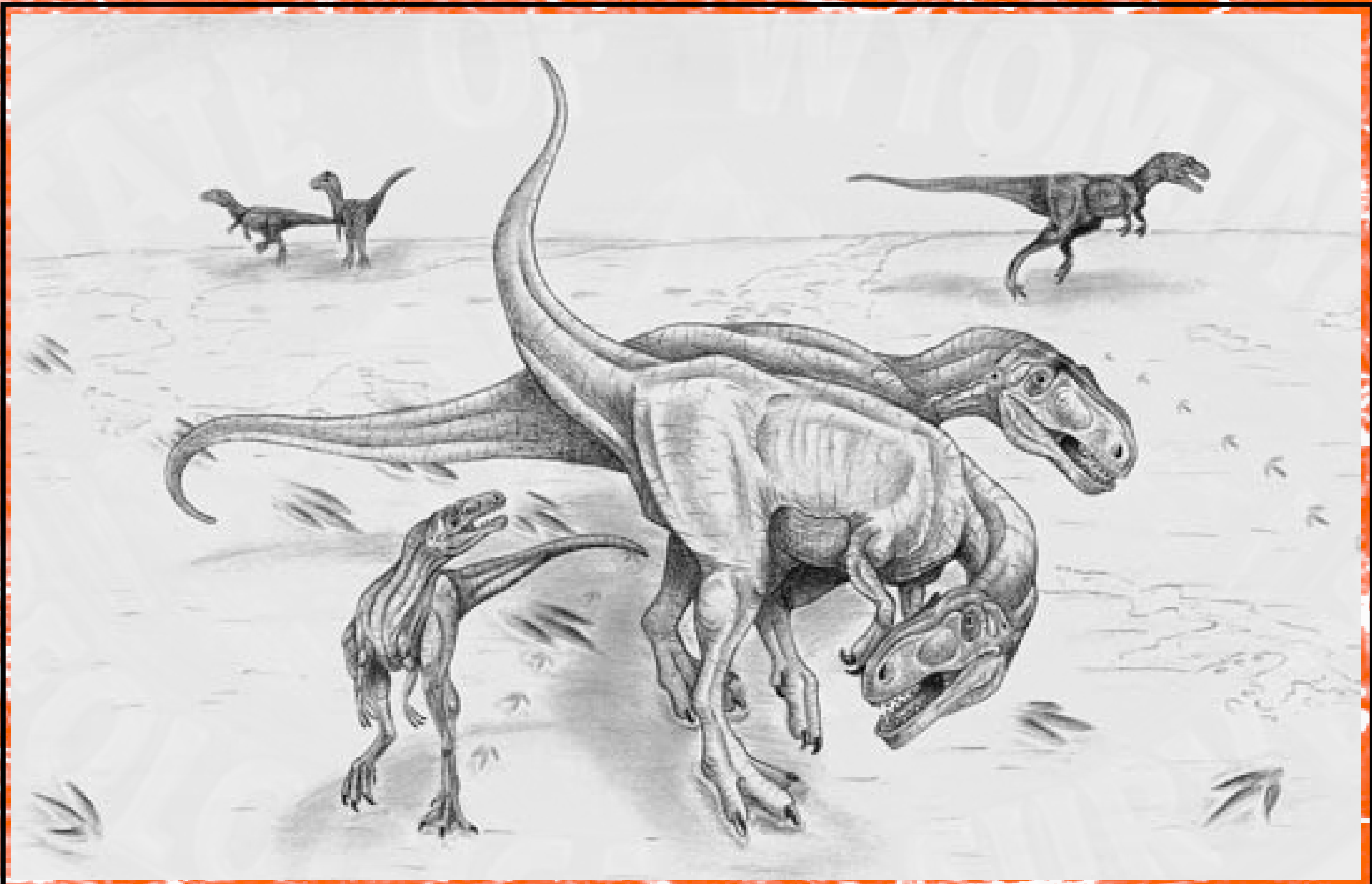
Wyoming Geo-notes

Number 78



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Wyoming State Geological Survey
Lance Cook, State Geologist

Laramie, Wyoming
November, 2003

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

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****Please note: the mailing address for the WSGS has changed; the new address is included on the back cover.**

Richard W. Jones, Wyoming PG-2972
Editor

Jaime R. Moulton
Layout and design

Front cover: Artist's conception of hypothetical carnivorous dinosaurs from the Middle Jurassic Sundance Formation in the Bighorn Basin, Wyoming. These trackmakers at the Yellow Brick Road Dinosaur Tracksite (see article on page 39) were small- to medium-sized (30 to 99 cm high at the hip), gregarious theropod dinosaurs. From an original 11" w x 7" h colored pencil sketch by Thomas L. Adams.

MINERALS UPDATE

Overview

Lance Cook, Wyoming PG-2577

State Geologist, Wyoming State Geological Survey

The October, 2003 forecast for mineral production and prices, made by the State of Wyoming's Consensus Revenue Estimating Group (CREG), is now available. Both prices and volumes for natural gas production have changed substantially. Oil production and price forecasts as well as the forecast for coal prices have improved; the forecast for trona production has not changed; the forecasts for coal and uranium production have decreased slightly; and the forecast for the price of mined trona also decreased from last January's CREG estimates. The new CREG forecasts are presented in **Tables 1** and **2** and can be compared with the January, 2003 forecasts published in the previous issue of *Wyoming Geo-notes* (No. 77, June, 2003, Tables 1 and 2, p. 1). See the individual mineral update articles in this issue for a more complete discussion and analysis of the CREG forecasts.

The natural gas situation in Wyoming is especially important and warrants further discussion. CREG's natural gas price forecast has changed substantially from last January's estimate (**Figure 1**). The estimate for calendar year 2003 has gone from $2.00 per thousand cubic feet (MCF) to $4.25 per MCF, and the long-term base price has grown from $2.25 to $3.25. This change is significant for the State of Wyoming in that the State's revenue grows by $1.6 million per year for every 1-cent increase in the yearly average price of natural gas. Clearly, the new forecast suggests a dramatic growth in State revenues.

