Oil and Gas Section, March, 2002.*

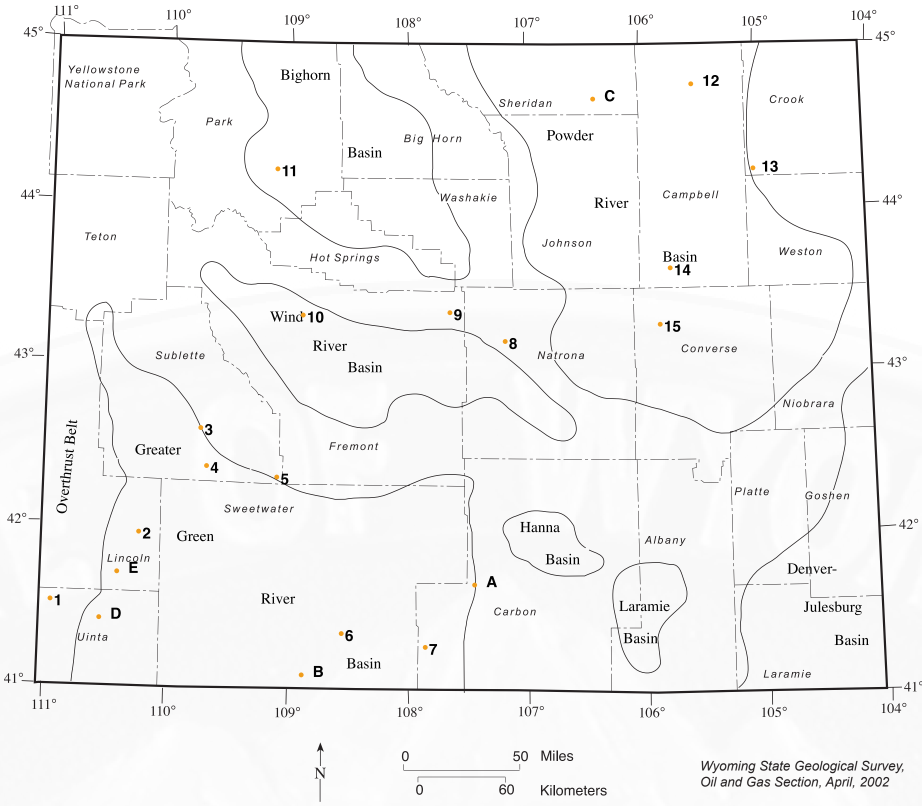

Figure 11. Oil and gas exploration and development activities (numbers) and coalbed methane activities (letters) in Wyoming during the fourth quarter of 2001. Locations are approximate and may represent more than one well location or project.

Coal Update

Robert M. Lyman, PG-656

Staff Geologist–Coal, Wyoming State Geological Survey

As 2001 coal production in Wyoming surged to a new record 368.7 million tons, demand in the fourth quarter had begun to slow with the mild winter weather and large stockpiles at utility companies. Spot prices for Powder River coal declined at year's end even though they were still about $2.00 per ton higher than at the end of 2000. Production will slow in 2002 as Wyoming coal mines exercise some restraint and retain the higher prices now being paid. Average coal prices statewide are expected to increase (albeit only slightly) over of the next six years, and hopefully improve the state's economic outlook.

Wyoming's high production rate drives the federal lease-by-application (LBA) process. Several coal companies applied for new or revised LBAs in the last quarter and several federal lease sales were imminent. A single environmental impact statement for five coal tracts in the Powder River Coal Field is being written so the 1.47 billion tons of recoverable coal contained in them can be offered for bid in the next year. Some activity in the LBA process even occurred in southern Wyoming, where Bridger Coal and Black Butte Coal are seeking additional federal coal leases to expand and sustain their operations.

Production and prices

Wyoming's 2001 coal production, according to the Wyoming State Inspector of Mines (Stauffenberg, 2001) reached 368.7 million short tons, eclipsing last year's record by 30 million short tons. This represents an increase of 8.8% over production in 2000 (**Tables 1** and **15**) and exceeded the 354.5 million short tons predicted by the Wyoming State Geological Survey (WSGS) by about 4%. Most of the mines in Campbell County reported production increases, which accounted for most of the increase statewide. A drop in production in southern Wyoming was offset by an equal increase in Converse County. Of interest in the Powder River Basin (PRB), two traditional mining areas have now ceased production. Glenrock Coal Company's Dave Johnston mine in Converse

Table 15. Wyoming coal production by county[1,2] (in millions of short tons), 1996 through 2001 with forecasts to 2007.

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Powder River Basin												
Campbell County	245.3	246.3	274.1	296.3	299.5	329.5	322.0	330.0	332.7	335.5	338.3	341.1
Converse County	15.8	17.8	23.4	24.0	23.6	24.6	25.0	26.0	27.0	28.0	29.0	30.0
Sheridan County	M	M	M	M	M	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Subtotal	261.1	264.1	297.5	320.0	323.1	354.1	347.0	356.0	359.7	363.5	367.3	371.1
Southern Wyoming												
Carbon County	4.7	5	3.5	3.5	2.0	0.5	M	2.0	2.0	2.0	2.0	2.0
Sweetwater County	8.2	7.8	9.2	8.0	10.0	9.5	9.0	9.0	9.0	9.0	9.0	9.0
Lincoln County	4.4	4.6	4.7	4.7	3.7	4.5	5.0	5.0	5.0	5.0	5.0	5.0
Subtotal	17.3	17.4	17.4	16.4	15.7	14.5	14.0	16.0	16.0	16.0	16.0	16.0
Total Wyoming[3]	**278.4**	**281.5**	**314.9**	**336.5**	**338.9**	**368.7**	**361.0**	**372.0**	**375.7**	**379.5**	**383.3**	**387.1**
Annual change	**5.5%**	**1.1%**	**11.9%**	**6.9%**	**0.7%**	**8.8%**	**-2.1%**	**3.0%**	**1.0%**	**1.0%**	**1.0%**	**1.0%**
Higher-priced coal[4]	**24%**	**22%**	**17%**	**13%**	**9%**	**6%**	**4%**	**4%**	**4%**	**4%**	**1%**	**1%**

[1]Reported tonnage from the Wyoming State Inspector of Mines (1995 through 2000). [2]County estimates by the Wyoming State Geological Survey, February, 2001 for 2001 through 2007. Totals may not agree because of independent rounding. [3]Estimate modified from CREG's Wyoming State Government Revenue Forecast, October, 2001. [4]Estimated percentage of Powder River Basin coal production that is sold at prices above $5.00/ton (older long-term contracts that have not yet expired). M=minor tonnage (less than a million tons). *Wyoming State Geological Survey, Coal Section, March, 2002.*

County is now on "reclamation only" status, after furnishing coal to the power plant at Glenrock since 1958. Sheridan County coal production has also ceased with the last mine in the county (Big Horn No. 1) now closed and reclaimed. The county had reported coal production every year since the first mines opened in the latter part of the 19th Century.

A mild winter decreased the demand for PRB and other coal during the final quarter of the year. Wyoming mines shipped 89.2 million short tons of coal in the fourth quarter, a decrease of about 3 million short tons from the third quarter (**Table 16**). Monthly coal deliveries during the last quarter (**Figure 12**) document this decrease; although contract coal deliveries leveled off (**Figure 13a**), they were accompanied by a drop in spot coal deliveries (**Figure 13b**). With many electric utility companies holding large stockpiles, the market may be quiet until the end of the first quarter of 2002.

. . . current oversupply at many utilities and the continuing mild winter weather may force many PRB producers to restrain their 2002 production. . .

Spot prices for PRB coal moved slightly downward in December, 2001 and at year's end stood at an estimated $5.60 per ton for 8400-Btu coal and $6.60 per ton for 8800-Btu coal, both FOB mine. However, these prices are still slightly over $2.00 a ton more than at the end of 2000 (**Figure 14**).

The Enron debacle may have clouded the spot market for Wyoming's PRB coals at the end of the year. Several unit trains of coal were sold over-the-counter at bargain prices as trading interests moved away from positions with Enron. According to U. S. Coal Review's sources, the spot market prices dropped in December because some trainloads of coal were "dumped" by traders selling where they could. Thus, the drop in December spot prices may have been over-exaggerated (U. S. Coal Review, 12/17/2001).

The challenge for marketing Wyoming coal in the coming year will most likely depend on factors such as a return of colder winter weather and a return to some production rate discipline by the state's mines. In response to the eastern coal shortage in the second quarter of 2001, many of the PRB operators ramped up their production. The eastern coal shortage precipitated a strong mid-year price increase for Wyoming coal and the producers responded with 30 million short tons of added capacity in the PRB. However, current oversupply at many utilities and the continuing mild winter weather may force many PRB producers to restrain their 2002 production and keep the higher coal prices. Accordingly, we have revised our estimate of coal production for the state. For the year

Table 16. Estimated monthly coal deliveries from Wyoming's mines in short tons (January, 1997 through December, 2001).

	1997		1998		1999		2000		2001	
	Monthly	Cumulative	Monthly	Cumulative	Monthly	Cumulative	Monthly	Cumulative	Monthly	Cumulative
January	25,165,405	25,165,405	26,536,217	26,536,217	27,105,791	27,105,791	27,773,610	27,773,610	27,743,000	27,743,000
February	20,743,224	45,908,629	23,196,152	49,732,369	25,803,390	52,909,181	25,594,109	53,367,719	27,827,000	55,570,000
March	22,566,012	68,474,641	23,861,472	73,593,841	28,222,743	81,131,923	28,262,696	81,630,415	33,739,000	89,309,000
April	20,961,008	89,435,649	24,768,989	98,362,830	25,965,867	107,097,791	25,549,039	107,179,454	27,302,000	116,611,000
May	23,102,867	112,538,516	25,278,960	123,641,790	28,698,498	135,796,288	26,222,515	133,401,969	27,752,000	144,363,000
June	20,862,610	133,401,126	24,450,835	148,092,625	24,753,829	160,550,118	25,085,516	158,487,485	33,968,000	178,331,000
July	24,074,929	157,476,055	25,663,577	173,756,202	28,266,458	188,816,576	28,881,862	187,369,347	29,200,000	207,531,000
August	23,002,254	180,478,309	26,591,950	200,348,152	28,346,757	217,163,333	29,075,295	216,444,642	27,662,000	235,193,000
September	22,452,566	202,930,875	26,041,099	226,389,251	27,373,417	244,536,749	25,865,389	242,310,032	35,369,000	270,562,000
October	21,623,057	224,553,932	26,659,121	253,048,372	26,837,295	271,374,045	26,441,615	268,751,646	29,869,000	300,431,000
November	21,695,072	246,249,004	25,620,216	278,668,588	26,843,021	298,217,066	27,400,245	296,151,892	29,308,000	329,739,000
December	24,695,740	270,944,744	26,102,620	304,771,208	26,834,927	325,051,993	28,300,773	324,452,665	29,984,000	359,723,000
Total Utility Tonnage[1]		**270,944,744**		**304,771,208**		**325,051,993**		**324,452,665**		**359,723,000**
Total Tonnage Other [2]		**10,536,772**		**10,190,883**		**11,407,945**		**14,399,483**		**8,955,135**
Total Tonnage Produced[3]		**281,481,516**		**314,962,091**		**336,459,938**		**338,852,148**		**368,678,135**

[1]From Federal Energy Regulatory Commission (FERC) Form 423 1997 through 1998, FERC Form 423 as modified by WSGS for 1999 through 2001. [2]Includes estimates of residential, industrial, and exported coal. [3]Wyoming State Mine Inspector's Annual Reports. *Wyoming State Geological Survey, Coal Section, March, 2002.*

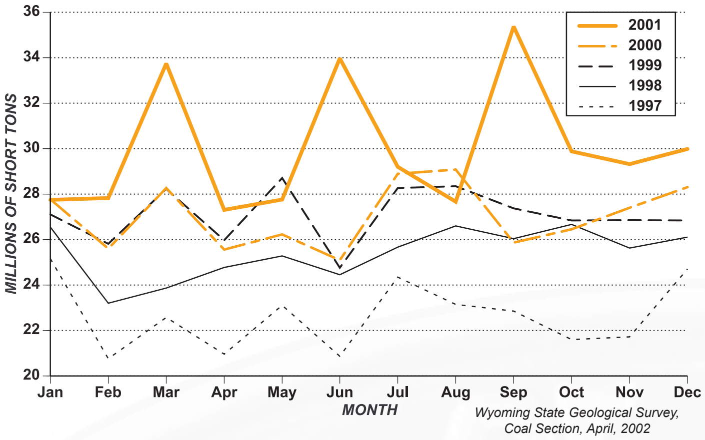

Figure 12. Reported monthly deliveries from Wyoming coal mines (1997 through December, 2001). From Form 423 of the Federal Energy Regulatory Commission (FERC) as modified by the WSGS for 1999 through 2001.

2002, we expect that the production restraint will result in a decrease in coal production of 2.1%, followed by a rebound of 3% in 2003 (**Table 15** and **Figure 15**). We are conservatively estimating a 1% increase in the state's coal production from 2004 through 2007.

Because the increase in spot coal prices is expected to have an impact on contracts for 2002 and beyond, the Coal Section of the WSGS, in consultation with the Wyoming Consensus Revenue Estimating Group (CREG) has revised the previous estimate (*Wyoming Geo-notes No. 72*, December, 2001) of average prices received for Wyoming coal (**Table 17**). As mentioned in earlier issues of *Wyoming Geo-notes*, CREG estimates are biased on the conservative side, and for the first time since 1992, the estimates show coal price gains over the next six years (**Figure 16**). We expect this will improve the state's economic outlook from 2002 to 2007.

Developments in the Powder River Basin

The U.S. Bureau of Land Management (BLM) set a lease sale for the North Jacobs Ranch LBA tract for January 15, 2002, with bids opening at the Wyoming State Office in Cheyenne the next day. The tract (**Figure 17**) contains an estimated 538 million tons of minable coal. Kennecott Energy and Arch Coal are both expected to bid on the tract.

The public comment period on North American Power Group's Two Elk Generation Partners' proposed transmission line ended December 5, 2001. This line would extend between the planned 275-megawatt (MW) coal-fired power plant near the Black Thunder mine to the Antelope substation. Power lines rated at 230 kilovolts would cross 7 miles of private land and approximately 11 miles of the Thunder Basin National Grassland, which is under jurisdiction of the U.S. Forest Service. Ultimately, the target area for marketing the power is the Denver/Colorado Front Range area.

RAG American applied to BLM for a 1500-acre coal lease easement adjacent to their Eagle Butte mine (**Figure 17**). This tract would add seven to eight years of mine life, with mining on the new tract beginning in 2008.

Kennecott Energy submitted an LBA to BLM in late September for a lease on what Kennecott calls the Big Thunder Reserve (**Figure 17**). The tract covers all of the reserves that Arch Coal nominated in 2000 as the Little Thunder Tract (**Figure 17**). The Kennecott version of the LBA includes an additional 2269 acres. While the Little Thunder LBA process will proceed, the spring 2002 meeting of the PRB Regional Coal Team will ultimately decide how to handle the competing applications (Coal Outlook, 10/22/2001).

Powder River Coal's Rawhide mine is on schedule to reopen at the start of 2002. The company reported receiving the necessary permits from the Wyoming Department of Environmental Quality to resume mining operations after being idle since March, 1999. The company said that the majority of the mine's 8 million short tons annual production is already committed for 2002 (Coal Outlook, 11/19/2001).

RAG Wyoming Land Company was the only bidder on the 244-acre Belle Ayr LBA tract at BLM's October 11, 2001 lease sale. The company bid $6,443,280 on coal reserves of 31.4 million short tons. The bid of 20.5 cents per ton was rejected by the BLM as insufficient and not meeting BLM's estimate of fair market value (COAL Daily, 10/15/2001).