The new strength in Wyoming's natural gas prices is due to two main factors. The historical leaders in production of natural gas, Texas, Louisiana, Oklahoma, and New Mexico, are showing stagnant or declining production. Canada, the largest supplier of natural gas imports to the U.S., is having difficulty maintaining export volumes. In the future, Canada is likely to use more of their domestically produced natural gas in the syncrude hydrogenation process, reducing the amount of gas available for export. Meanwhile, U.S. natural gas consumption is currently stable, and is expected

Table 1. Wyoming mineral production (1987 through 2002) with forecasts to 2008[1].

Calendar Year	Oil[2,3]	Methane[3,4]	Carbon Dioxide[3,4]	Helium[4,5]	Coal[6]	Trona[7]	*In situ* Uranium[8]
1987	115.9	628.2	114.2	0.86	146.5	12.4	0.00
1988	114.3	700.8	110.0	0.83	163.6	15.1	0.09
1989	109.1	739.0	126.1	0.94	171.1	16.2	1.1
1990	104.0	777.2	119.9	0.90	184.0	16.2	1.0
1991	99.8	820.0	140.3	1.05	193.9	16.2	1.0
1992	97.0	871.5	139.2	1.05	189.5	16.4	1.2
1993	89.0	912.8	140.8	1.06	209.9	16.0	1.2
1994	80.2	959.2	142.6	1.07	236.9	16.1	1.2
1995	75.6	987.5	148.8	1.11	263.9	18.4	1.3
1996	73.9	1023.4	149.0	1.10	278.4	18.6	1.9
1997	70.2	1040.7	151.0	1.10	281.5	19.4	2.2
1998	65.7	1072.6	151.0	1.10	315.0	18.6	2.3
1999	61.3	1133.1	161.0	1.10	336.5	17.8	2.8
2000	60.6	1293.3	161.0	1.10	338.9	17.8	2.1
2001	57.5	1437.6	174.0	1.20	368.8	17.7	1.6
2002	54.7	1572.6	174.0	1.20	373.2	17.2	1.4
2003	52.5	1602.8	196.0	1.20	376.8	18.0	1.4
2004	50.4	1602.8	196.0	1.20	380.6	18.0	1.4
2005	50.4	1652.8	196.0	1.20	384.4	18.5	1.4
2006	52.4	1707.8	196.0	1.20	388.3	18.5	1.4
2007	54.5	1765.5	196.0	1.20	392.1	18.5	1.4
2008	57.7	1824.3	196.0	1.20	396.0	18.5	1.4

[1]From CREG's Wyoming State Government Revenue Forecast, October, 2003; [2]Millions of barrels; [3]Wyoming Oil and Gas Conservation Commission, 1987 through 2002; [4]Billions of cubic feet, estimates for methane include 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, 1987 through 2002); [7]Millions of short tons (Wyoming Department of Revenue, 1987 through 2002; Wyoming State Inspector of Mines, 2002); [8]Millions of pounds of yellowcake (Wyoming Department of Revenue, 1987 through 1999; Wyoming State Inspector of Mines, 2000 through 2002).

Table 2. Average prices paid for Wyoming oil, methane, coal, and trona (1987 through 2002) with forecasts to 2008[1].

Calendar Year	Oil[2]	Methane[3]	Coal[4]	Trona[5]
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	5.78	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	21.59	3.66	5.75	38.00
2002	22.08	2.09	6.66	38.00
2003	25.75	4.20	6.80	37.50
2004	22.50	3.50	6.00	37.50
2005	20.50	3.25	6.03	37.50
2006	20.50	3.25	6.12	37.50
2007	20.50	3.25	6.24	37.50
2008	20.50	3.25	6.40	37.50

[1]From CREG's Wyoming State Government Revenue Forecast, October, 2003; [2]First purchase price in dollars per barrel (weighted average price for sweet, sour, heavy, stripper, and tertiary oil). Source: Energy Information Administration, 1987-2002; [3]Wellhead price in dollars per thousand cubic feet (MCF), includes coalbed methane. Source: American Association, 1998-2002; Wyoming Office of State Lands and Investments, 1989-2002 (derived from State royalty payments); and Minerals Management Service, 1987-1988 (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, 1987-1990 and derived from Department of Revenue, 1991-2002; [5]Dollars per ton of trona, not soda ash. Source Wyoming Department of Revenue, 1987-2002.

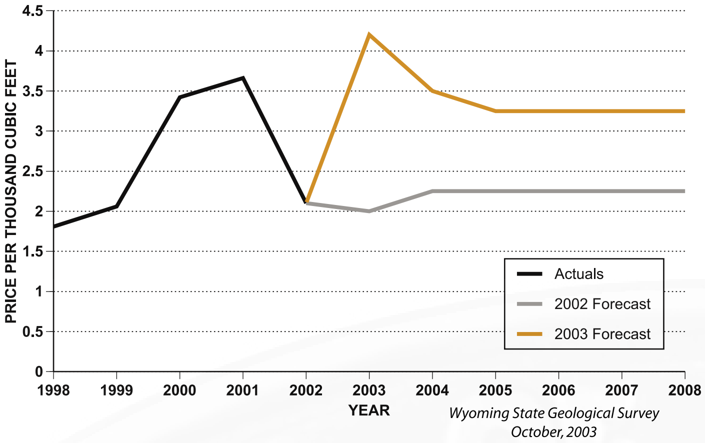

Figure 1. Average prices for Wyoming methane (1998 through 2002) showing differences between the 2002 and 2003 CREG forecasts for 2003 through 2008.

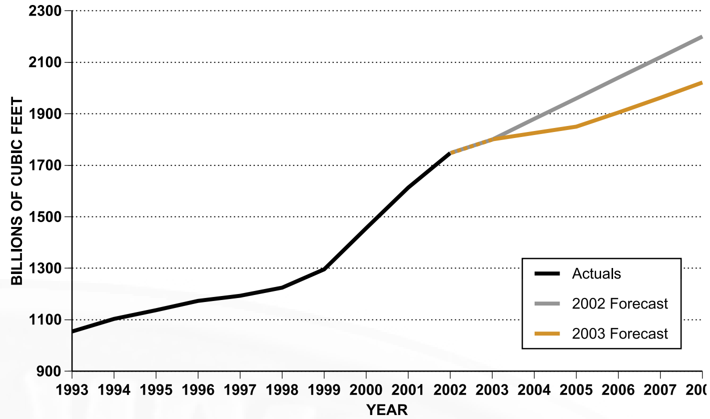

Figure 2. Annual natural gas production from Wyoming (1993 through 2002) showing differences between the 2002 and 2003 CREG forecasts for 2003 through 2008.

to resume growth soon. The second factor relates to transportation capacity. In the past few years, Wyoming producers had more natural gas to sell than there was capacity to move the gas into the national pipeline system. Recent expansion of the Kern River Pipeline by about 700 million cubic feet (MMCF) per day has reversed much of that imbalance, and the gas price differential between natural gas produced in Wyoming and natural gas produced in other areas has shrunk dramatically (from $1.50 per MCF last year to 50 cents now). Additional pipeline capacity out of Wyoming is due to come online in the next few years, and hopefully this will avoid another period of large price differentials.