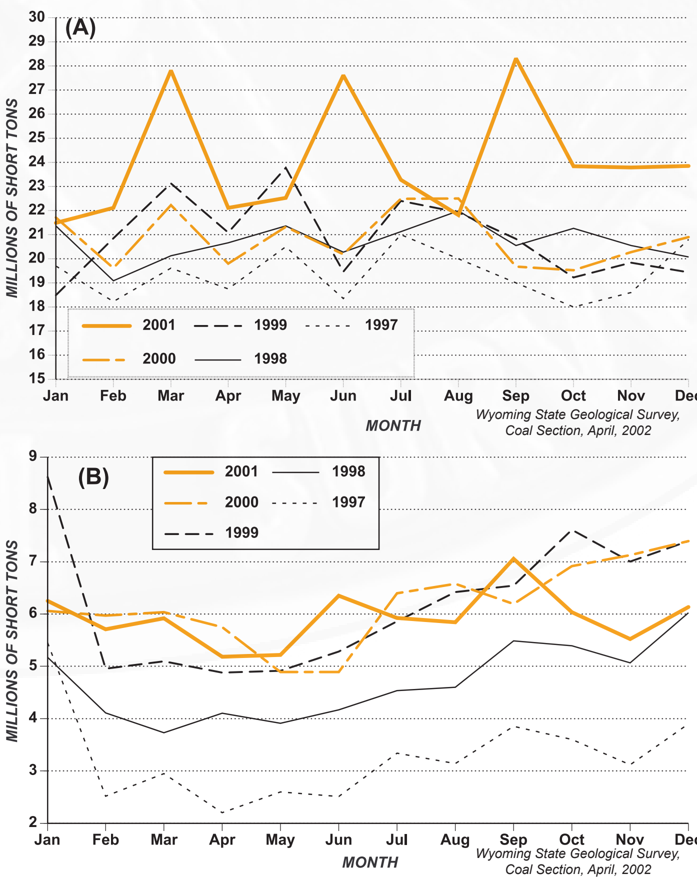

Figure 13. Monthly coal deliveries from Wyoming (1997 through December, 2001). (A) Coal sold on contract and (B) coal sold on the spot market. From Form 423 of the Federal Energy Regulatory Commission (FERC) as modified by the WSGS for 1999 through 2001.

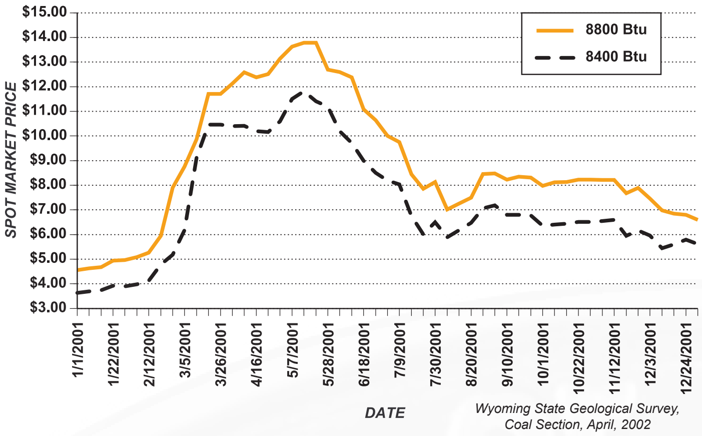

Figure 14. Wyoming PRB coal spot price watch (January 1, 2001 through December 31, 2001). Modified from COAL Daily's spot market index, and Coal Week's short-term spot market price index.

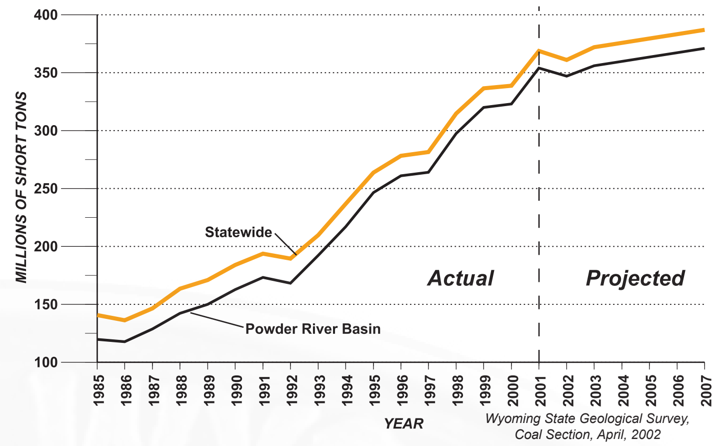

Figure 15. Annual coal production from Wyoming and the Powder River Basin (1985 through 2001) with forecasts to 2007. Sources: Wyoming State Inspector of Mines (1985 through 2001), CREG (2002 through 2007), and the Wyoming State Geological Survey.

Developments in southern Wyoming

Bridger Coal has asked BLM to initiate an environmental review for the federal coal tract known as Ten Mile Rim. The company is seeking the coal tract in association with its plans for a possible underground mine expansion of their current surface mine. The deep mine would most likely be a longwall unit to supply the nearby Jim Bridger power plant with a 15- to 20-year fuel supply. The Ten Mile Rim LBA tract contains some 110 million short tons of federal coal and includes more than 7000 acres of federal surface and mineral rights, 950 acres of split estate consisting of federal surface and state minerals, and 8100 acres of private property (Coal Outlook, 12/17/2001).

Black Butte Coal Co. is seeking permission to modify its existing coal leases at their Black Butte surface mine so they can mine an 80-acre tract located next to their Pit 19 operation. The tract is estimated to contain 2.6 million short tons of coal reserves. Under the lease modification procedure, the added acreage would not have to go through the competitive bid process because by assigning the acreage to the current mine lease, it will avoid a bypass coal situation.

Table 17. Breakdown of average prices paid for coal from northeastern Wyoming, southern Wyoming, and Wyoming as a whole (1988 through 2000) with forecast to 2007.

	Year	Northeastern	Southern	Statewide
ACTUAL	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	$4.93	$16.19	$5.40
FORECAST	2001	$5.31	$16.00	$5.70
	2002	$5.38	$15.50	$5.75
	2003	$5.45	$15.00	$5.86
	2004	$5.51	$15.00	$5.91
	2005	$5.59	$15.00	$6.00
	2006	$5.67	$15.00	$6.07
	2007	$5.76	$15.00	$6.15

Statewide data for 1988 through 1990 are from reports by the U.S. Department of Energy's Energy Information Administration; data for 1991 through 2000 are derived from Wyoming Department of Revenue information; estimates for 2001 through 2007, and all regional breakdowns by the *Wyoming State Geological Survey, Coal Section, March, 2002.*

Transportation developments

The Dakota, Minnesota & Eastern Railroad (DM&E) has received approval from the Surface Transportation Board (STB) for their PRB build-in project. However, environmental groups are lining up to fight the project at every level and some financial analysts believe the major hurdle for the project will be DM&E's ability to obtain the financing levels needed for the $1.4 billion project.

Jim Valentine of Morgan Stanley, in a November 12, 2001 article in Coal Outlook, pointed out "the greatest issue facing the project, in our opinion, is the lack of current and potential customers. Today DM&E only serves two very small utility plants, and would need to interchange all the remainder of its potential coal volumes with another railroad or transload

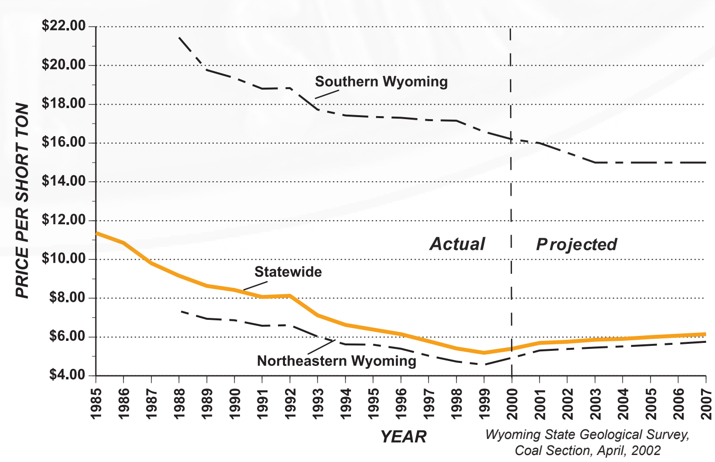

Figure 16. Average prices paid for Wyoming coal by producing area (1985 through 2000) with forecasts to 2006. Sources: U.S. Energy Information Administration (1985 through 1990); Wyoming Department of Revenue (1991 through 2000); and CREG (2001 through 2006).

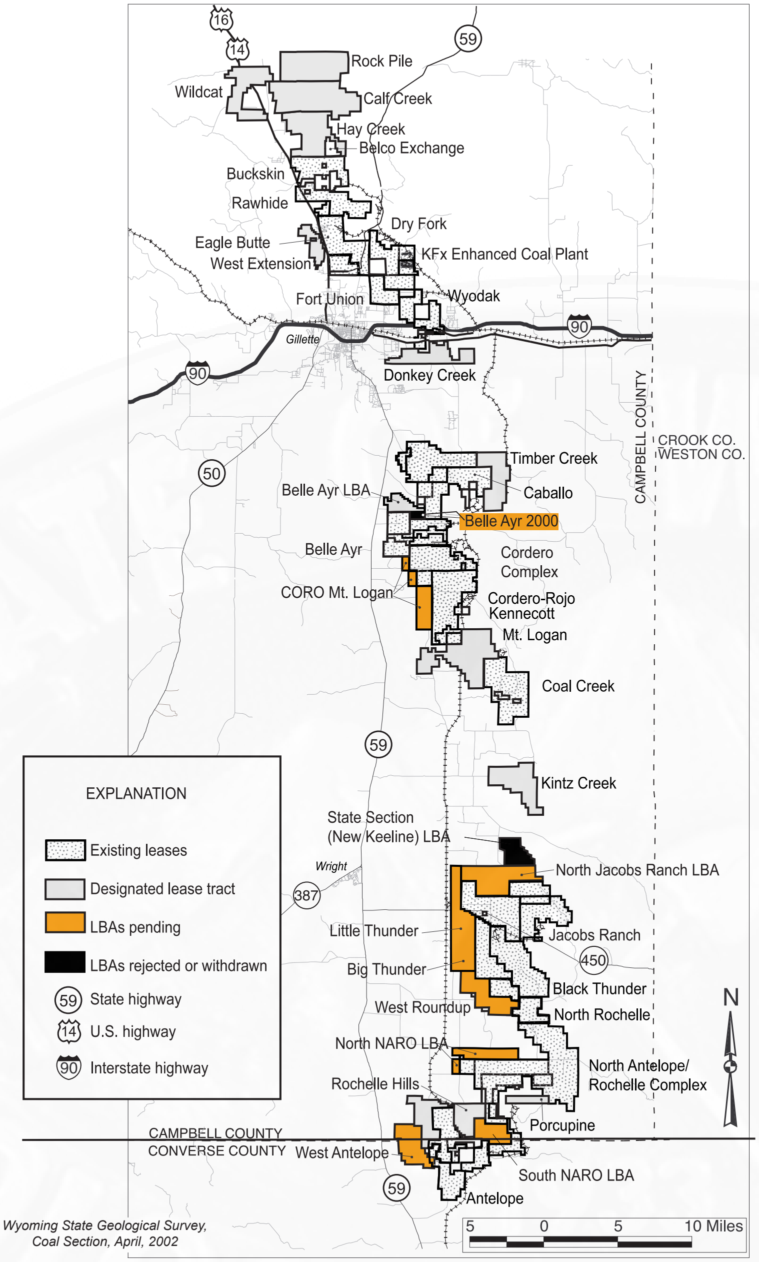

Figure 17. Location of existing federal coal leases, proposed coal lease tracts, exchanges, pending LBAs (yellow), and proposed LBAs, eastern Powder River Basin, Wyoming. Sources: U.S. Bureau of Land Management web sites, including http://www.wy.blm.gov/minerals/coal/prb/prb_maps.htm; ftp://ftp.wy.blm.gov/pub/casper/coal/; and http://www.wy.blm.gov/minerals/coal/prb/prb.htm.

the coal to barges for delivery to barge-served power plants on the inland river system."

In October the joint rail line in the PRB, operated by the Union Pacific Railroad (UP) and Burlington Northern Santa Fe (BNSF), set a new monthly record by moving 1904 loaded coal unit trains. The daily average of 61.4 trains also was a record. Through the first ten months of the year, the railroads have averaged 58.5 unit trains per day. During the same period in 2000, the railroads averaged 56 unit trains per day (Coal Outlook, 11/12/2001).

On December 13, 2001, three PRB unit trains were involved in a collision just west of St. Louis, Missouri. A loaded 133-car coal train being pulled by a three-engine configuration rear-ended another loaded 119-car train. Shortly after the first collision, a third empty unit train returning to the PRB slammed into the wreckage. Sixty cars were derailed, creating a large coal spill that closed a nearby highway and disrupted Amtrak service between St. Louis and Kansas City (Coal Outlook, 12/17/2001).

Regulatory developments

The BLM intends to write one environmental impact statement (EIS) to cover four LBAs received last year for five federal coal tracts in Wyoming's PRB (**Figure 17**). An EIS is a normal part of the leasing process–each of these tracts will go to bid within the next year. BLM has simplified the process by considering all the proposed LBA tracts under a single EIS (COAL WEEK, 10/8/2001).

The LBAs which will be covered under the single EIS include: the NARO North and NARO South, nominated by Powder River Coal and located next to their North Antelope-Rochelle mine complex; Arch Coal's Little Thunder tract adjacent to their Black Thunder mine; Triton Coal's West Roundup tract next to their North Rochelle mine; and Kennecott Energy's West Antelope tract adjacent to their Antelope mine (**Figure 17**). The combined coal tracts consist of 13,359 acres containing an estimated 1.47 billion tons of recoverable coal (COAL WEEK, 10/8/2001).

Last winter the Wyoming State Legislature passed a law to set up the Miner's Hospital Board effective July 1, 2001, and allocated the board $600,000 from interest being earned on the $50 million miner's hospital fund. In 1890, the Legislature established a hospital for miners, and two years later Rock Springs was chosen as the site. Under the new law, the Legislature decided that there is no singular miner's hospital in Wyoming and the new board is planning statewide programs to serve disabled miners. The board will focus on four areas of health where miners traditionally have more problems than the general population: hearing loss, musculoskeletal, heart, and lungs.

The Miner's Hospital Board can draw up to 5% of the $50 million fund annually (or about $2.5 million) for the miners' health program once it gets off the ground. The legislation also authorized a five-member legislative oversight committee to monitor the Miner's

Hospital Board, and requires the board to submit an annual report (Casper Star-Tribune, 12/24/2001).

Market developments and opportunities

Northern Indiana Public Service Company (NIPSCO) is in the process of shutting down its Mitchell generating station in Gary, Indiana. Completion of the shut down is March, 2002. Originally built in 1955, the aging coal-fired station was NIPSCO's oldest and least efficient in their generating system. Fuel for the plant last year was slightly over 1 million short tons of PRB coal (U.S. Coal Review, 12/10/2001). What will happen to the coal currently directed to the Mitchell plant is uncertain, as NIPSCO's contracts are not plant specific. PRB coal is also used at NIPSCO's Michigan City and R.M. Schahfer plants.

On the other side of the marketing coin, Southern Co. announced that Georgia Power, owner of the 3300-MW Scherer plant, has decided to pursue switching Scherer Units 1 and 2 to PRB coal by the end of 2004. Units 3 and 4 at Scherer were converted to PRB coal in 1994. Georgia Power's 2004 time frame will allow existing coal supply contracts to expire and permit construction of additional railcars needed to get more coal out of the PRB. In 2001, Units 3 and 4 consumed about 4.9 million tons of PRB coal (Coal Outlook, 12/17/2001).

In December, Alliant Energy announced their comprehensive energy plan "Power Iowa" to ensure reliable power to its Iowa customers in the future. The plan calls for additional new natural gas and coal-fired generating plants and electric power transmission enhancements. As part of their plan, a new 400- to 500-MW clean coal facility would be sited and online by the end of 2007.

Table 18 tabulates some of the contract, spot sales, test burns, and solicitations for Wyoming coal, announced during the fourth quarter of 2001.

References cited

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

Stauffenberg, D.G., 2001, Annual report of the State Inspector of Mines of Wyoming, for the year ending December 31, 2001: Wyoming Department of Employment, Office of the State Inspector of Mines, Rock Springs, Wyoming, 81 p.

Table 18. Marketing activities for Wyoming coal producers during the fourth quarter of 2001*.

Utility	Power Plant	Coal Mine/Region	Activity	Tonnage	Comments
Alliant Energy	System	PRB	C	1.5 mt	Delivery in 2002
Ameren	System	PRB	So	3 mt	For delivery in 2002-2003
Archer Daniels Midland	Unspecified	PRB	So	1.2 mt	For 5 plants; delivery in 2002
Colorado Springs Utilities	Nixon	Caballo/PRB	Sp	~40,000 t	Delivery in late 2001 to early 2002
Hastings Utility Department	Whelan Energy	Rawhide/PRB	C	350,000 t	Delivery in 2002
MidAmerican Energy	System	PRB	C	2.5 mt/y	For delivery in 2003-2005
Otter Tail Power	Big Stone	Belle Ayrl/PRB	C	1.8-2 mt/y	Beginning in 2002
San Antonio	Deely and Spruce	Cordero=Rojo/PRB	C	1.5 mt	Delivery in 2002
UtilCorp, for St. Joseph Light & Power	Lake Road Station	Arch PRB/Hanna	C	400,000 t	PRB and PRB/Hanna blend for 2002 delivery
Western Fuels Association	Various Association members	PRB	So	18-23.65 mt	Over 10 years, beginning in 2002

*Data obtained from: COAL WEEK, COAL Daily, Coal Age, FERC database, and personal contacts. Note: C = contract; mt = million short tons; mt/y = short tons per year; PRB = Powder River Basin; Sp = spot coal; So = solicitation; and t = short tons. *Wyoming State Geological Survey, Coal Section, March, 2002.*

Coalbed Methane Update

Robert M. Lyman, PG-656

Staff Geologist–Coal, Wyoming State Geological Survey

Rodney H. De Bruin, PG-3045

Staff Geologist–Oil and Gas, Wyoming State Geological Survey

Over 11,341 coalbed methane (CBM) wells had been drilled in the Powder River Basin (PRB) of Wyoming by the end of 2001. At the end of the year, 8066 wells were in production, and an additional 3275 were shut-in. Wyoming's CBM operators produced 250.6 billion cubic feet (BCF) of methane in 2001 (**Table 19**). This production made up 15.6% of Wyoming's natural gas production.

The average monthly production of coalbed methane in Wyoming was nearly 20.9 BCF. The 2001 production was an increase of 99.9 BCF over 2000 production, and represents an annual growth in Wyoming CBM production of 66.3%. Wyoming's CBM production has continued its spectacular growth over the past five years (**Figure 18**). Wyoming CBM production occurs on federal, state, and private leases and

Table 19. Monthly Wyoming coalbed methane production in MCF (1997 through December, 2001)*.

	1997		1998		1999		2000		2001	
	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative
January	868,062	868,062	1,962,669	1,962,669	3,660,434	3,660,434	8,461,780	8,461,780	17,870,205	17,870,205
February	771,635	1,639,697	1,882,421	3,845,090	3,462,685	7,123,119	8,706,458	17,168,238	16,741,272	34,611,477
March	1,034,623	2,674,320	2,134,042	5,979,132	4,110,431	11,233,550	9,872,362	27,040,600	19,271,964	53,883,441
April	1,033,885	3,708,205	2,154,252	8,133,544	4,040,989	15,274,539	10,565,807	37,606,407	19,216,625	73,100,066
May	1,117,202	4,825,407	2,254,160	10,387,257	4,422,581	19,697,120	11,831,227	49,437,634	20,390,450	93,490,516
June	1,100,462	5,925,869	2,369,015	12,756,559	4,605,167	24,302,287	12,199,486	61,637,120	20,078,486	113,569,002
July	918,571	6,844,440	2,455,931	15,212,490	4,877,924	29,180,211	13,024,856	74,661,976	20,993,443	134,562,445
August	1,324,372	8,168,812	2,654,655	17,867,145	4,793,060	33,973,271	14,180,161	88,842,137	21,906,856	156,469,301
September	1,220,247	9,389,059	2,988,544	20,855,689	5,125,811	39,099,082	14,390,965	103,233,102	21,385,829	177,855,130
October	1,445,545	10,834,604	3,158,168	24,013,857	5,961,192	45,060,274	15,393,978	118,627,080	23,717,045	201,572,175
November	1,536,287	12,370,891	3,188,985	27,202,842	5,947,893	51,008,167	15,220,163	133,847,243	23,635,973	225,208,148
December	1,677,667	14,048,558	3,434,905	30,637,747	7,180,697	58,188,864	16,852,924	150,700,167	25,377,179	250,585,327
Total		**14,048,558**		**30,637,747**		**58,188,864**		**150,700,167**		**250,585,327**

*Data from the Wyoming Oil and Gas Conservation Commission. *Wyoming State Geological Survey, March, 2002.*

is reported monthly by the Wyoming Oil and Gas Conservation Commission. Monthly production by lease ownership in 2001 (**Figure 19**), when totaled for the year, reveals that CBM production from private leases was 72.7% of the total, federal leases produced 19.6% of the total, and 7.7% of the total was on state leases.

Activities of coalbed methane companies

Petroleum Development Corp. is continuing its development of CBM wells in coals of the Almond Formation (Mesaverde Group) on the southeastern flank of the Washakie Basin (**location A, Figure 11**). A water reinjecting facility was being connected in the fourth quarter of 2001 (**Figure 20**) and the company hopes to test the feasibility of CBM production in the near future.

Portrush Petroleum joined with CP Resources of Denver, Colorado in a joint venture to drill four prospect wells located on the southeastern flank of the Rock Springs uplift (**location B, Figure 11**). The exploratory program will target CBM potential of Almond coals. Portrush will hold a 25% interest in the project (Coalbed Methane Alert, October, 2001).

Williston Basin Interstate Pipeline is planning a new 245-mile-long, 16-inch-diameter gas pipeline that will cross Wyoming, Montana, and North Dakota. Initially the pipeline will carry 80 to 120 million cubic feet (MMCF) per day, with increases in capacity as more production comes online (Coalbed Methane Alert, November, 2001).

Rocky Mountain Gas, Inc. completed 18 wells on their Clearmont, Wyoming properties in the PRB (**location C, Figure 11**). The company reported encouraging results, and plans to expand the project with an application for an additional 58 well permits.

Rocky Mountain Gas, Inc. also reported that they drilled and completed four additional wells in the Hams Fork Coal Field (**location D, Figure 11**). The wells tested coals in the Frontier and Adaville formations. Rocky Mountain Gas, Inc. is a subsidiary of U.S. Energy Corp.

In November, 2002, Kerr-McKee Rocky Mountain Corp. scheduled two wells 6 miles southwest of Kemmerer. Both are designed to evaluate the CBM potential of the Upper Cretaceous Adaville Formation (**location E, Figure 11**).

Prima Energy Corp. drilled 114 CBM wells in the first 11 months of 2001 and planed to drill approximately 10 more by the end of the year. Prima owns leases covering 150,000 acres in the PRB and has organized its acreage into 28 defined project areas. Of the company's 280 wells drilled to date in the PRB, 272 are in only six of these project areas.

A new Laramie-based company, WellDog Inc., has developed an instrument that connects to standard wire-line logging equipment and is lowered down to a targeted coal bed.

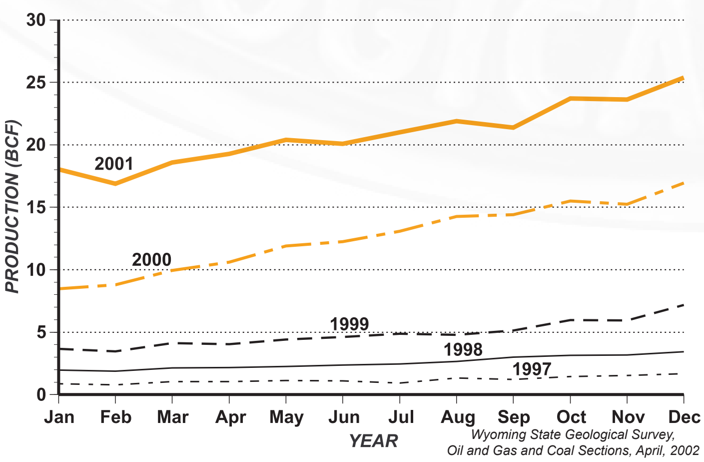

Figure 18. Coalbed methane production in Wyoming by month in BCF (January, 1997 through December, 2001). Data from the Wyoming Oil and Gas Conservation Commission.

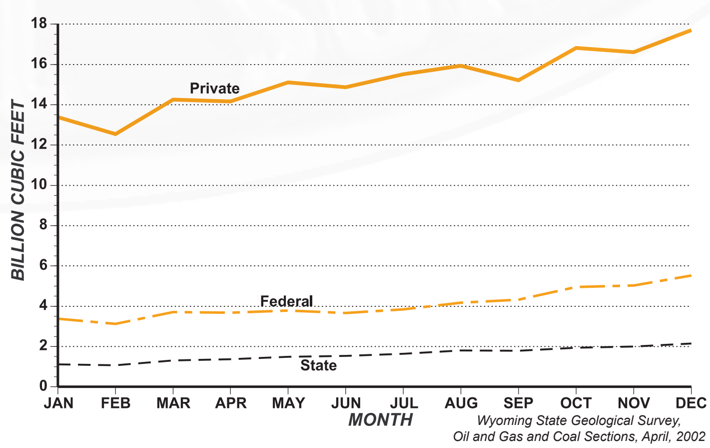

Figure 19. Monthly coalbed methane production in Wyoming, by month in BCF, from federal, state, and private leases for 2001. Data from the Wyoming Oil and Gas Conservation Commission.

Figure 20. Water injection facilities operated by Petroleum Development Corporation north of Baggs. Tanks store produced water, which is then reinjected by pumps (in building behind stairway) powered by a portable generating unit (on left).

The instrument pushes a probe into the coal, which detects chemical characteristics of the coal (including presence of CBM) and sends the information back to a laptop computer manned at the surface. WellDog's methane "sniffer" was developed in connection with one of the company's other products, Seadog, which was designed to detect methane effluent from gas hydrate beds in the ocean (Casper Star-Tribune, 1/6/2002).

Regulatory issues

The City of Gillette Public Works Director Bill Carson hopes reinjecting CBM-produced water into the Fort Union aquifer would help offset daily loses from the rock unit. Static water level in the unit has dropped more than 300 feet in recent years. Currently, the city's water comes from three sources: sandstones in the Fort Union Formation, the Fox Hills Sandstone, and the Madison Limestone. The city mixes the Fort Union water to buffer the hardness of the water from Madison wells. Without more Fort Union water, blending in the future can only be done on a more limited scale (Casper Star-Tribune, 1/1/2002).

Several CBM operators in conjunction with coal operators are coordinating efforts with the State of Wyoming to sprinkle about 25 miles of unpaved roads with dust-suppressing chemicals. The effort is aimed at keeping the areas around air quality monitoring stations in southern Campbell County in compliance by reducing dust levels. During 2001, the monitors measured four instances where the PM10 (particulate matter smaller than 10 microns measured in a 24-hour period) levels were higher than permitted standards. The exceedances were the first such events recorded in more than ten years. The monitors were put in place originally to monitor coal-mining activity in the area.

Industrial Minerals and Uranium Update

Ray E. Harris, PG-46

Staff Geologist–Industrial Minerals and Uranium, Wyoming State Geological Survey

The production of some industrial minerals, especially construction aggregate, in Wyoming slows seasonally with the coming of cold weather and snow. According to new data recently released for 2001, gypsum production increased to the highest level in history, while trona mining and sodium product manufacture decreased about 1%. Bentonite production increased to the second highest level in history, only exceeded in 1981. Wyoming's startup dimensional stone industry continues to produce a few blocks per month, although a high level of interest to develop new quarries and fabricating plants continues. One new company, Stone Masonry Units, constructed a small stone fabricating plant in Laramie in late 2001. Some of the financial uncertainty caused by the economic downturn that began in late 2000 is causing investors some concern. Overall, Wyoming's industrial mineral industries did very well in 2001, and are expected to continue doing well in 2002. However, with the closure of one mine and *in situ* recovery plant in 2000, the state's uranium production in 2001 decreased 21%.

The Industrial Minerals and Uranium Section's web page (on the Wyoming State Geological Survey web site) was recently revised to include 2001 industrial minerals and uranium production. For a table of the latest statewide production figures, see http://wsgsweb.uwyo.edu/minerals/1996-01.asp.

Bentonite

Refined bentonite products are produced at fourteen mills in Wyoming (**Figure 21**). Bentonite products listed, in order by amount of production, include kitty litter, foundry mold binding clay, drilling mud, environmental adsorbents, water barriers, and other uses (see *Wyoming Geo-notes, No. 70*, July, 2001). Bentonite ranks second after mined trona in value of industrial minerals produced in Wyoming. Bentonite production increased in 2001 to 4,777,026 short tons (Stauffenberg, 2001), just short of 1981 when 4,805,005 tons were produced. Almost all of the production in 1981 was for drilling mud.

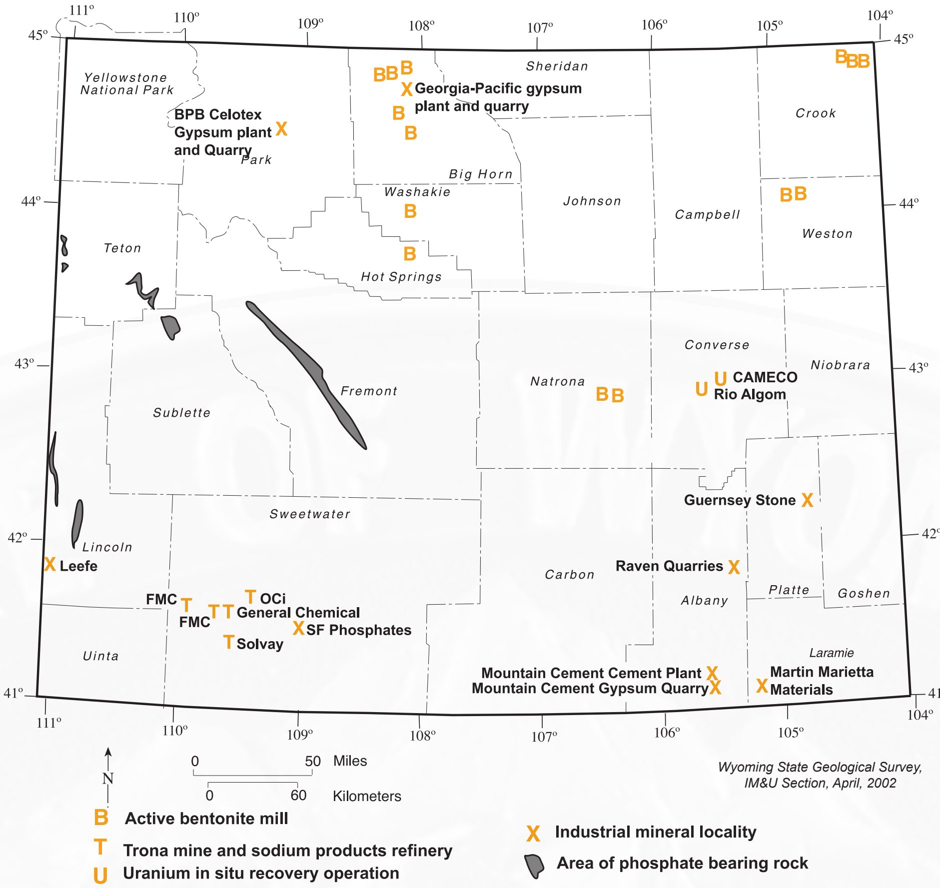

Figure 21. Index map of Wyoming showing the location of industrial mineral and uranium sites mentioned in the text. Locations are approximate and may represent more than one site.