In the opinion of the CREG members, there has been a major shift in the fundamental supply/demand factors that control Wyoming natural gas prices. The state should experience a period of enhanced natural gas prices, resulting in substantial revenue growth. While this advantageous situation may not last forever, and there will probably be short-term price fluctuations, CREG believes that the outlook for natural gas prices is strong over the next few years.

The volumes of natural gas produced reveal another positive side to the State revenue picture. Wyoming has experienced a strong production growth profile (**Figure 2**) and in fact, Wyoming natural gas production (which includes not only methane from conventional reservoirs but also methane from coal beds, carbon dioxide, and helium) has grown every year for the past 18 years (no other state has matched this growth record). We (the WSGS and CREG) predict that 2003 will be another record year. Currently, due to uncertainties surrounding federal land use processes and federal permitting delays, we are not sure that 2004 will see the historical growth rate. Issuance of coalbed methane drilling permits in the Powder River Basin are proceeding slowly in the face of several lawsuits, and the Jonah and Pinedale fields in the Green River Basin may experience a delay or reduction in permitting. Jonah is currently the state's largest field in natural gas production, and Pinedale is the state's fastest growing field. Until these uncertainties can be overcome, we are predicting no growth in 2004 for natural gas production. However, in 2005, we believe that production growth will resume, although at a slightly lower rate of growth than predicted earlier (**Figure 2**). By about 2007, Wyoming should be producing nearly 2 trillion cubic feet (TCF) per year (**Table 1**). Certainly, Wyoming has the resource base necessary to support a 2 TCF per year production rate for many years to come.

Future oil production forecasts are encouraging, as planned carbon dioxide floods in several large Wyoming oil fields may even be enough to reverse the state's decline curve, at least for a few years. Oil prices continued to hold steady during the first half of 2003, and are predicted to be over $25.00 a barrel by year's end. Average coal prices for the next few years are expected to remain high as spot prices have flattened out at about $1.00 per short ton higher than what they were just two years ago. Wyoming producers continue to hold the line on prices for new contracts and spot sales. Coal production is expected to increase steadily each year (although overall levels are somewhat less than predicted earlier) but may be threatened by new environmental regulations on mercury emissions from power plants and by regional haze restrictions.

Industrial mineral production during the first half of 2003 continued at about the same level as last year, with Wyoming expected to lead the nation in trona, bentonite, and uranium production for another year. Trona production is expected to increase in 2003 despite closure of FMC's trona mine and soda ash refining plant at Granger. We hope that Wyoming will benefit by the new beer bottle manufacturing plant announced by Budweiser for its brewery north of Fort Collins, Colorado. Wyoming producers may be in the running to supply silica sand for the plant (depending on specifications not yet announced); and almost certainly Wyoming soda ash producers will be called upon to supply the plant.

Exploration for metals and precious stones continued in Wyoming in 2003. Two gold properties have been leased and one gold anomaly will be explored, claims have been filed on a jasperoid occurrence, and the discovery of opals and breccia pipes near Riverton is under investigation. Platinum group metal exploration continued on identified targets in the Medicine Bow Mountains and interest remained high

Summer interns honored

Richard W. Jones, Wyoming PG-2972

Editor/Geologist–Publications, Wyoming State Geological Survey

The Wyoming State Geological Survey (WSGS) had four participants in the State of Wyoming's Summer Intern Program for 2003 (**Figure 3**). The State honored these interns in a recognition ceremony in Cheyenne on August 20, 2003, with Governor Dave Freudenthal and several other State officials. The interns received a Certificate of Recognition, a beautiful desk clock, and had their photograph taken with the Governor. The certificate recognized each intern's accomplishments "for putting his education to practical use while gaining governmental experience during a summer internship with the State of Wyoming."

The Intern Program began in 2002 and the WSGS employed three interns; two were students at the University of Wyoming (UW). Those two interns are now working for the WSGS as Geographic Information Systems (GIS) technicians under a STATEMAP grant. Based on last year's success, the WSGS offered internships to four UW students for the 2003 internship program. Under this program, each intern is allowed to work 520 hours, which is about three months of full-time work, or six months part-time. Most of the WSGS interns chose to work part-time so they could continue to work while attending classes this fall.

Figure 3. Participants in the 2003 Summer Intern Program at the Wyoming State Geological Survey. From left to right: Christopher R. Lange, Ross J. Moore, Erin A. Dobler, and Per G. Malmberg. Photograph by Susanne G. Bruhnke.

Erin Dobler, who lists Cheyenne as her hometown, interned in the Publications Section at the WSGS, assisting in both the sales office and in the editorial office. Erin is working toward a degree in Marketing with a minor in Public Relations at UW. She gained experience in using a number of computer programs and learned how our sales office and the WSGS manages a retail operation. We enjoyed her enthusiasm and sense of humor, and we are glad that she will continue on at the Survey working part-time in the Geologic Hazards Section.

Per Malmberg, a native of Stockholm, Sweden, interned as a GIS technician in the Publications Section. He received a B.S. degree in both Economics and Geography from UW this summer. Per worked with both Joe Huss, GIS Coordinator, and Ray Harris, Head of the Industrial Minerals and Uranium Section, on a new digital map of Wyoming's industrial minerals and construction materials. He said that he gained practical, hands-on experience that he didn't have before. After completing his internship, Per has continued to work at the WSGS under a grant for the Survey's STATEMAP projects.

Ross Moore, whose hometown is Douglas, served his internship in the Information Technology Section. He also gained practical experience through a variety of assignments, which included extensive upgrading of the WSGS web site and upgrading hardware and software on the WSGS computers, especially to help maintain security. He even received academic class credits for a computer independent study related to his work. Ross will graduate in December, 2003 with a B.S. degree in Management Information Systems at UW.