Construction aggregate

Construction aggregate production in Wyoming slows down in the fourth and first quarters of the year due to seasonal closure of some quarries and the seasonal shut down of highway construction projects. The two largest construction aggregate operations in Wyoming, Martin-Marietta Materials west of Cheyenne and Guernsey Stone at Guernsey, continue year-round production. Despite the seasonal slow downs, construction aggregate production in 2001 totaled 16,053,510 short tons and exceeded 2000 production by 32%. Construction aggregate includes sand and gravel, crushed stone (granite and limestone), railroad ballast, and crushed scoria (clinker) as reported to the Wyoming State Inspector of Mines (Stauffenberg, 2001). Some of the scoria and crushed stone reported is decorative aggregate and is not included in the construction aggregate total above.

Decorative aggregate and stone

Decorative aggregate production in Wyoming continued to increase in 2001. Moss rock and dark-colored flagstone and fieldstone grew in popularity. Dark gray, rusty-appearing slate quarried in Pennsylvania and Maryland is one of the most popular stones used in new residential construction in California. A similar slate is found in Wyoming and small amounts are being marketed in the Colorado Front Range.

Dimensional stone

Dimensional stone is quarried by Raven Quarries in northern Albany County (**Figure 21**). Raven Quarries produced the stone used on the tops of the new desks in the legislative chambers in the Wyoming State Capitol. Pink Mirage® granite was used on the House of Representatives' chamber desks (**Figure 22**) and black Raven® granite was used on the Senate chamber desks (**Figure 23**). A new operation, Stone Masonry Units (SMU) began construction of a fabricating plant in Laramie. SMU reportedly operates a similar plant in California. SMU has asked the Industrial Minerals and Uranium Section of the Wyoming State Geological Survey (WSGS) about suitable quarry sites near Laramie. Seven entities (one more than the third quarter of 2001) continue to pursue exploration and/or financing to develop additional dimensional stone quarries and processing plants in Wyoming. However, the economic uncertainties that began in late 2000 have been a factor in preventing some companies from obtaining loans to begin large-scale quarrying and construction of large plants.

Figure 22. New desks with pink granite tops being installed in the Wyoming House chamber in January, 2002.

Figure 23. Detail of a new desk with the black granitic top in the Wyoming Senate chamber, January, 2002.

Gypsum

Gypsum, hydrous calcium sulfate, is mined at two localities in the Bighorn Basin (**Figure 21**) where it is used as the primary ingredient in wallboard. The mines south of Lovell and near Cody are near wallboard manufacturing plants. Gypsum production in Wyoming declined significantly in 2000 from the previous year, despite the increase in national gypsum production, but recovered in 2001 to a record 592,342 short tons. Gypsum is also mined south of Laramie (**Figure 21**) where it is used as a retardant in cement which is manufactured at Mountain Cement's nearby plant.

Limestone

Limestone (calcium carbonate) is quarried in Wyoming for construction aggregate, cement, and emissions control in coal-fired power plants. The largest producer of limestone is Mountain Cement at Laramie (**Figure 21**), which quarries around a half million tons of limestone for cement manufacture. The limestone is calcined and mixed with gypsum, siliceous shale, and other additives to make several types of cement.

Phosphate

Phosphate is mined in the neighboring states of Idaho and Utah for use in soil conditioners. The production from Utah is transported by slurry pipeline to the SF Phosphates plant southwest of Rock Springs (**Figure 21**). There the phosphate is calcined and processed with sulfur into soil conditioners. Phosphate had been mined in Wyoming prior to 1977 at Leefe, west of Kemmerer in Lincoln County (**Figure 21**), and at other locations in the Overthrust Belt, especially near Cokeville. Wyoming contains significant resources of phosphate rock in the Permian Phosphoria Formation in the Overthrust Belt and the northeastern flank of the Wind River Range in Fremont County (**Figure 21**).

Trona

Four companies in Wyoming mine trona (sodium sesquicarbonate) by underground and solution recovery methods at five locations and produce sodium products at plants near the mines (**Figure 21**). Soda ash is the primary product refined from trona. Soda ash is an industrial chemical used to manufacture a variety of products including glass, soap and detergents, soil conditioners, water treatments, and when purified, it is baking soda. Soda ash is also manufactured in the U.S. from sodium sesquicarbonate extracted from alkali lake deposits in California and from nahcolite (sodium bicarbonate) at an *in situ* mine in northwestern Colorado. The amount of trona mined in 2001 decreased slightly from 2000 (Stauffenberg, 2001). The Wyoming State Mine Inspector's report is for conventionally mined trona only and does not include trona mined by *in situ* and mine-water recovery methods.

Uranium

Uranium continued to be mined by *in situ* methods at two Converse County locations (CAMECO and Rio Algom) in the southern Powder River Basin (**Figure 21**). Yellowcake from the two on-site recovery mills is shipped for enrichment and conversion into nuclear power plant fuel. Although the COGEMA mine closed in early 2000, it did contribute to yellowcake production that year. Without COGEMA in 2001, Wyoming's uranium (yellowcake) production decreased to 1,640,669 short tons (**Table 1**), down 21% from 2000 (Stauffenberg, 2001).

The spot market price of yellowcake (the product of uranium mills) increased to $9.80 per pound as of February 18, 2002, according to the Ux Consulting Company, LLC., the Uranium Exchange Company (see http://www.uxc.com/top_review.html), and the Rocky Mountain Minerals Scout. The price has continued a steady climb upwards with no declines since January, 2001 (**Figure 24**).

There has been no sale announcement of the Smith Ranch operation, reported in *Wyoming Geo-notes No. 72*, December, 2001. Rio Algom, the current operator, was reportedly near selling this operation in September.

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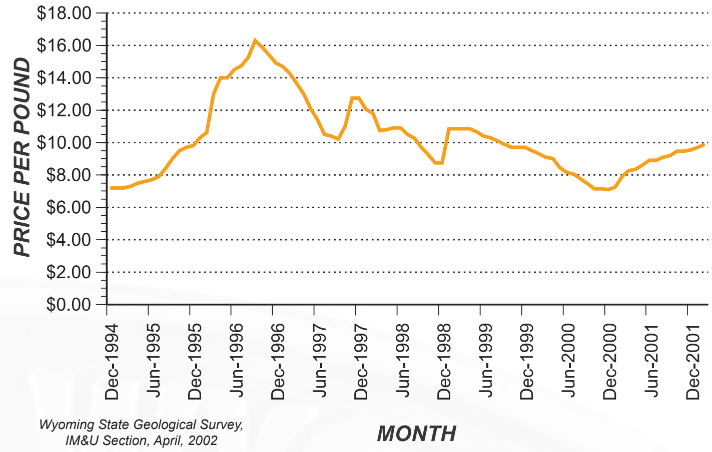

Figure 24. Spot market yellowcake prices (January, 1995 through February, 2002). Source: Uranium Exchange Weekly Reports.

Metals and Precious Stones Update

W. Dan Hausel, PG-1025

Senior Economic Geologist–Metals and Precious Stones, Wyoming State Geological Survey

Wayne M. Sutherland, PG-2767

STATEMAP Project Geologist–Metals and Precious Stones, Wyoming State Geological Survey

Activities involving metals and precious stones continued in the fourth quarter of 2001. Gold prospecting is still a popular pastime at South Pass, more sapphire and iolite gemstones from Palmer Canyon are being cut and marketed, and three more diamond properties in the Colorado-Wyoming State Line District are apparently going to be tested at the Sloan diamond recovery plant south of Laramie, with the possibility of testing even more of the district's kimberlites in the future.

The Metals and Precious Stones Section at the Wyoming State Geological Survey (WSGS) has completed drafts of two reports, one on kimberlites in the Iron Mountain district, the other on lamproites in the Leucite Hills area. Work continues on a reconnaissance map of part of the Granite Mountains (emphasizing the Precambrian complex) and funding has been approved for mapping the Keystone 1:24,000-scale Quadrangle in the Medicine Bow Mountains beginning in August, 2002. The Keystone mining district contains mineral deposits in both the Keystone Quartz Diorite and the Mullen Creek layered mafic complex.

One can only wonder what one diamond mine or one platinum-group metal mine could do for Wyoming's economy.

Metal and gemstone prices

Metal and gemstone prices in early 2002 were on the rise. On February 28, 2002, the price of gold was $297 per ounce, platinum was $493 per ounce, palladium was $377 per ounce, and rhodium was $900 per ounce. Some gem-quality Argyle pink diamonds from Australia recently sold for more than $1 million per carat and a small 49 millimeter jade ring sold for $2.57 million.

The above prices are worth noting because all the precious metals and gemstones mentioned are also found in Wyoming. One can only wonder what one diamond mine or one platinum-group metal mine could do for Wyoming's economy. In the first quarter of 2002, some pinkish-red sapphires from Wyoming sold for $150 to $300 per carat and Wyoming iolites sold for $50 to $150 per carat.

Exploring for gold at South Pass

South Pass has become a well-known region to search for gold: specimen-grade samples and gold nuggets are found each year by treasure hunters and prospectors. According to some historical reports, gold may have been found in the region as early as 1842, and a later gold strike at the Carissa mine in 1867 led to a major but short-lived gold rush. South Pass City was estimated to have had anywhere between 2000 to 10,000 occupants, somewhat different from today's small but variable population (**Figure 25**).

In addition to the discovery of some rich lode deposits, several placers in drainages across the auriferous structures yielded some gold (**Figure 26**). Placer mining sporadically occurred in the district since the initial gold discovery. In many of these placers, fine gold along with nuggets were found. As incredible as it may seem, some placer property was overlooked by the early prospectors.

This summer, the Metals and Precious Stones Section of the WSGS is sponsoring another field trip to the South Pass area to inform the general public about the geology, mining history, and gold mineralization in the district (see **CALENDAR OF UPCOMING EVENTS**, p. 4). In past years, this has been a very popular field trip.

Sapphire, ruby, and iolite

In 1996, the WSGS discovered a gemstone deposit west of Wheatland in Palmer Canyon (Hausel, 1998; Hausel and Sutherland, 2000). The potential for economic development of this deposit was considered high, as it is locally enriched in gemstones, many of which appeared to be very high quality. After the WSGS released information about the site, mining claims were filed by Eagle-Hawk Mining from Lyons, Colorado.

Several thousand carats of ruby, sapphire, and iolite were recovered by the WSGS during initial reconnaissance of the deposit, and the first specimens of corundum and cordierite have now been manufactured into faceted gems by Eagle-Hawk Mining. The gemstones include sapphire and iolite (for photograph, see *Wyoming Geo-notes No. 72*, December, 2001).

More recently, additional corundum from Palmer Canyon was cut producing two dark, pinkish-red sapphires weighing 2.5 and 3.5 carats, respectively, which were sold to a private collector (Vic Norris, personal communication, 2002). Much larger gems are expected, as the WSGS recovered high-quality iolite weighing 3000+ carats from the deposit. Some of the faceted gems were sent to the Gemological Institute of America's research laboratory (**Figure 27**).

Diamonds

State Line district

According to a Consolidated Pacific Bay Minerals News Release (November, 2001):

> *. . . the company entered into an agreement to acquire 100% of Dia Met Mineral's Sloan diamond recovery plant, situated 35 miles south of Laramie. The plant lies adjacent to the Sloan 1 and 2 diamondiferous kimberlites in the Colorado-Wyoming State Line district.*
>
> *During the initial stages of BHP/Dia Met's exploration and evaluation of the Lac De Gras, NWT, Canadian diamond properties, this plant served as the principal bulk kimberlite test and diamond recovery facility; and thus played a vital roll in the evaluation and development of the present day Ekati diamond mine in Canada. In the State Line District, the Sloan plant has been used to treat approximately 10,000 tons of kimberlite from nearby Sloan 1 and 2 kimberlites.*
>
> *Pac-Bay currently holds the right to acquire 100% of the George Creek, Pearl Creek and Sand Creek diamond prospects in the State Line district. In the 1980s,*

Figure 25. The population at South Pass City has dwindled since the 1867 gold rush when the populace lived in cabins and tents in the area. Much of the gold at South Pass still remains in the ground, as only a very small portion of the gold-bearing structures were ever explored or mined (photograph courtesy of Sharon Hall, 2001).

Figure 26. View of the Rock Creek washing plant with dredge tailings. This creek was placer mined during the 1800s, and again in the 1930s. However, considerable gold still occurs in the stream gravel as well as in the tailings. Gold nuggets are commonly found each year in the district's waste piles (photograph courtesy of Sharon Hall, 2001).

bulk sample processing of 3,000 tonnes of kimberlite from the George Creek dike resulted in the recovery of 89,155 macrodiamonds. The ore grades of bulk samples from that property averaged 75 carats per hundred tonnes (CPHT), and ranged from 45 to 135 CPHT.

The Sloan plant is rated at 120 tonnes per day, and is in excellent operating condition. Pac-Bay intends to use the plant for testing and early development of its George Creek diamond property, and will also test its Pearl Creek and Sand Creek properties.

Pac-Bay sees the acquisition of the Sloan plant as a vital step toward development of the George Creek property, and an excellent opportunity to acquire and test other nearby diamond-bearing kimberlites within and surrounding the Colorado/Wyoming State Line District.

The Section considers the State Line district and nearby regions to have high potential for the discovery of additional gemstone diamonds. Several kimberlites in the district have yet to be evaluated even though diamonds recovered from the Kelsey Lake mine on the Colorado-Wyoming border have included many high-quality gemstones, some weighing as much as 28.3 carats. Diamond distribution curves and mineralogical evidence indicate that there is potential for recovery of much larger stones from the mine (Howard Coopersmith, personal communication, 2002). The Kelsey Lake mine has resumed testing following its purchase by a Wyoming company.

Figure 27. Spectacular iolite (blue) gemstones with a pinkish-brown and reddish-pink sapphire (photograph by Maha Tannous©, GIA, courtesy of and used with permission of the Gemological Institute of America).

Rock Hound's Corner: Calcite and Onyx

W. Dan Hausel, PG-1025

Senior Economic Geologist–Metals and Precious Stones, Wyoming State Geological Survey

Calcite ($CaCO_3$) is a relatively soft mineral with a hardness of only 3 and can be scratched with a knife. Calcite is also relatively light in weight, having a specific gravity of only 2.71. Because it is relatively soft, calcite is not a gemstone, although calcite crystals, geodes filled with calcite, and calcite onyx may be attractive to many collectors.

Calcite may be clear, white, or an off-white color. Because of impurities, specimens of russet, pale pink, and rose-colored manganese-bearing calcite are sometimes found. Under ultraviolet light, many calcite specimens will brightly fluoresce red, pink, green, blue, or yellow. It is soluble in hydrochloric acid, and will vigorously effervesce in cold, dilute (10%) hydrochloric acid.

Calcite is hexagonal in crystal form and will crystallize as rhombohedral or scalenohedral crystals, and as finely crystalline masses. It sometimes crystallizes as elongated, hexagonal sand crystals containing as much as 60% sand-sized particles (Vanders and Kerr, 1967). Clear specimens of crystalline calcite also show distinct double refraction: when clear calcite is placed on top of a dot on a piece of paper, the viewer sees two dots.

Calcite may also occur in a form of onyx, known as *Mexican onyx*. This is similar to chalcedony onyx, although it is considerably softer. Calcite onyx occurs with alternating dark and light color bands as the result of deposition from spring waters saturated with calcite. The material, because of its softness, does not polish; however, it can be easily carved. Collectors often cut specimens of calcite onyx and coat them with acrylic spray, producing attractive bookends.

Calcite is also found as septarian concretions, which are rounded nodules of clay, silt, and limestone that have been fractured and recemented with calcite or siderite that fills cracks in the concretions. Many of these are well-cemented and may contain well-crystallized calcite and rarely quartz.

Continued on next page.