Chris Lange, a native of Riverton, was an intern for the Industrial Minerals and Uranium Section. Chris attended Central Wyoming College in Riverton before completing a B.S. degree in Business Administration at UW this summer. He was accepted into UW's E-Business Program for a master's degree. Chris had an excellent experience in applying science (geology) to practical problems through his work on developing county-based maps and GIS databases for uranium mining, occurrences, and deposits in Wyoming.

In total, the Summer Intern Program at the WSGS has been a resounding success. The interns benefited by gaining practical experience and by applying their education to everyday problems and situations. The WSGS benefits from the program by completing projects and having the opportunity to work with potential candidates for future employment.

for the colored gemstones iolite, cordierite, and sapphire in the Laramie Mountains as more of these minerals are cut and finished.

The STATEMAP 2002 grant from the U.S. Geological Survey ended with delivery of mapping and/or digitizing projects for three 1:100,000-scale quadrangles (Kaycee, Reno Junction, and Rattlesnake Hills) and a 1:24,000-scale quadrangle (Keystone). Work immediately began on STATEMAP 2003 projects by the Mapping, Publications, Industrial Minerals and Uranium, and Metals and Precious Stones sections of the WSGS. A summary of activities under the STATEMAP program appears in the **Geologic Mapping, Paleontology, and Stratigraphy Update** in this issue of *Wyoming Geo-notes*.

Finally, as seen on the cover of this issue of *Wyoming Geo-notes*, we present the second part of our two-part series on a Middle Jurassic dinosaur track site in the Bighorn Basin. Our first article, published in *Wyoming Geo-notes No. 76*, April, 2003, p. 28-32, discussed methods of study and documentation at the site, as well as the site's geology and the track morphology. This second article presents the authors' results, interpretations, and conclusions on a heretofore-unknown Middle Jurassic dinosaur population. The WSGS was especially pleased about the favorable response to the first article and we look forward to publishing short articles on student research projects at the University of Wyoming in the future.

Oil and Gas Update

Rodney H. De Bruin, Wyoming PG-3045

Senior Staff Geologist–Oil and Gas, Wyoming State Geological Survey

Wyoming oil and gas producers received higher prices for both oil and natural gas in the first half of 2003 compared to prices received during the first half of 2002. Average oil prices for the first six months of 2003 were $7.31 per barrel higher than average oil prices for the first six months of 2002, while natural gas prices for the first half of 2003 were $2.16 per thousand cubic feet (MCF) higher than for the first half of 2002. Oil production declined 4.4% from first half of 2002 to first half of 2003, while natural gas production increased 3.9% during the same period. Natural gas production for the first half of the year was 883 billion cubic feet (BCF), again boosted by an increase in coalbed methane (CBM) production in the Powder River Basin (PRB), which made up 19.1% of Wyoming's total gas production. Increased gas production from Jonah Field and the Pinedale anticline in the northern Green River Basin accounted for another 18.6% of the state's total.

New projections for oil and gas by the State of Wyoming's Consensus Revenue Estimating Group (CREG) were made in October, 2003. These new estimates are discussed in more detail (see ***Prices and production***, below) and most of the news is encouraging. New oil production, as enhanced oil recovery projects using carbon dioxide injection come on line, may reverse Wyoming's oil production decline seen each year since 1985. Oil prices are predicted to be higher than the last CREG estimates for 2003 through 2008 as prices continue to strengthen. Natural gas prices are forecast to increase and remain strong as price differentials between Opal and Henry Hub have been alleviated by increased pipeline capacity out of Wyoming and as natural gas supplies tighten in the next few years. Although natural gas production is expected to continue to increase nearly every year, the CREG estimates are less than previously predicted.

In the first half of 2003, three federal lease sales brought in total revenues of over $3.3 million. The average price per acre at the three sales was $35.99; however, only 198 total parcels were offered. Two state lease sales brought in almost $1.4 million with an average price of $18.85 per acre. The number of applications for permit to drill in the first half of 2003 remained healthy and 140 more applications were approved than in the first half of 2002. Applications were mainly for CBM wells in the PRB; however, applications for conventional wells in Sublette and Sweetwater counties were up sharply from last year. The number of approved seismic permits was lower, but the number of 3-D miles permitted was nearly 500 more than last year. The number of conventional miles permitted decreased significantly. The rig count in the first half of 2003 averaged 44, four more than the average for the comparable period in 2002. Many of these rigs were drilling for natural gas in southwestern Wyoming.

Prices and production

Prices paid to Wyoming oil producers during the first six months of 2003 averaged $27.34 per barrel (**Table 3**). This average price is $7.31 higher than for the comparable period in 2002. Oil prices continue to strengthen, as sweet and sour crude and first purchase prices have climbed back to levels seen near the end of 1999 (**Figure 4**). Oil prices forecast by CREG (**Table 2** and **Figure 5**) for 2003 through 2008 have been increased over last year's projections (see *Wyoming Geo-notes No. 76*, April, 2003, p. 2) because of the continued strength in oil prices over the last several years (**Table 3**). Although the CREG estimate is more optimistic than last year's estimate, it is still conservative for 2005 through 2008, with no yearly price increases predicted.

Oil production reported by the Wyoming Oil and Gas Conservation Commission (WOGCC) for the first half of 2003 was 26.1 million barrels (**Table 4**). This production decreased 4.4% from the first half of 2002 and by year's end is expected

Table 3. Monthly average price of a barrel of oil produced in Wyoming (1999 through July, 2003).