Iron Mountain district

Results of mapping and sampling in the Iron Mountain district north of the State Line district by the WSGS show that the district is the second largest field of kimberlites in the U.S. and there is a high probability for the discovery of more kimberlites. Both buried kimberlite within the mapped area, as well as exposed and hidden kimberlite immediately north of the mapped area, are highly probable. Mapping of the district terminated in the middle of the project due to loss of research funds. The final report on the research that was completed has been delayed, but should be out in early fall, 2002.

Geochemical data show that some of the Iron Mountain kimberlites have diamond potential similar to some kimberlites in the State Line district. The report will include information on the recent kimberlite discoveries made by the WSGS as well as geochemical, geophysical, and geological data. This area may provide great prospecting opportunities for individuals and companies. However, the presence of private land in the area requires permission to explore large parts of the district.

The Leucite Hills

Our final report on the geology and geochemistry of the Leucite Hills in southwestern Wyoming is being written. The Leucite Hills (see **Front cover** photograph) are the largest lamproite field in North America. The report will include information on geology, volcanology, mineralogy, and geochemistry of these unique rocks.

Lamproites are considered potential diamond targets. Although no diamonds have been found in the Leucite Hills to date, very little sampling has occurred. Of several samples analyzed, a few spinels yielded geochemical signatures that suggest some lamproites may have had a limited sampling of the diamond stability field. Thus, the authors highly recommend future exploration in the area, especially to search for hidden olivine lamproites. Incidentally, during field investigations by the WSGS, another gem known as peridot (olivine) was found.

8th International Kimberlite Conference

The largest scientific conference in the world related to diamonds and their host rocks is scheduled for North America in 2003. The conference, based in Vancouver, Brit-

Continued from previous page.

Septarian concretions have been reported in outcrops of the Cody Shale in several parts of the state including the flanks of the Bighorn Mountains and in the northern Medicine Bow Mountains. Where found in the Cody Shale, the concretions typically occur in the unnamed lower shale member, in the Carlile Shale Member, and in the Niobrara Shale Member.

The upper 90 feet of the Carlile Shale near Buffalo exhibits dark-gray fossiliferous limestone concretions that average 1 foot in diameter and sometimes contains veins of dark orange or yellow calcite. The lower 175 feet of the Niobrara Member in this area sometimes contains two or three beds with dark yellowish-orange, fossiliferous, silty septarian concretions with veins of light-yellow calcite (Mapel, 1959). Some septarian concretions from the Niobrara have measured up to 10 feet in diameter, although these are generally too fractured for lapidary use (Sutherland, 1990).

Some places to look for calcite

Good hexagonal sand calcite crystals are found in the Goshen Hole area of eastern Wyoming (Norma Beers, personal communication, 1998). These unusual crystals consist of hexagonal calcite with considerable sand-sized particles (that were incorporated during crystallization), such that they appear to be nodules of sandstone. These are formed of calcite and will effervece in dilute hydrochloric acid.

Mexican onyx is found at Fish Canyon, Patten Creek, Webb Canyon, and a few other locations in the Hartville uplift north of Guernsey. The onyx occurs in the Permo-Pennsylvanian Hartville Formation and the Mississippian-Upper Devonian Guernsey Limestone.

Septarian concretions have been reported in the Niobrara Shale at the northern end of the Medicine Bow Mountains in the Coad Mountain area along the banks of Pass Creek (Hausel and Sutherland, 2000).

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ish Columbia, will include amongst a number of field trips, a six-day field trip to the Wyoming Craton to examine lamproites, diamondiferous kimberlites, and to visit the Kelsey Lake diamond mine. The WSGS will assist in the logistics of this prestigious conference. Information and updates on the 8th International Kimberlite Conference are located at http://www.venuewest.com/8IKC/.

Granite Mountains STATEMAP subproject

The authors are working to complete a U.S. Geological Survey (USGS) funded STATEMAP 01 subproject focused on a reconnaissance map of that portion of the Granite Mountains uplift within the Rattlesnake Hills 1:100,000-scale Quadrangle. As mentioned previously, much of the work completed to date has differentiated the Archean rocks in the uplift. The Section is compiling sixteen 1:24,000-scale geologic maps using aerial photographs. Due to time constraints, only limited field reconnaissance is possible and will concentrate primarily on areas of structural complexity and supracrustal rocks (see *Wyoming Geo-notes No. 72*, December, 2001, for recent discoveries made in the area).

The Precambrian complex in the Granite Mountains of central Wyoming is one of the least studied blocks of Precambrian rocks in North America. The authors believe the area has potential for large-tonnage, low-grade gold deposits; small-tonnage, high-grade gold deposits; some gemstones; and uranium. For example, the WSGS discovered a gold district along the northern edge of the Granite Mountains in 1981. Since the discovery, dozens of gold anomalies have been detected, and more than 1 million ounces of gold may have been outlined during company drilling projects. Even so, many gold anomalies in the district remain unexplored (Hausel, 1996).

Keystone STATEMAP subproject

The Section was granted a STATEMAP 2002 project beginning August, 2002 to complete a study of the Keystone district. The USGS-funded project will result in a geologic map of the Keystone 7.5-minute Quadrangle in the Medicine Bow Mountains. This quadrangle encloses the Keystone Quartz Diorite as well as the eastern portion of the Mullen Creek layered mafic complex.

The Keystone Quartz Diorite hosts some shear zone gold-copper deposits that were mined in the late 1800s. These lode deposits were collectively known as the Keystone mining district. Several gold placers were also found–the area became known as the Douglas Creek district.

A part of the quadrangle is also underlain by part of the 60-square-mile layered Mullen Creek complex, which has already yielded some palladium, copper, gold, platinum, vanadium, titanium, nickel, and chromium anomalies. The complex includes one commercial deposit at the historical New Rambler mine, one of the past's only known commercial palladium-platinum-copper-gold mines in North America. The mine is situated in shear zone cataclastics along the extreme northeastern edge of the layered complex.

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GEOLOGIC MAPPING AND HAZARDS UPDATE

HAZUS for Wyoming

James C. Case, PG-1138

Senior Staff Geologist–Geologic Hazards, Wyoming State Geological Survey

Thomas A. Huebner, GIT

Assistant Earthquake Program Manager, Wyoming State Geological Survey

The Geologic Hazards Section at the Wyoming State Geological Survey (WSGS) receives funding from the Wyoming Emergency Management Agency (WEMA) and the Federal Emergency Management Agency (FEMA) to manage FEMA's Earthquake Program for Wyoming. The program's scope has expanded beyond earthquakes to include landslides, liquefaction, hazards mitigation, and computer/GIS applications and support for cities and counties in Wyoming. Currently the Hazards Section is working on items described in previous issues of *Wyoming Geo-notes* (e.g., Numbers 68 through 72) as well as a significant methodology called HAZUS which is used to estimate losses from natural hazards. HAZUS stands for HAZARDS U.S. and this article describes the methodology and how it is being applied to Wyoming.

HAZUS is a personal computer (PC)- and Geographic Information Systems (GIS)-based computer program originally designed to provide the user with an estimate of the type, extent, and cost of damages and losses that may occur during and following an earthquake. It was developed for FEMA by the National Institute of Building Sciences (NIBS). There have been a number of versions of HAZUS generated by FEMA, with new versions being designed to incorporate flood and hurricane modules. The WSGS is working with and refining the earthquake module, which includes a consideration of historical earthquakes, active faults, probabilistic seismic hazards, landslides, liquefaction, soils, building type and construction, essential facilities, schools, utility systems, and transportation systems.

Analysis options and modules

HAZUS allows the user to generate a variety of scenarios for an earthquake, including annualized losses. The user can select what type of earthquake or ground motion to use in an analysis, in addition to selecting damage and economic impacts for various elements of the infrastructure. HAZUS has incorporated a number of modules listed below to assist with the analyses. These modules can provide the user with estimates of damages or losses.

- Direct physical damage module: Estimates damage to buildings, facilities, and lifelines;
- Induced physical damage module: Estimates damage through fire, debris generation and removal, and inundation (seiche, dams, levee);
- Direct economic and social losses modules: Estimates economic losses for buildings, transportation systems, utilities, and communications systems and social losses including casualties and shelter needs; and
- Indirect economic impact module: Loss of future customers, jobs, and economic activity.

The damage and economic analyses are based upon the degree of ground shaking and ground failure that may occur for a particular earthquake scenario. HAZUS utilizes another module, the Potential Earth Science Hazards (PESH) module, to generate needed ground shaking and failure estimates. HAZUS cannot generate loss estimates without first utilizing PESH.

Potential Earth Science Hazards Module

The earthquake-related hazards utilized by HAZUS in evaluating casualties, damage, and resultant losses are referred to as potential earth science hazards or PESH. PESH includes ground motion, ground failure (liquefaction, landslides, and surface fault rupture), and seiche (earthquake/landslide-induced wave). Various PESH data are supplied with HAZUS, and they can be used to run a basic analysis. In order to generate a more advanced and valid analysis, however, user supplied data is required. Descriptions of the various data categories, default data supplied, and preferred user-supplied data are presented below.

Ground motion. Ground motion estimates are generated from one of three sources–deterministic ground motion analyses using data supplied by HAZUS, U.S. Geological Survey (USGS) probabilistic ground motion maps supplied with HAZUS, and user-supplied probabilistic or deterministic ground motion maps. The ground motion is characterized by peak ground acceleration, peak ground velocity, and spectral response (modeled acceleration or velocity in buildings with various natural frequencies). Descriptions of each of the three sources are presented below.

- Deterministic analysis using HAZUS data: In a deterministic analysis, the user determines what level of ground shaking may occur as a result of a specific event. The event may be the activation of an exposed fault, a historic earthquake, or a user-defined earthquake. HAZUS comes with databases for faults and historic earthquakes, although the databases are not complete for Wyoming.

  When an earthquake occurs, seismic waves are generated at the source, usually an exposed or buried fault. As the seismic waves radiate outwards from the source, their amplitude and energy are generally reduced (attenuated). This is the reason that earthquakes are usually not felt as strongly 50 miles from an epicenter as they are at 5 miles from an epicenter. There are a number of models incorporated into HAZUS that provide pre-determined attenuation functions. In a default analysis mode, they all present ground motions for sites on rock.

- USGS probabilistic ground motion maps: This federal agency periodically generates probabilistic ground motion maps for the entire U.S. The maps show modeled peak ground accelerations and spectral accelerations for various timeframes. Instead of modeling a single source, as with the deterministic analysis, multiple sources are utilized, including faults, historic earthquakes, and "random" earthquakes. The USGS probabilistic ground motion and spectral acceleration maps are used in the current International Building Code. The maps with a ground motion return period of 2500 years are used in the Code. The default data supplied with HAZUS assumes that ground motions are for sites on rock.

- User-supplied maps: HAZUS allows the user to supply their own ground motion maps. The maps may be generated as a result of a site-specific study, or may be based upon detailed data from an actual earthquake. It is assumed that the user-supplied ground motion maps account for amplifications of ground motions that may occur in various soils at the surface.

Amplification of ground motion. As described above, default HAZUS analyses assume that structures are located on rock. HAZUS, however, can utilize six soil classifications that can be used to modify the ground shaking that is modeled for sites on rock. The soil types are as follows: Hard Rock (Site Class A), Rock (Site Class B), Very Dense Soil and Soft Rock (Site Class C), Stiff Soils (Site Class D), Soft Soils (Site Class E), and Soils Requiring Site Specific Evaluations (Site Class F).

If soils in Site Classes C through E are present at the surface, ground motions are usually amplified above what is expected in rock. The default data in HAZUS assumes only one soil type (Site Class B) for an entire state. It is necessary for the user to generate and incorporate a modified soils map in order to utilize amplification factors associated with other soil classes.

Ground failure. Three types of ground failure can be considered in HAZUS–liquefaction, landslides, and surface fault rupture. Data and maps on each of the ground failure types require user input; no defaults exist with the data supplied in HAZUS. Considering that Wyoming has some of the highest landslide densities in the U.S., it is important to provide such information to HAZUS. A description of each is presented below.

Considering that Wyoming has some of the highest landslide densities in the U.S., it is important to provide such information to HAZUS.

- Liquefaction: A liquefaction susceptibility map can be user-generated by applying various factors supplied in the HAZUS technical manual to surficial and bedrock geologic maps. In addition, depth-to-groundwater maps are needed, although HAZUS does supply a map with a default depth to groundwater of 5 feet. The use of the default map, however, will result in error where depth to groundwater is greater.

- Landslides: A landslide susceptibility map can be user-generated by applying various factors supplied in the HAZUS technical manual to a geologic map and groundwater map. In Wyoming, however, landslide maps at various scales have already been generated. They can be used as susceptibility maps because most landslides in the state occur within areas of previously mapped landslides. A 1:500,000-scale map has already been incorporated into HAZUS by the WSGS and FEMA, and the WSGS is in the process of incorporating more detailed 1:24,000-scale maps.

- Surface fault rupture: HAZUS can also incorporate surface fault rupture data into the program. Such data must be supplied by the user.

Seiche. Although HAZUS states that seiche hazards or susceptibilities can be incorporated, it appears that no specific guidance has been provided.

Analysis area

HAZUS (1999 version, Service Release 2) is designed to generate damage assessments and associated ground motions based upon analysis at the census tract level. HAZUS calculates a ground motion value for the centroid of the census tract, and applies that value to the entire tract. In reality, parts of a census tract may actually be subjected to ground motion values that are significantly greater or less that the value at the centroid. As a result, damage assessments can be considerably off in areas with significant differences in ground motion within a census tract.

Default databases

HAZUS is designed to be used with data supplied by the user, although default data is supplied with the program. The default databases include the following:

- General building stock: This includes buildings classified as residential, commercial, industrial, agricultural, religious, governmental, and schools. Individual buildings are not listed, but rather classes of buildings are supplied along with the number and square footage of buildings of each class within individual census tracts.
- Transportation systems inventories: Items inventoried include highway segments, highway bridges, highway tunnels, railroad track segments, railroad bridges, railway tunnels, railway facilities, bus facilities, airport facilities, and airport runways. Generally, the individual databases are incomplete.
- Utility systems: This includes crude and refined oil pipelines, crude and refined oil facilities, natural gas pipelines, natural gas facilities, electric power facilities and distribution lines, communication facilities and distribution lines, potable water pipelines and facilities, and wastewater facilities. Generally the individual databases are incomplete or outdated.
- Hazardous materials inventory: This includes facility name, state, Environmental Protection Agency (EPA) ID number, and location (latitude/longitude and GIS coverage). There are numerous empty fields in the database.
- Demographics: Data includes census tract, population in census tract, households in census tract, number of people in general quarter, people under 16 years old, number of people between 16 and 65, number of people over 65, populations of ethnic groups (white, black, native American, Asian, Hispanic), household income levels, number of people at residential property during day and night, total working population in commercial and industrial industries, number of people commuting at 5 p.m., owner-occupied housing by housing type, renter-occupied housing by housing type, vacant housing by type, number of structures built prior to 1940, number of structures built after 1940, average rent per unit, and average value per owner occupied unit. All these data are derived from the 1990 census and will be updated to 2000 census data following the upcoming September, 2002 release by the U.S. Census Bureau.
- High potential loss facilities: This database includes nuclear power plants, dams, and military installations. In Wyoming, default data are provided only for dams. The dam data, however, is not incorporated into a HAZUS analysis until site specific studies are completed.
- Agricultural product inventory: The database structure is provided, but no data is included.
- Vehicle inventory: The database structure is provided, but no data is included.

. . . the HAZUS database on natural gas facilities in Wyoming is significantly out of date, and does not include the many new compressor stations.

Required expertise

HAZUS is designed to be performed by those with knowledge (basic to advanced) of geology, seismology, and/or engineering. The results from HAZUS are designed to be used by planners, emergency managers, geologists, and engineers.

HAZUS levels of analysis

HAZUS may be used at three levels of complexity ranging from a default data application to an application that requires detailed site information. The three levels are as follows:

Level 1

The Level 1 HAZUS analysis uses default databases supplied with the HAZUS software. A basic knowledge of earthquakes and their effects is needed to run HAZUS using default data. One soil type is used for an entire state, and liquefaction-prone areas and landslides are not used. High potential loss facilities, such as dams, military installations, and nuclear power plants are not considered or incorporated into a Level 1 analysis. From a geotechnical standpoint, uncertainty is very large. This level of analysis is useful only for very preliminary evaluations of an area and crude comparisons among different regions. In the opinion of the WSGS, Level 1 data should not be released to the public.

Level 2

Level 2 requires user-supplied data and user-modified default data to gain more refined study results. Along with refined datasets of building stock and transportation systems, detailed information about local geology, such as digital landslide maps, digital soil maps, and digital liquefaction potential maps are required to run analyses at this level. This refinement gives HAZUS greater certainty when projecting losses suffered during an earthquake.

Level 3

Level 3 uses geotechnical and engineering experts to study special conditions of the study area. Special conditions can include dam failure, mine collapse, or other site-specific problems caused by an earthquake. This level of HAZUS analysis is the most refined and provides the most accurate results.

Status of HAZUS in Wyoming

The WSGS has been working with various aspects of HAZUS for a few years and has discovered a number of strengths and weaknesses with HAZUS. Items being addressed to date include analysis area by census tract, default data, soils maps, landslide maps, liquefaction maps, fault maps, and capabilities of local users to use HAZUS.

Analysis area

The WSGS worked with DTI, Inc., FEMA's subcontractor on HAZUS, to modify the census-tract approach currently used with HAZUS. We generated a new approach based upon nearness to active faults and population. A square-mile analysis grid was generated for all areas near an exposed active fault and for all areas with more than 5 people per square mile. All other areas had an analysis cell the size of a 7.5-minute quadrangle. The centroid of each of these cells is still used for analysis, but the cells are considerably smaller than census tracts. As a result, ground motions used for each cell more closely approximate those projected for a specific location by geologists and seismologists. DTI, Inc. is currently working on a census-block-based area of analysis, which may provide further refinement in populated areas.

. . . the WSGS is proposing to run HAZUS analyses for the counties, with the analyses in part based upon new data supplied by the counties.

Default data

Various types of default data are supplied with HAZUS. In general, most default databases are outdated or incomplete, and will require much time and effort to update. For example, the HAZUS database on natural gas facilities in Wyoming is significantly out of date, and does not include the many new compressor stations. It also does not include data on facility design level, building type, or replacement cost, although generic default values are supplied for these elements.

The existing HAZUS database on general building stock in Wyoming does not include data on individual buildings, but rather data on classes of buildings along with the number and square footage of buildings of each class within individual census tracts. We are working with DTI, Inc. to update this database to square footage values in 2002, and these will be available for Wyoming in both grid and census block level formats. Data at that level will provide more accuracy in analysis, but it still may not be at the level desired by some communities. In some areas it may be desirable to acquire data on specific buildings (industrial, commercial, or residential) for inclusion in a site-specific HAZUS analysis, which will take some time and effort. In addition, damage estimates of buildings are currently based upon building replacement costs, not actual value. That can present an underestimate of impacts of losses in areas like Jackson Hole.

Default soils, landslide, and liquefaction data in HAZUS show only one soil type and no landslides or liquefaction potential for Wyoming. The WSGS has worked with FEMA Region VIII to generate a new soils map for inclusion in HAZUS. The map is currently based upon a 1:500,000-scale surficial geology map of Wyoming (HSDM 98-1) that was generated by the WSGS in 1998. The map is an improvement over default data, but site-specific data still need to be collected from areas of concern. A landslide map for Wyoming was also created from the 1:500,000-scale surficial geology map, and has been incorporated into HAZUS at the WSGS. Better detail will be provided by including 850 landslide maps at a scale of 1:24,000 into HAZUS. The maps were generated at the WSGS, and 200 have already been digitized. At the present rate it will take six more years to complete the digitization process. In order to generate a statewide liquefaction map, it will take approximately three months of full-time effort to generate a preliminary map.

HAZUS default databases do not include any data on railroad tunnels, potable water systems, wastewater (except for Cheyenne), military facilities, agricultural products, or vehicles. In addition, while HAZUS includes databases on shelters, the databases are not directly used in any analysis. The shelter database is currently composed of Civil Defense shelters, most of which are not suitable as earthquake shelters. The WSGS recommends that cities and counties work on developing new lists of shelters that may be earthquake resistant. The dam database needs to be significantly expanded to include site-specific data for each dam before it can be utilized in HAZUS.

In the opinion of the WSGS, a HAZUS analysis based solely upon default data (Level 1) should not be released to the public. While a Level 1 HAZUS analysis has some utility as an in-house planning tool, the default data are too incomplete and in some cases incorrect to warrant releasing the analysis to the public. A Level 2 analysis is required before results should be considered for release to the general public with qualification. In addition, updating inventories for Level 2 studies will improve future HAZUS flood loss estimations.

Fault maps

HAZUS includes fault maps that can be used for site-specific analyses. The fault data, however, is not complete and some faults are not accurately located. The WSGS has been generating new digital fault maps over the last six months.

HAZUS and counties

In Wyoming, few counties have the expertise, equipment, time, or personnel to consistently work with HAZUS. A basic knowledge of earthquakes is required to generate a Level 1 HAZUS analysis. Advanced knowledge of geology, engineering, and seismology is needed to generate Level 2 and Level 3 HAZUS analyses.

HAZUS 99 can run with either ESRI's MapInfo® or ArcView 3.2a®. HAZUS 03 (not yet released) will require modules of ESRI's ArcGIS® to function. Many counties may not be able to dedicate a copy of ESRI's ArcGIS® to a computer needed to run HAZUS. Some counties may not have the funds to even purchase ESRI's ArcGIS®. For these reasons, the WSGS is proposing to run HAZUS analyses for the counties, with the analyses in part based upon new data supplied by the counties.

Highway-affecting Landslides of the Snake River Canyon—Part II, Wolf Mountain Slide and Debris Flow

Mark A. Falk, P.E., PG-29–Project Geologist, WYDOT, Cheyenne, Wyoming

G. Michael Hager, PG-12–Chief Engineering Geologist, WYDOT, Cheyenne, Wyoming

This is the second in a three-part series detailing work by the Wyoming Department of Transportation (WYDOT) on landslides in Snake River Canyon and WYDOT's efforts to mitigate potential damage and protect the highway and its travelers. Part I (see *Wyoming Geo-notes No. 72*, December, 2001, p. 30-34) gave an overview and background on the canyon highway and discussed the Elbow Slide. Part III will discuss two other landslides in the canyon, the Blue Trail and the Deer Canyon landslides. We thank the staff at the Wyoming State Geological Survey for their interest in our work and for helping prepare these articles.

On May 18, 1997, a large snowmelt-triggered landslide occurred on a steep slope approximately 1500 feet vertically above U.S. Highway 26/89 through Snake River Canyon in northwestern Wyoming. The resultant debris flow of rock, mud, and trees covered a 300-foot-long section of the highway with a deposit 15 feet thick. The debris flow continued to be active for about two weeks, during which time up to 100,000 cubic yards (yd^3) of material flowed down the slope.

. . . a large rotational landslide had developed, exposing a large cirque-like head scarp.

The area was declared a disaster by the Governor, and the Wyoming National Guard was mobilized to help clear the roadway. Closure of the highway had an immediate negative economic impact on the area. Within three weeks, the road was opened to twice-a-day commuter traffic and six weeks after the initial slide, the highway was opened to full-time traffic.

To protect the highway that summer, a series of two small basins were constructed above the roadway to catch small-scale mud flows, and a 48" diameter culvert was installed under the road to carry the water. Due to the limited size of the catchment basins and continual small mud flows, regular cleaning of the basins was required throughout the summer.

The longer-term, most cost-effective solution for this slide was to expand the capacity of the catchment basins from 500 yd^3 to 6000+ yd^3. This was done in early 1998 and has (so far) been successful in mitigating the problems.

The event

In the early morning hours of May 18, 1997, WYDOT maintenance personnel in Jackson received a report that muddy water was flowing across the road at milepost 135.67 on U.S. Highway 26/89 in Snake River Canyon (**Figure 28**). A crew was immediately dispatched to clear the road and close it, if necessary. The flow of muddy water continued until dawn, at which time the water flow turned into a viscous mixture of mud and rocks which began to accumulate on the road. At this time, the source of the material was still unknown. By 9:00 a.m., several large trees (in excess of 40 feet in length) had been carried by the mud and covered the road. At approximately noon, the WYDOT Resident Engineer from Jackson hiked up the mountain to determine the source and/or cause of the mud flow. The thick timber, very steep terrain, and snow cover made it very difficult to observe the mud flow along the lower portion of the mountain. In a clearing approximately 1300 feet above the roadway, water and mud was observed flowing from an isolated point in a small drainage. Above this point, large semi-circular tension cracks were observed in the snow.

The next morning, WYDOT Geology Program personnel flew to Jackson to observe the mud flow. The group took

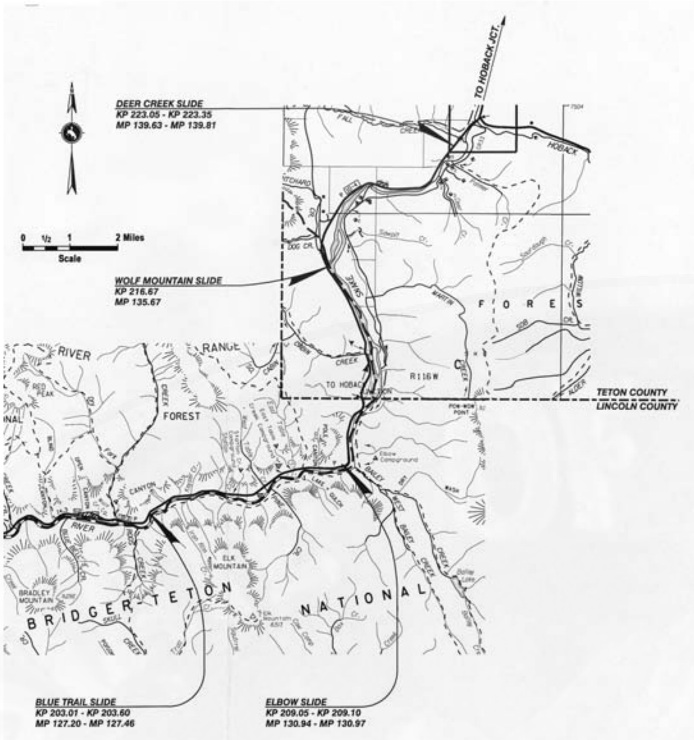

Figure 28. Detailed map of part of the Snake River Canyon showing locations of four major landslide stabilization projects. Map courtesy of Chuck James, WYDOT.

a helicopter tour of the area to get an overall view of the slide (**Figure 29**). By this time, a large rotational landslide had developed, exposing a large cirque-like head scarp. The slump block which had formed below the scarp was approximately 400 feet wide at the face (**Figure 30**) and measured about 450 feet from the back scarp to the face of the block (**Figure 31**). The head scarp above the back of the slump block was approximately 100 feet high. At the base of the slump block, a near-vertical 50-foot-high face had formed. At this time, it was possible to visually observe the movement of the slide. It was a glacier-like movement: large masses of the material from the face of the slump block caved off into the water stream (similar to "calving" at the front of a glacier) which emanated from the base of the block. The water flow was estimated to be in excess of 200 gallons per minute. When the material from the face was mixed with the water flow, it formed a liquid-concrete-like consistency and flowed down the slope in the form of a debris flow. Approximately 450 feet vertically below the slump block, the channel narrowed from 400 to 80 feet wide (**Figure 32**). At this point, the trees and rocks in the debris flow formed small dams that would block the flow until enough material accumulated to breach the dam. The material was then transported farther down the channel (**Figure 33**) in a series of surges, ultimately covering the roadway.

Due to the economic impact the road closure was having on the businesses . . . Governor Jim Geringer declared the site a disaster area on May 27.

By the end of the day on May 19, a 300-foot length of the highway was covered with a 15-foot-thick deposit of mud, trees, and rocks. The delta which had formed below the roadway extended approximately 250 feet out into the Snake River (**Figure 34**). The river bed in this area is very wide, so the addition of the material into the river did not significantly affect the river's flow characteristics. At this time, district personnel were advised that there was nothing that could be done to stop the debris flow and the slide would have to "run its course." The district personnel made plans for a long-term road closure and informed the public that the highway would be closed until the slide stabilized.

For the following six days, significant amounts of debris continued flowing down the slope and accumulating on the roadway. By May 27, the volume of material flowing onto the roadway began to decrease; apparently the slide was starting to dry out and becoming more stable. The primary concern at this point was to get the roadway open so that traffic could once again safely pass. This became more critical after Memorial Day, which is the official beginning of the tourist season and the time when traffic volumes in the canyon increase dramatically.

Due to the economic impact the road closure was having on the businesses and commuters in the area, Governor Jim Geringer declared the site a disaster area on May 27. The Governor was then able to mobilize a National Guard Engineering Unit to clear the debris from the roadway. However, several other regulatory hurdles had to be cleared before starting this operation. The first problem was what to do with the removed material. The Guard unit did not have the capability to truck-haul the material to an off-site waste area and it would have cost about $350,000 for a contract to haul the material to another location. An application was made to the U.S. Army Corps of Engineers for an emergency permit to place material removed from the roadway on the "delta" of slide debris which had formed in the channel of the Snake River. The emergency permit was issued on May 29 allowing up to 20,000 yd^3 of material to be placed on the delta.

The second problem was that this site is within a designated critical eagle habitat area, which prohibits any activity with construction equipment during this time period to avoid disturbing recently hatched bald eagle chicks. An agreement was made with the U.S. Fish and Wildlife Service (FWS) to relax these restrictions. The FWS agreed to monitor the behavior of the eagles to determine if the slide removal operation had any negative impact. WYDOT and the National Guard would try to limit activity and noise, when possible, during the eagles' early morning and late afternoon feeding times.

A special use permit was also required from the U.S. Forest Service (FS) to build some access trails outside the

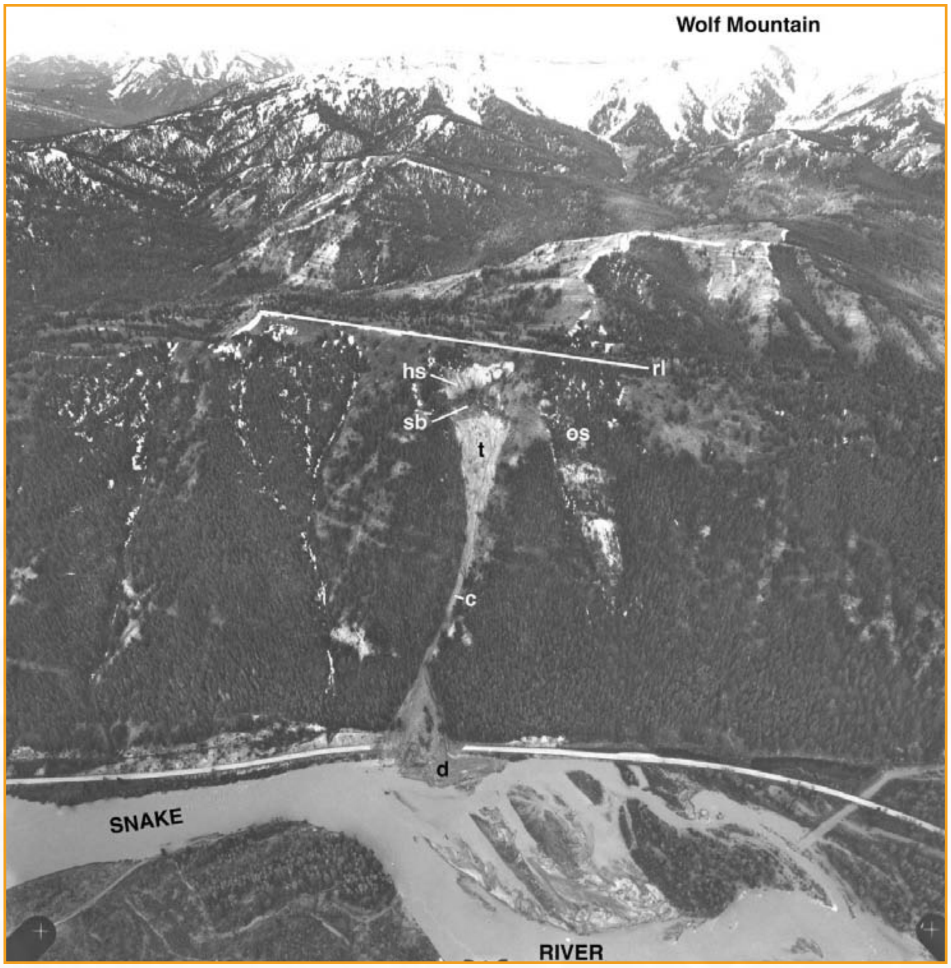

Figure 29. Air oblique photograph of Wolf Mountain Slide area as it appeared May 28, 1997, several days before removal of debris from roadway began. View is to west from the east side of the Snake River; annotations show the major components of the slide: d=delta of debris flow into Snake River, c=chute or channel, t=toe of slump block with vertical face above, sb=slump block, hs=head scarp, rl=ridge line, and os=old landslide area. Vertical distance from river to ridge line is about 1500 feet. Total vertical relief from river to Wolf Mountain is about 4400 feet. Photograph by WYDOT Photogrammetry and Survey.

highway right-of-way as part of the cleanup operation. Given the tight time frame for negotiating and finalizing all of these agreements, there was very good cooperation among all of the agencies involved.