	1999		2000		2001		2002		2003	
	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative
January	$9.30	$9.30	$24.01	$24.01	$24.62	$24.62	$15.70	$15.70	$28.02	$28.02
February	$9.09	$9.20	$26.48	$25.25	$24.82	$24.72	$16.63	$16.17	$31.00	$29.51
March	$11.77	$10.05	$27.24	$25.91	$22.71	$24.05	$20.64	$17.66	$28.92	$29.31
April	$14.34	$11.12	$22.92	$25.16	$22.85	$23.75	$22.63	$18.90	$24.50	$28.11
May	$15.16	$11.93	$26.06	$25.34	$23.68	$23.74	$22.86	$19.69	$24.87	$27.46
June	$15.36	$12.50	$28.31	$25.84	$22.99	$23.61	$21.71	$20.03	**$26.75**	**$27.34**
July	$17.39	$13.20	$27.12	$26.02	$22.55	$23.46	$23.29	$20.49	**$27.00**	**$27.29**
August	$18.43	$13.86	$28.18	$26.29	$23.67	$23.49	$24.27	$20.97		
September	$20.97	$14.65	$30.22	$26.73	$22.02	$23.32	$25.47	$21.47		
October	$20.01	$15.18	$28.75	$26.93	$17.71	$22.76	$24.27	$21.75		
November	$22.20	$15.82	$29.63	$27.17	$16.44	$22.19	$22.66	$21.83		
December	$23.22	$16.44	$23.60	$26.88	$14.86	$21.58	$24.85	$22.08		
Average yearly price		**$16.44**		**$26.88**		**$21.58**		**$22.08**		

All averages are derived from published monthly reports by the Energy Information Administration, except that averages in bold print in 2003 are estimated from various unpublished bulletins listing posted prices. *Wyoming State Geological Survey, Oil and Gas Section, August, 2003.*

to be 52.5 million barrels (**Figure 6**). CREG's forecast for Wyoming oil production is more optimistic than in past years. The usual yearly decline in oil production disappears in 2005 and actually increases in 2006 through 2008 (**Table 1** and **Figure 6**) due to the enhanced oil projects (carbon dioxide injection) that Anadarko plans to begin at Patrick Draw in late 2003 and at Salt Creek in early 2004. If these projects are as successful as the company hopes, CREG's oil production estimates for 2004 through 2008 may be too low.

Spot prices for natural gas at Opal, Wyoming averaged $4.30 per MCF during the first half of 2003. This is $2.16 per MCF higher than the average price for the first half of 2002 (**Table 5** and **Figure 7**). The new CREG estimates for natural gas prices in 2003 through 2008 (**Table 2** and **Figure 8**) are more optimistic than last year's projections (see *Wyoming Geo-notes No. 77*, June, 2003, p. 1). Natural gas prices were forecast to increase because: (1) recently completed pipeline projects increasing the capacity out of Wyoming have decreased the differential in prices between Opal and Henry

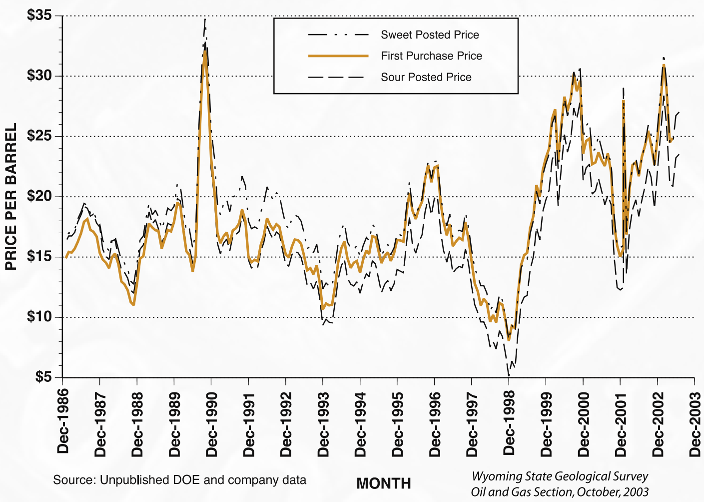

Figure 4. Wyoming posted sweet and sour crude oil prices and first purchase prices, averaged by month (January, 1987 through June, 2003).

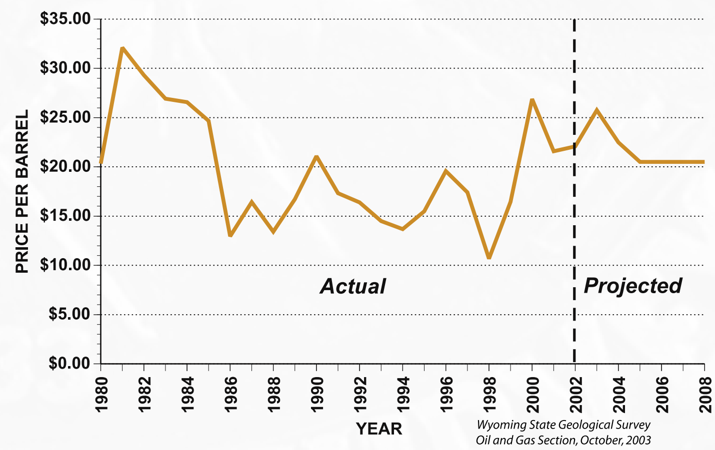

Figure 5. Average prices paid for Wyoming crude oil (1980 through 2002) with forecasts to 2008.

Table 4. Monthly oil production from Wyoming in barrels (1999 through June, 2003).

	1999		2000		2001		2002		2003	
	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative
January	5,333,257	5,333,257	5,185,683	5,185,683	5,001,928	5,001,928	4,711,532	4,711,532	4,692,090	4,692,090
February	4,744,527	10,077,784	4,871,733	10,057,416	4,493,565	9,495,493	4,238,372	8,949,904	4,109,024	8,801,114
March	5,297,674	15,375,458	5,202,533	15,259,949	4,969,821	14,465,314	4,629,468	13,579,372	4,444,366	13,245,480
April	5,065,591	20,441,049	5,003,812	20,263,761	4,802,352	19,267,666	4,565,445	18,144,817	4,309,442	17,554,922
May	5,200,031	25,641,080	5,201,564	25,465,325	4,930,856	24,198,522	4,687,127	22,831,944	4,416,017	21,970,939
June	5,000,039	30,641,119	5,001,932	30,467,257	4,664,829	28,863,351	4,495,524	27,327,468	4,138,544	26,109,483
July	5,164,705	35,805,824	5,077,548	35,544,805	4,846,220	33,709,571	4,595,080	31,922,548		
August	5,190,052	40,995,876	5,093,558	40,638,363	4,761,492	38,471,063	4,626,308	36,548,856		
September	5,081,384	46,077,260	4,983,126	45,621,489	4,718,493	43,189,556	4,492,324	41,041,180		
October	5,163,165	51,240,425	5,156,755	50,778,244	4,821,224	48,010,780	4,623,348	45,664,528		
November	5,010,985	56,251,410	4,877,512	55,655,756	4,645,045	52,655,825	4,456,006	50,120,534		
December	5,090,959	61,342,369	4,970,686	60,626,442	4,744,316	57,400,141	4,596,150	54,716,684		
Total Barrels Reported[1]		**61,342,369**		**60,626,442**		**57,400,141**		**54,716,684**		