Actual removal of the slide debris began on Sunday, June 1. At first, the removal of material was very slow because of the number of trees in the debris, and they had to be removed one at a time. As part of the agreement with the FS, all trees removed from the debris were stockpiled to be sold as salvage timber. As a safety measure, whenever equipment was working at the base of the slide, there were three spotters placed at various positions along the slide path to watch for any dangerous movement of material. These spotters were in constant radio contact, so if there was a significant debris flow event, personnel at the base of the slide could have adequate warning.

By June 4, most of the material had been removed from the road and equipment could pass from one side of the slide to the other. There was still approximately 100 gallons per minute of muddy water flowing down the slide chute at this time. This was a major consideration, because prior to the slide, no culvert existed under the road here, and the roadway could not be opened until the water flow was controlled. A 48-inch diameter culvert was installed under the road, and the water flow diverted to this culvert. The National Guard spent the remainder of this two-week exercise removing slide debris from the backslope above the roadway. A private contractor completed the backslope work and constructed two retention ponds to contain small amounts of material carried down the mountain during rainfall events. In addition, an access trail was constructed to allow the retention ponds to be cleaned.

Beginning on June 9, the road was opened for commuter traffic. In the mornings northbound traffic was allowed through for one hour, and in the evenings southbound traffic was allowed through for one hour. On June 17, the road was opened for all traffic during daylight hours. During this period, flaggers were present, as well as spotters on the mountain to monitor any slide movement. By July 3, the slide had stabilized enough to open the road to unrestricted two-way traffic 24 hours a day.

The investigation

After the road was re-opened, WYDOT concentrated on developing a long-term plan for dealing with the slide. From a wide and varied option list, three alternatives were proposed to the executive staff of WYDOT: 1) relocating the highway to the other side of the river; 2) constructing a tunnel-like structure across the slide path to allow future slides to flow over the road; and 3) building a bridge which would span the slide path, allowing future slides to pass under the bridge and allowing the river to naturally carry away the material. The alternatives were based on two assumptions: the landslide which created the debris flow would continue to move and provide large amounts of material for additional debris flows every year; and since a well-defined channel now existed where there once was a densely vegetated slope, snow avalanches down the channel in the winter would be a constant maintenance problem.

Immediately after failure on the landslide scarp, there was concern that the slump block (containing some 500,000 yd^3 of material) was very unstable and had the potential for a catastrophic failure. At that time, it was thought that the slide failed in a

Figure 30. Head-on view of uppermost part of Wolf Mountain Slide showing 100-foot-high head scarp, active slump block (note full-grown pine trees leaning at various angles), face of slump block, top of channel, and approximate location of springs (s). Photograph taken from helicopter by G.M Hager, May 19, 1997.

Figure 31. View to south in June, 1997 across upper part of slump block and head scarp. Note chaotically tilted pine trees that mark upper surface of slump block.

thick sequence of colluvium that had been deposited in the bowl-shaped valley. It was not known whether the water flow from the base of the slump block would stop as snowmelt was completed, or if the landslide had interrupted the natural groundwater flow and a perennial high-volume spring had developed. Given these few facts and the many unknowns associated with this slide, a conservative approach was taken by the Geology Program, and concern was raised about the potential stability along the entire ridge between Dog Creek to the north and Cabin Creek to the south.

Before implementing any long-term plan for dealing with the slide, a good understanding of the slide was needed including how it was affected by such things as the geology, topography, presence of water on the slope, vegetation, and potential triggering mechanisms. Understanding these factors was the key to analyzing the potential for other failures along this ridge, so the WYDOT Geology Program undertook a thorough mapping project of the entire ridge. The ridge is in a proposed wilderness area, and this designation limited access.

The ridge on which the Wolf Mountain Slide (WMS) occurred is a north-south trending ridge approximately 3 miles long (**Figure 28**), which parallels the Snake River from Dog Creek to Cabin Creek. Maximum vertical relief from the river to the crest of the ridge is approximately 1600 feet. The geologic formations along the ridge dip west into the ridge from 25° to 30°. A complete geologic section from the Middle Jurassic Twin Creek Limestone (which crops out at the river) through the Lower Cretaceous age Bear River Formation (which forms the top of the ridge) is exposed along the ridge (**Figure 35**) (Love and Christiansen, 1985; Albee, 1968). Wolf Mountain is the 9483-foot peak located about 4 miles immediately west of the slide area.

Figure 32. View looking down debris channel towards Snake River in June, 1997. Photograph taken where debris flows dammed up before being breached and entering the narrow part of the channel below.

Figure 33. View in June, 1997 across steep, narrow part of channel through which debris flowed down to Snake River. Note person standing near edge of channelway (lower right corner), large upright trees on either side of channel, and downed trees in channel that were stripped of their branches.

Figure 34. A delta of debris from Wolf Mountain Slide formed in the Snake River as the debris flow covered the roadway and flowed across it. View to northeast (looking upstream) in late May, 1997 from atop debris flow covering the highway. Note tree-covered gravel bar on outside bend of river and highway (below arrow) to north of debris flow.

The WMS occurred within the shales and interbedded friable sandstones and siltstones of the lower part of the Bear River. The base of the slide terminated at the top of the limestone which forms the top of the Cretaceous Gannett Group (**Figure 35**). Since the formations along this ridge dip west, the truncated ends of the formations on this east-facing slope are subject to erosion. The hard, resistant, cross-bedded sandstone which forms the ledge rock is well exposed above the failure (**Figure 35**) and becomes less prominent along the ridge in both directions. A 10- to 15-foot-thick layer of colluvium overlying the failed shale bedrock is evident along the north and west side of the slide. Along the south side of the slide, the contact between colluvium and bedrock is not apparent. A seismic traverse run along this edge indicates that the colluvium along this side is in excess of 30 feet thick.

A cross-section made from the topographic map (created before the slide failed) showed that before failure, the slope angle within the shales of the Bear River Formation was 32°. Aerial photographs indicated there were fewer trees in this "bowl" compared to some of the adjacent drainages. An area of vegetation indicative of high-moisture-content soils and the presence of some slight water seeps was noted at the southeast corner of the slump block.

In the drainage immediately north of the WMS there is a large, old failure which is nearly identical in size and shape to the WMS ("os" on **Figure 28**). The cross-bedded sandstone ridge above this old failure is very prominent, and the scarp geometry of the circular failure in the shale is identical to the WMS. The slump block has moved down so that the toe of the slide is directly on top of upper limestone of the Gannett Group. This large slide is divided into a north and south slump, with the south slump being the most recently active. Cores taken from trees in this portion of the slump block indicate that they are approximately 80 years old. Although no cores were taken from trees in the north (oldest) part of the slump block, based on the diameter of these trees, it is estimated they could be on the order of 130 to 140 years old. Looking at this old slide relative to the Snake River, we theorize that this large slide and resulting debris flow deposited a large amount of material in the river some time before the highway was built. This explains the gravel bar present on the outside bend of the river (**Figure 34**), which is not the typical depositional pattern. Given the fact that this old slide has a slump block nearly identical in shape and size to the WMS slump block, we concluded that the potential for further large-scale catastrophic movement of the WMS slump block is low.

Approximately 2000 feet south of the WMS at the highest point along the entire ridge, erosion has truncated the shale layers within the lower Bear River Formation (**Figure 28**). From this point southward to Cabin Creek, no shale is exposed on the easterly facing slope. We conclude that along this part of the ridge there is very little possibility of a failure similar to the WMS.

This investigation identified only one area that appears to have the potential to experience a catastrophic failure similar to the WMS. This area is located in the drainage immediately to the south of the WMS (**Figure 28**). This area is a fairly deep bowl with relatively little vegetation. The ridge of cross-bedded sandstone above this bowl is quite prominent, and

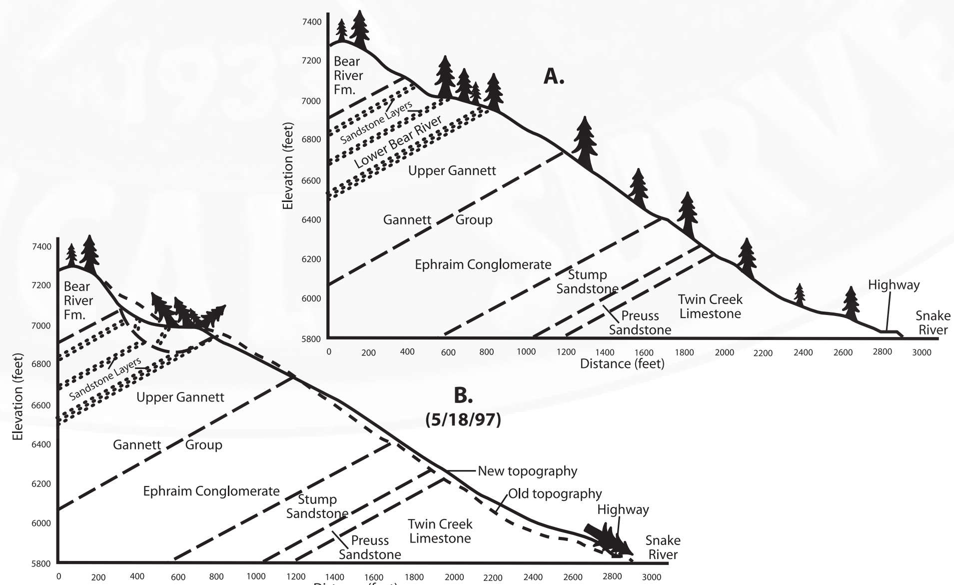

Figure 35. Cross sections of the Wolf Mountain Slide showing geologic formations and topographic relief. Horizontal: vertical ratio is 1:1 (no vertical exaggeration), section goes approximately along centerline of landslide block, channel, debris flow, and delta on Snake River. (A) Before Wolf Mountain slide/debris flow and (B) after slide/debris flow (dashed line indicates profile before, solid line shows current profile). Adapted from Falk and Hager (1998).

the shale in the Bear River Formation is standing at a slope angle of about 27°. There is no evidence that any failure has taken place in this bowl. There are very few trees on the ridge above the bowl, and it appears that large amounts of snow collect in this deep drainage. In addition, there is a fairly well-defined drainage channel from this bowl to the roadway.

A major factor in the stability of this bowl is believed to be the 27° slope angle within the shale, compared to the 32° angle present within shale at WMS before it failed. Also, it remained stable throughout back-to-back years of near-record precipitation, and if weather patterns return to somewhat normal for a year or two, this material will probably become more stable.

. . . remediation efforts concentrate on stabilizing and controlling the material which was generated from the failure of the slide.

In addition to the geologic and topographic information gathered, we researched temperature affects on snowmelt-triggered landslides. A study done on 20 historical slides in the central Rocky Mountain region by the U.S. Geological Survey (Chleborad and others, 1997; Chleborad, 1997) indicated a strong relationship between landslide events and rising temperatures. This study concluded that the highest percentage of snowmelt-triggered slides occur within 18 days after the first yearly occurrence of a six-day running average where the daily maximum temperature is greater than or equal to 58°F at the site. The WMS took place five days after the six-day running average reached 58° (Alan Chleborad, U.S. Geological Survey, Personal communication, 1997; University of Wyoming, 1997).

The solution

Based on our mapping and other investigations, we reported to the WYDOT executive staff that the potential for further catastrophic failures along this road section was low enough not to warrant expensive alternatives such as moving the highway to other side of the river, building a tunnel or "mud shed," or building a bridge to span the slide path. We recommended that remediation efforts concentrate on stabilizing and controlling the material which was generated from the failure of the slide. These efforts included enlarging the retention pond and seeding the slopes to help prevent small-scale surface erosion.

Enlarging the retention pond was the most cost-effective option. To minimize additional disturbance, the retention pond was designed to be within the limits of the slope that had been affected by the slide. In plan view, this required a triangular excavation which had a relatively flat bottom and 1:1 (horizontal:vertical) side slopes up to 180 feet high. Parallel to the roadway, a berm with 1.5:1 side slopes was constructed to a height approximately 10 feet above the bottom of the retention pond. This retention pond was designed to have a capacity of 7800 yd^3 when material is level with the top of the berm. To obtain this capacity, it was necessary to excavate approximately 117,000 yd^3 of the hillside.

Construction of this $1.24 million project began on January 3, 1998. Because the WMS was within a critical eagle habitat area, the project had to be completed by February 15, 1998; since it was no longer an emergency situation, all regular FWS restrictions applied. Before construction began, small explosive charges were dropped within the chute above where the retention pond was to be constructed to relieve potential snow avalanches. The snow showed very little avalanche response to the bombing, so from this fact and the observed slope angles within the slide path, it was concluded that avalanches were not going to be a significant problem at this site. All of the material which was removed to create the retention pond had to be truck-hauled to waste sites (**Figure 36**). Half of the material was taken to a site 11 miles from the slide, and the other half was taken to reclaim an old gravel pit 18 miles from the site. As part of this contract, it was recommended that the 48-inch-diameter culvert which is the outlet for the pond be replaced with a larger structure, possibly a concrete box culvert (**Figure 37**), to allow the mud to flow under the roadway easier. Given the extremely tight time schedule and very difficult winter working conditions, it was not possible to install this structure under this contract. Even though five days were lost to bad weather and approximately 6 feet of snow accumulated during construction, the project was completed in early February, two days ahead of schedule (and the eagles were not disturbed!).

The results

In mid-March, 1998, three days of temperatures in the low 50s (°F) triggered some activity at the slide. The flow of water increased from the trickle that was present during construction to 30 to 40 gallons per minute. Mud and rocks

Figure 36. Construction of retention pond and berm at Wolf Mountain Slide in January, 1998 required removal of 117,000 cubic yards of material, which was hauled by truck to sites 11 and 18 miles away. Four feet of snow fell during construction.

Figure 37. Concrete box culvert now in place below Wolf Mountain Slide allows water and debris shed off the slide to exit the retention pond and flow into Snake River. Culvert can be blocked off, allowing water to accumulate in the retention pond so it can then be used to flush the culvert of debris when needed.

were beginning to accumulate in the retention pond, and it was feared that the pond would quickly fill. Geology personnel inspected the site on March 31 and determined that most of the material had come from within the slide chute on the bottom half of the mountain. The weather returned to a more normal pattern for the next four weeks, with lower temperatures, very little new snow accumulation, and relatively slow snowmelt. As a result of this, there was little additional accumulation of material in the retention pond, and the water flowing through the pond was removing material in a self-cleaning action.