[1]Monthly production reports for 1998 from Petroleum Information/Dwights LLC.; 1999 through June, 2003 are 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, August, 2003.*

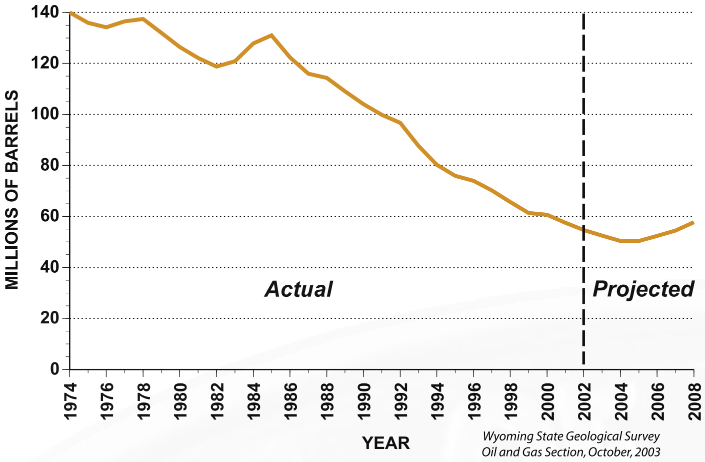

Figure 6. Annual crude oil production from Wyoming (1974 through 2002) with forecasts to 2008.

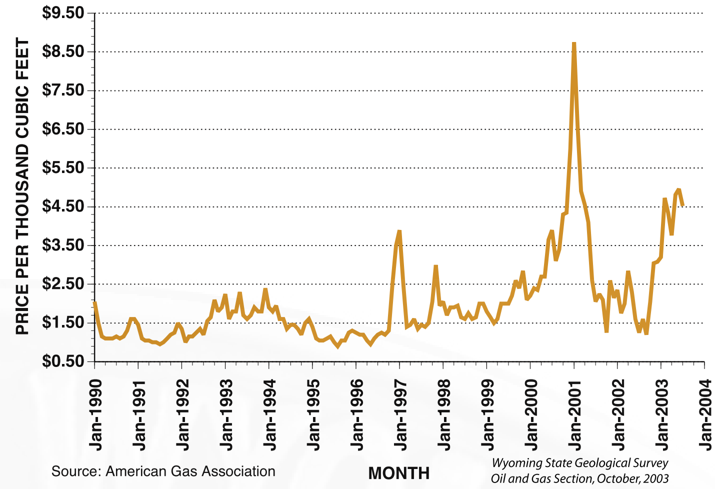

Figure 7. Spot sale prices for methane at Opal, Wyoming, averaged by month (January, 1990 through June, 2003).

Hub and (2) tight supplies of natural gas are very possible in coming years.

Natural gas production in Wyoming for the first six months of 2003 was 883.0 BCF according to production figures from the WOGCC. This production is up 3.9% from the comparable period in 2002 (**Table 6**). CBM production from the Powder River Basin accounted for 168.7 BCF of that total and was 19.1% of Wyoming's natural gas production. Increased gas production from Jonah Field and from wells on the Pinedale anticline accounted for 164.2 BCF, or 18.6% of Wyoming's total production.

CBM production rates have declined every month since peaking in November, 2002 when production averaged 970 million cubic feet (MMCF) per day. In June, 2003 the average production rate was about 917 MMCF per day. The slowdown was primarily due to no new drilling permits being issued by the U.S. Bureau of Land Management (BLM), because of the delay in issuing the record of decision (ROD) for the environmental impact statement (EIS). The ROD was eventually submitted in early May, 2003 and permitting resumed in July, 2003.

The new CREG estimates are less optimistic than previous estimates for natural gas production from 2004 through 2008 (**Table 1**). Natural gas production was decreased (**Figure 9**) from the previous estimate (see *Wyoming Geo-notes No. 76*, April, 2003, p. 3-4) because of a slowdown in CBM drilling and because of a possible drilling slowdown in Jonah Field and on the Pinedale anticline due to pending environmental analyses.

Projects, transactions, and reports

Expansion of the Kern River natural gas pipeline was approved by the Federal Energy Regulatory Commission (FERC) and the expansion went into service May 1, 2003. The $1.2 billion expansion project consisted of 717 miles of loop pipeline to the existing system, 163,700 horsepower of added compression, and modifications to existing meter stations. The expansion enables Kern River to transport about 1.73 BCF of gas per day, more than double the previous capacity. The pipeline transports natural gas from southwestern Wyoming to Utah, Nevada, and southern California. Soon after Kern River started shipping gas, the pipeline filed a rate reduction request with FERC. Reduced shipping rates should make natural gas transported on Kern River more competitive in the marketplace. The differential between spot gas prices at Opal in southwestern Wyoming and at Henry Hub in the southern U.S. narrowed dramatically after the Kern River expansion went into service. The differential is now hovering around 50 cents per MCF, while it was often over $2.00 per MCF last winter.

Table 5. Monthly average spot sale price for a thousand cubic feet (MCF) of natural gas at Opal, Wyoming (1999 through August, 2003).

	1999		2000		2001		2002		2003	
	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative
January	$1.80	$1.80	$2.20	$2.20	$8.75	$8.75	$2.35	$2.35	$3.20	$3.20
February	$1.65	$1.73	$2.40	$2.30	$6.60	$7.68	$1.75	$2.05	$4.73	$3.97
March	$1.50	$1.65	$2.35	$2.32	$4.90	$6.75	$2.00	$2.03	$4.34	$4.09
April	$1.60	$1.64	$2.70	$2.41	$4.55	$6.20	$2.85	$2.24	$3.76	$4.01
May	$2.00	$1.71	$2.70	$2.47	$4.10	$5.78	$2.30	$2.25	$4.81	$4.17
June	$2.00	$1.76	$3.65	$2.67	$2.60	$5.25	$1.60	$2.14	$4.96	$4.30
July	$2.00	$1.79	$3.90	$2.84	$2.05	$4.79	$1.25	$2.01	$4.52	$4.33
August	$2.20	$1.84	$3.10	$2.88	$2.25	$4.48	$1.60	$1.96	$4.65	$4.37
September	$2.60	$1.93	$3.40	$2.93	$2.10	$4.21	$1.20	$1.88		
October	$2.40	$1.98	$4.30	$3.07	$1.25	$3.92	$2.04	$1.89		
November	$2.85	$2.05	$4.35	$3.19	$2.60	$3.80	$3.04	$2.00		
December	$2.10	$2.06	$6.00	$3.42	$2.15	$3.66	$3.08	$2.09		
Average yearly price		**$2.06**		**$3.42**		**$3.66**		**$2.09**		

Source: American Gas Association's monthly reports. *Wyoming State Geological Survey, Oil and Gas Section, August, 2003.*

Table 6. Monthly natural gas production from Wyoming in thousands of cubic feet (MCF) (1999 through June, 2003).

	1999		2000		2001		2002		2003	
	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative
January	108,524,793	108,524,793	122,078,095	122,078,095	135,968,875	135,968,875	143,510,891	143,510,891	160,661,959	160,661,959
February	94,288,888	202,813,681	114,204,669	236,282,764	123,372,642	259,341,517	132,981,761	276,492,652	139,253,545	299,915,504
March	111,012,987	313,826,668	121,104,908	357,387,672	138,969,778	398,311,295	143,707,799	420,200,451	153,059,070	452,974,574
April	102,363,550	416,190,218	118,775,280	476,162,952	132,559,769	530,871,064	141,016,463	561,216,914	144,688,309	597,662,883
May	104,746,697	520,936,915	118,462,106	594,623,058	138,100,005	668,971,069	146,950,768	708,167,682	142,084,165	739,747,048
June	102,717,295	623,654,210	116,887,377	711,512,435	126,733,129	795,704,198	141,368,350	849,554,032	143,274,597	883,021,645
July	106,733,493	730,387,703	120,690,168	832,202,603	131,151,216	926,855,414	145,796,954	995,350,986		
August	107,536,099	837,923,802	122,412,623	954,615,226	132,329,266	1,059,184,680	139,407,056	1,134,758,042		
September	108,200,542	946,124,344	119,730,975	1,074,346,201	130,725,850	1,189,910,530	142,448,905	1,277,206,947		
October	118,545,893	1,064,670,237	127,507,997	1,201,854,198	136,704,129	1,326,614,659	151,247,991	1,428,454,938		
November	110,904,046	1,175,574,283	122,846,630	1,324,700,828	136,260,720	1,462,875,379	155,751,286	1,584,206,224		
December	119,648,215	1,295,222,498	130,711,331	1,455,412,159	142,912,497	1,605,787,876	162,039,833	1,746,246,057		
Total MCF Reported[1]		**1,295,222,498**		**1,455,412,159**		**1,605,787,876**		**1,746,246,057**		

[1]Monthly production reports for 1998 from Petroleum Information/Dwights LLC.; 1999 through June, 2003 are from Wyoming Oil and Gas Conservation Commission; [2](Total MCF produced) minus (total MCF reported by Petroleum Information/Dwights LLC.); [3]Wyoming Oil and Gas Conservation Commission. *Wyoming State Geological Survey, Oil and Gas Section, August, 2003.*

Cheyenne Plains Gas Pipeline, a subsidiary of El Paso Corp. and an affiliate of Colorado Interstate Gas (CIG), filed an application with FERC to construct, own, and operate a new interstate pipeline to transport natural gas from the Cheyenne Hub just south of Cheyenne to Greensburg, Kansas. The proposed 30-inch-diameter line would have an initial capacity of 560 MMCF per day, which could be expanded by about 500 MMCF per day if supported by demand. Construction of the pipeline will begin following FERC approval, with gas shipments expected in mid-2005.

FERC also approved a pipeline by Williston Basin Interstate Pipeline that would transport natural gas from the PRB in northeastern Wyoming and southeastern Montana to Northern Border Pipeline's system in North Dakota. The new Grasslands Pipeline will be capable of transporting approximately 80 MMCF of gas per day. The part of the project in Wyoming includes 28 miles of 16-inch diameter pipeline loop adjacent to the company's existing Bitter Creek supply lateral in Campbell County. About 223 miles of 16-inch diameter pipeline will be installed in Montana and North Dakota.

TEPPCO Partners L.P. has plans to expand both pipeline and processing capacity on its Jonah Gas Gathering (JGG) system in southwestern Wyoming. This includes construction of about 80 miles of natural gas pipeline that will loop JGG's system in both Pinedale and Jonah fields, as well as the mainline system to Opal, and installation of 3200 horsepower of compression. TEPPCO will also construct a new 250-MMCF-per-day gas plant near Opal. The Pioneer plant will provide processing capacity for a part of the substantial increase in natural gas production from Jonah and Pinedale fields. The new pipeline will boost JGG's gathering capacity from 820 MMCF to 1.18 BCF per day. TEPPCO expects gas volumes in 2004 to exceed 1 BCF per day.

The new pipeline will boost JGG's gathering capacity from 820 MMCF to 1.18 BCF per day.

In a related news item, Shell Exploration & Production selected Williams to process incremental natural gas produced by Shell from the Pinedale anticline. At its gas plant

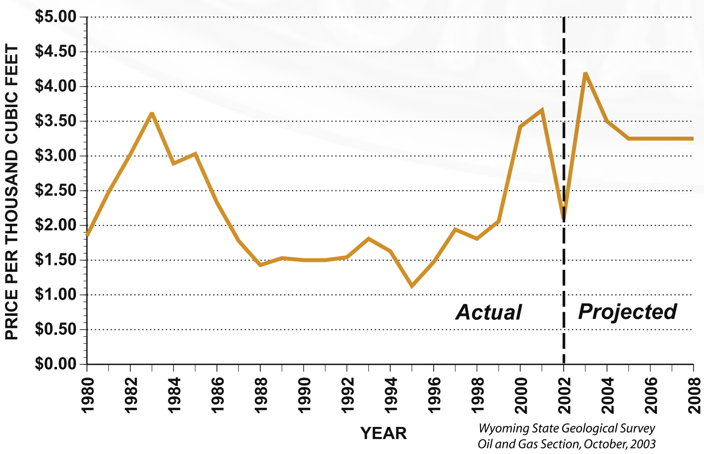

Figure 8. Average prices paid for Wyoming methane (1980 through 2002) with forecasts to 2008.