On April 29, 1998, WYDOT Geology personnel inspected the retention pond at 5:00 p.m. A week of weather in the 50s and 60s (ºF) had activated the slide again. A water flow estimated to be 100 gallons per minute was carrying mud and some 2- to 3-foot diameter rocks into the pond. At this time, the mud was flowing directly from the slide chute to the 48″ culvert and passing under the roadway with very little material accumulating in the pond. During that night, several large trees and root balls came down and plugged the culvert and by 7:00 a.m. on April 30, the pond was completely full, level with the top of the berm (**Figure 38**). At this time, equipment was mobilized to clean the inlet of the culvert and begin removing material from the pond to allow storage of more debris. The slide remained very active for the next 24 hours, with most of the material originating from the area below the slump block where the slide path narrows from 300 feet wide to approximately 80 feet wide.

After this 24-hour period, the majority of the snow was gone from slide chute and significant movement of mud had ceased. The flow of water emanating from the base of the slump block had increased to approximately 200 gallons per minute, and this increased water flow was begining to clean significant amounts of mud and rock out of the retention pond. Between the natural cleansing action of the water and the equipment removing material from the pond, approximately one-third of the material was removed by May 5. After this event, a temperature study determined that on April 29, the six-day moving average temperature of 58°F was reached (University of Wyoming, 1998).

The next phase of the slide remediation was the aerial seeding of the slide debris within the chute (**Figure 39**) in mid-May, 1998. If some vegetation can be established within the slide debris, the amount of material that will reach the retention pond during snowmelt and extended rainfall events can be significantly reduced.

The snowpack in 1999, 2000, and 2001 was below normal, so the amount of material shed by the landslide was minimal. The catch basin received very little material, and it was mostly water, which flowed out the culvert and into the river. There was no debris in the basin which had to be cleaned out.

Conclusions

The most critical debris flow events at the WMS appear to be snowmelt-related and can be expected to occur yearly. In the future, running temperature records will be kept to help determine the most critical time for debris flows. It is anticipated that the amount of material which comes down will decrease each year, as vegetation begins to grow in the slide chute and the loose material in the chute flattens close to its natural angle of repose. It is imperative that WYDOT clean the retention pond each fall so that in the spring there is sufficient storage capacity to hold the debris flows. Although the natural actions of soil, water, and gravity cannot be prevented, we believe that an effective method has been developed to manage the results of these debris flows with minimum inconvenience to the traveling public.

Figure 38. The newly constructed retention pond was tested the next spring (end of April, 1998), as debris from the slide filled the entire pond to the top of the berm. Debris from the slump block washed down through the channel and entered the steep-sided catchment basin, eventually entering the retention pond where it was easily removed.

Epilog

Since the precipitation levels have been so low in the last three years, the catch basin size has only been tested once; this was in 1998 when it was completely filled by debris shed by the original landslide. It is hoped that the seeding program is stabilizing the superficial soils on the slide enough so that minimal debris will come down in the future. There is always a chance that a wet year will cause more debris to come down. We are currently in the design phase of the road section that involves the catch basin. It is our intent to keep the basin as is and hope a large debris event does not overtop the catch basin and close the highway.

Figure 39. Upper part of catchment basin just below the chute. The water flow from the slump block and the channel is now confined to the center of the basin and serves to cleanse debris. Uppermost part of retention pond can be seen in lower right corner of photograph. The chute (channel) has been reseeded to prevent movement of debris, and with time will probably revegetate completely.

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PUBLICATIONS UPDATE

New Publications Available from the Wyoming State Geological Survey

Wyoming State Geological Survey publications

*2002 Calendar, *Exploring Wyoming's Geology*, by the Wyoming State Geological Survey, 2002: Poster – FREE.

**Knightia*, Wyoming State Fossil postcard (revised), 2002 – $0.25 each or five for $1.00.

Coalbed methane activity in the eastern Powder River Basin, Campbell and Converse Counties, Wyoming, by R.H. De Bruin, R.M. Lyman, and L.L. Hallberg, 2001: Coalbed Methane Map CMM 01-6 (updated in October, 2001, replaces CMM 01-3), on-demand plotted color map, rolled only - $30.00; digital version (ESRI ArcInfo®/ESRI ArcView® format) on CD-ROM, including Coalbed Methane Map CMM 01-7 – $100.00.

Coalbed methane activity in the western Powder River Basin, Campbell, Converse, Johnson, Natrona, and Sheridan Counties, Wyoming, by R.H. De Bruin, R.M. Lyman, L.L. Hallberg, and M.M. Harrison, 2001: Coalbed Methane Map CMM 01-7 (updated in October, 2001, replaces CMM 01-4), on-demand plotted color map, rolled only – $30.00.

Coalbed methane activity in the Powder River Basin, Campbell, Converse, Johnson, Natrona, and Sheridan Counties, Wyoming, by R.H. De Bruin, R.M. Lyman, L.L. Hallberg, and M.M. Harrison, 2001: Coalbed Methane Map CMM 01-8 (this is a reduced and combined version of CMM 01-6 and CMM 01-7 at 1:250,000 scale), on-demand plotted and laminated color map, rolled only - $50.00; on-demand plotted color map, rolled only – $40.00.

*Oil and gas map of the Powder River Basin, Wyoming, by R.H. De Bruin, 2002: Map Series MS-51 (scale 1:350,000), on-demand plotted color map, rolled only – $25.00; ESRI ArcInfo®/ESRI ArcView® format on CD-ROM (including MrSid® viewable files), – $20.00.

*Oil and gas map of the Greater Green River Basin and Overthrust Belt, Wyoming, by R.H. De Bruin, 2002: Map Series MS-52 (scale 1:350,000), on-demand plotted color map, rolled only – $25.00; ESRI ArcInfo®/ESRI ArcView® format on CD-ROM (including MrSid® viewable files), – $20.00.

*Oil and gas map of the central and northwestern Wyoming basins, Wyoming, by R.H. De Bruin, 2002: Map Series MS-53 (scale 1:350,000), on-demand plotted color map, rolled only – $25.00; ESRI ArcInfo®/ESRI ArcView® format on CD-ROM (including MrSid® viewable files), – $20.00.

*Oil and gas map of the southeastern Wyoming basins, Wyoming, by R.H. De Bruin, 2002: Map Series MS-54 (scale 1:350,000), on-demand plotted color map, rolled only – $25.00; ESRI ArcInfo®/ESRI ArcView® format on CD-ROM (including MrSid® viewable files), – $20.00.

*Oil and gas resource assessment of the Jack Morrow Hills and surrounding areas, southwestern Wyoming, by L. Cook, R.H. De Bruin, C.S., Boyd, and R.W. Jones, 2002: Open File Report 2002-1 – $25.00 (includes 3 oversized sheets) + $3.00 shipping and handling.

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 (see **STAFF DIRECTORY** on back cover).

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

Other publications

A tapestry of time and terrain: Geologic age of rocks in color, superimposed on the digital shaded relief map of the U.S., U.S. Geological Survey Geologic Investigations Series Map I-2720, 2000, 1 sheet, 55" x 40" (scale 1: 3,500,000) plus 24 p. pamphlet - $7.00.

General purpose map of America, U.S. Geological Survey, 2001, scale 1:5,000,000 (42" x 30") - $7.00. This is a detailed, full color reference map that shows International and state boundaries, large and small cities, state capitals, highways, railroads and ferries, rivers and lakes, oceans and bays, natural features, forests, mountain elevations, and terrain.

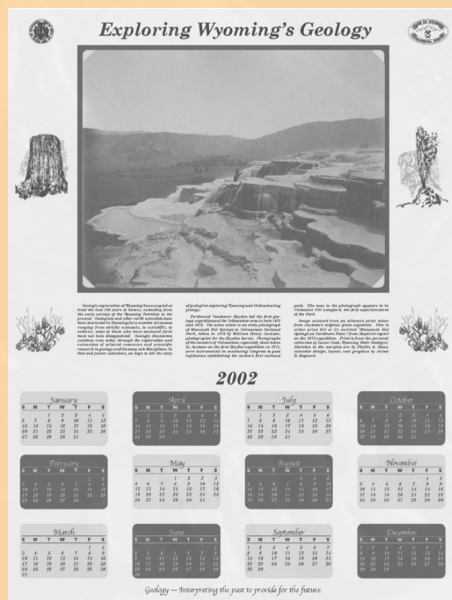
Landforms of the conterminous United States≠–A digital shaded-relief portrayal: U.S. Geological Survey Map I-2206, 1991, 1 sheet, 55" x 38" (scale 1:3,500,000) plus 16 p. pamphlet - $7.00.

This dynamic earth, the story of plate tectonics, U.S. Geological Survey, 1996, 77 p. booklet - $6.00.

This dynamic planet, world map of volcanoes, earthquakes, impact craters, and plate tectonics, U.S. Geological Survey, 1994 - $7.00.

Topo! Wyoming, Seamless USGS topographic maps on CD-ROM, 2000, National Geographic Maps, 6 CD-ROMs. Contains full-state coverage with TOPO! Mapping Software, GPS ready, with 3-D digital shading (toggles off and on) and photo-quality output. Five map scales include general reference map, National atlas series, 1: 500,000 map series, 1:100,000 map series, and 1:24,000 map series. Coverages extend outside state boundaries and include all boundary areas contiguous to Wyoming - $99.95.

2002 Calendar Published



The Wyoming State Geological Survey (WSGS) has published its first calendar. The poster-sized (25" x 33") calendar celebrates the first 150 years of geologic exploration in Wyoming with one of the earliest photographs of Yellowstone National Park taken by William Henry Jackson on the second Hayden Survey in 1872. Each year the WSGS hopes to focus on some aspect of "Exploring Wyoming's Geology." The calendar was designed by Jaime R. Moulton (Editorial Assistant at the WSGS) and uses sketches by Phyllis A. Ranz (cartographer and artist at the WSGS). The photograph on the calendar is from an albumen print (owned by Lance Cook) from Jackson's original glass negatives. Contact the WSGS to obtain your complimentary copy.

Attention users of All Topo Maps: Wyoming

As a dealer for iGage *All Topo Maps: Wyoming* products, the WSGS is proud to announce a drop in prices and some changes in the configurations of the products:

- *All Topo Maps: Wyoming*, Release 3 now sells for $88.00 and contains over 260 new maps; a uniform color palette for all maps; the ability to search by township, range, and section; the ability to search by National Geodetic Survey (NGS) control points, zip codes, and area codes; and the latest versions of the map seamer, the GPS Tool, and the All Topo Viewer. Those that purchased their Wyoming All Topos before April 11, 2001 can upgrade to Release 3 for $29.00.
- PLS Tool, a $68.00 option ($34.00 when purchased with upgrade), offers users a real-time display of the cursor position to the nearest 1/4 1/4 section (plus township and range) while viewing All Topo Maps. The Public Lands Survey (PLS) tool enables legal descriptions to be read directly from All Topos.
- Big Topo Pro Tool enables creation of unlimited sized maps for those using large format plotters and requiring large seamed maps. Normally a $120 option, this tool is available with the Release 3 upgrade for $90.

GIS Day Recognized

Joseph M. Huss

GIS Coordinator–Publications, Wyoming State Geological Survey

Geographic Information Systems (GIS) Day occurred on November 14, 2001 at the Wyoming Union on the University of Wyoming Campus in Laramie. Joe Huss, GIS Coordinator for the Wyoming State Geological Survey (WSGS) was responsible for the organization, planning, and setup of the event. All personnel in the Publications Section assisted with the event, which was organized in conjunction with Paul Caffrey of the Wyoming Geographic Information Science Center (WyGISC) and Wyoming Geographic Information Advisory Council (WGIAC).

The object of the annual event is to develop understanding and concepts of GIS in the community. This event educates all that attend and demonstrates the capabilities of both the science and technology of GIS (**Figure 40**). Governor Geringer initiated the day with a proclamation declaring November 14, 2001 GIS Day and that afternoon, he visited the event.

Over two dozen groups or agencies displayed their products and capabilities at the event, covering GIS activities in both the private and public sectors. Amongst the exhibitors were the U.S. Geological Survey; State of Wyoming agencies including the State Historic Preservation Office, Department of Revenue, State Engineers Office, and WSGS; University of Wyoming Department of Health Sciences; representatives of Albany County; Big Horn Basin Users Group; CBM and Associates; and Environmental Systems Research Institute (ESRI).

The mix of public agencies and private industry ensured a broad demonstration of GIS applications, uses, and technologies active in the state of Wyoming. Many of the attendees who took advantage of the event were amazed at the widespread use of GIS and its far-reaching capabilities. Attendees and participants all agreed that the event was the best ever, setting the new standard for all future events.

Figure 40. Wyoming State Geological Survey GIS Specialist Abby Kirkaldie demonstrates interactive GIS software to an interested participant at GIS Day. Photograph by Tim Chestnut, Laramie Daily Boomerang.

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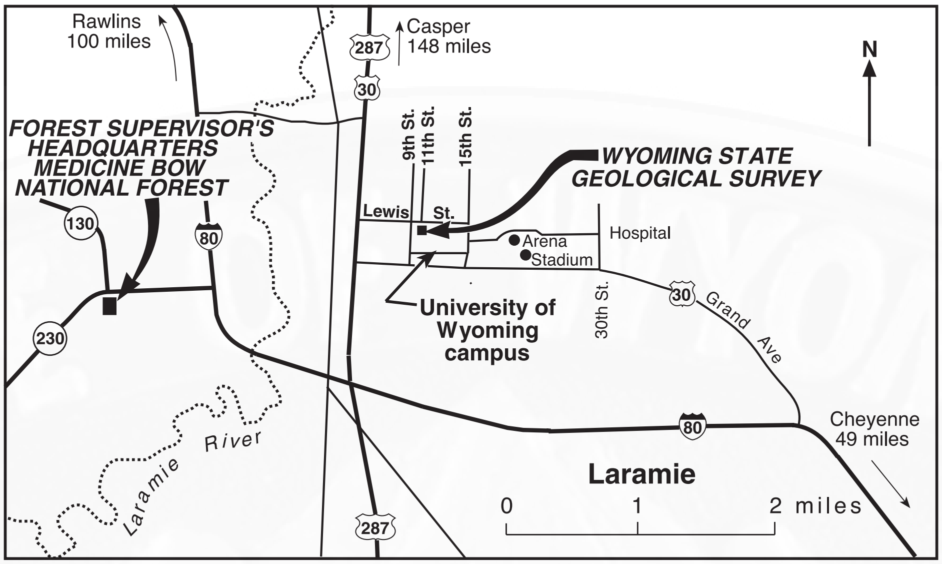
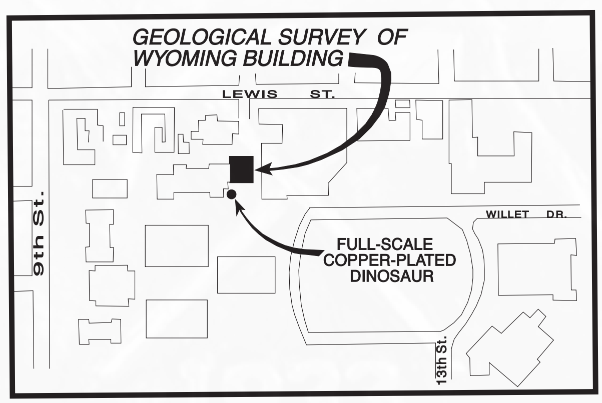
Many Wyoming State Geological Survey publications are also available for over-the-counter sales at the Wyoming Oil and Gas Conservation Commission office, Basko Building, 777 West First Street, Casper, Wyoming 82601.

Location Maps for the Wyoming State Geological Survey





Improved Telephone System at the Wyoming State Geological Survey

The Wyoming State Geological Survey recently upgraded their telephone system to include voice mail. Those wishing to contact a specific person or section may now do so directly by dialing the Survey's regular phone number (307-766-2286) and then entering the extension of the person to whom they would like to speak. An automated phone directory can also be accessed. Messages can be left for a person in a more convenient way. For persons wishing to place an order, or who have sales-related questions, simply dial "0" for an operator. For your convenience, the following list may help locate staff members or their sections.

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