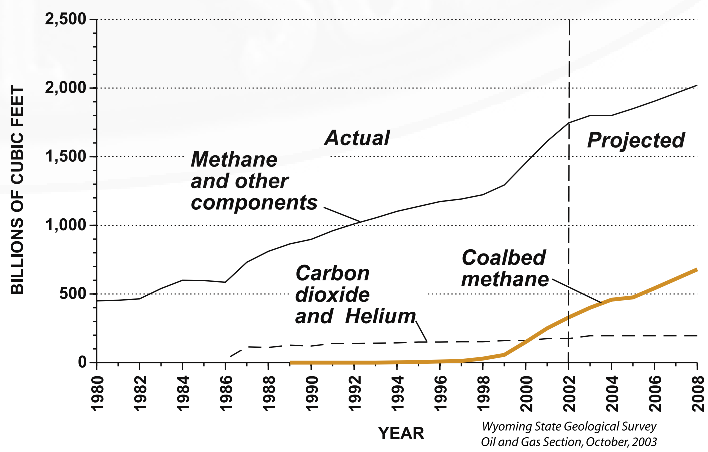

Figure 9. Annual natural gas production from Wyoming (1980 through 2002) with forecasts to 2008.

in Opal, Williams will add a fourth processing train with a capacity of 350 MMCF per day to accommodate the projected increase in gas volumes. Shell currently produces about 70 MMCF per day from the Pinedale anticline. The project will boost the Opal plant's processing capacity from 750 MMCF to 1.1 BCF of natural gas per day with the ability to recover in excess of 50,000 barrels of natural gas liquids per day. The expansion's expected completion date is in the fourth quarter of 2003. Gas is delivered to CIG, Kern River Pipeline, and Northwest Pipeline from the Opal plant.

Western Gas Resources completed the purchase of several natural-gas gathering systems from El Paso Field Services for approximately $37 million. Current throughput on the systems is currently about 139 MMCF of gas per day from 450 wells and 550 miles of gathering lines. Three of the larger systems are in the Greater Green River Basin (GGRB); six of the systems are in the PRB and gather CBM; and the remaining four systems are located in the Wind River Basin (WRB) in central Wyoming. Western had not owned any gas gathering facilities in the WRB previously, so the purchase of the four systems will give the company an entry point in the basin.

Anadarko Petroleum Corporation completed the acquisition of Howell Corporation during the fourth quarter of 2002. The acquisition gives Anadarko additional proved reserves of 45 million barrels of oil equivalent. The proved reserves are primarily in Salt Creek Field of the PRB and in Elk Basin Field of the Bighorn Basin. After the acquisition, Anadarko announced plans to invest an additional $200 million over the next four years to develop and install an enhanced oil recovery project in Salt Creek Field. Anadarko plans to buy carbon dioxide (CO_2) from ExxonMobil's Shute Creek Gas Plant in southwestern Wyoming to flood Salt Creek Field; they expect to recover an additional 150 million barrels of crude oil. A CO_2 flood of Elk Basin Field would extend that total even further.

That increase in production at Salt Creek would reverse Wyoming's declining oil production. . .

Anadarko expects to increase production from Salt Creek to 35,000 barrels of oil per day (equal to about 12.8 million barrels per year) by 2007 from the present level of 5300 barrels of oil per day (about 1.9 million barrels per year). That increase in production at Salt Creek would reverse Wyoming's declining oil production, at least for a few years. Anadarko started a pilot project in June, 2003 at Salt Creek Field that has already increased oil production at the field. Indications are that the CO_2 pipeline will be completed by early 2004, since the BLM gave final approval to the pipeline and Anadarko began shipping pipe to Casper in August, 2003.

The BLM also approved Anadarko's request for a right-of-way to construct, operate, and maintain a CO_2 pipeline and related facilities to transport CO_2 to the company's Monell Unit in Patrick Draw Field of southern Wyoming. The proposed 33-mile pipeline would bring CO_2 to the field for enhanced oil recovery in the Almond Formation. The line would originate from an existing valve terminal that is part of ExxonMobil's Shute Creek CO_2 distribution system.

The BLM is seeking public input on a 3-D seismic project covering about 513 square miles of public, state, and private lands in Fremont County, WRB. The Hoodoo Creek 3-D geophysical project is in the northern WRB in the area of the Owl Creek thrust fault. The BLM reported the formation of the Owl Creek Exploratory Unit, which has been designated but not yet approved, and comprises over 3600 acres in sections 7 to 9 and 17 to 20, T39N, R93W. Stone Energy, proposed operator of the unit, plans a deep drilling program in the area.

Veritas DGC Land Inc. plans a 137-square-mile 3-D seismic project in Sublette and Lincoln counties in southwestern Wyoming. The proposed project area is west of La Barge and southwest of Big Piney. Veritas has filed a *Notice of Intent to Conduct Geophysical Operations* with the BLM, and the BLM is soliciting input from the public on this project. The project will consist of 50% Vibroseis™ operations and 50% drilled shot holes.

Burlington Resources Inc. shut down production from its Madison wells in Madden Field after pipe abnormalities were discovered during a field inspection. The gas is sour (contains hydrogen sulfide) and is processed at Burlington's Lost Cabin gas plant. Production capacity into the plant is 310 MMCF per day with about 210 MMCF per day of treated sales gas coming out of the plant.

A new Department of Energy report (Natural Gas Resources of the Greater Green River and Wind River Basins of Wyoming, February, 2003, CD-ROM) estimates remaining in-place resources of natural gas in the GGRB at over 3600 trillion cubic feet (TCF) and in the WRB at over 1100 TCF. The report maintains that exploitation of these resources will require the development and application of advanced exploration, drilling, completion, stimulation, and production technologies. Analyses were conducted, using the Gas Systems Analysis Model, to estimate the amount of natural gas in place that is technically and economically recoverable with current technologies. The model determined that roughly 10% of the gas in place in the GGRB and WRB (360 TCF and 120 TCF, respectively) is recoverable.

Lease sales

Leasing activity at the Wyoming Office of State Lands and Investments' (State Lands') April, 2003 sale was concentrated in the PRB and in southwestern Wyoming (**Figure 10**). The high per-acre bid of $350 was made by James Sullivan for

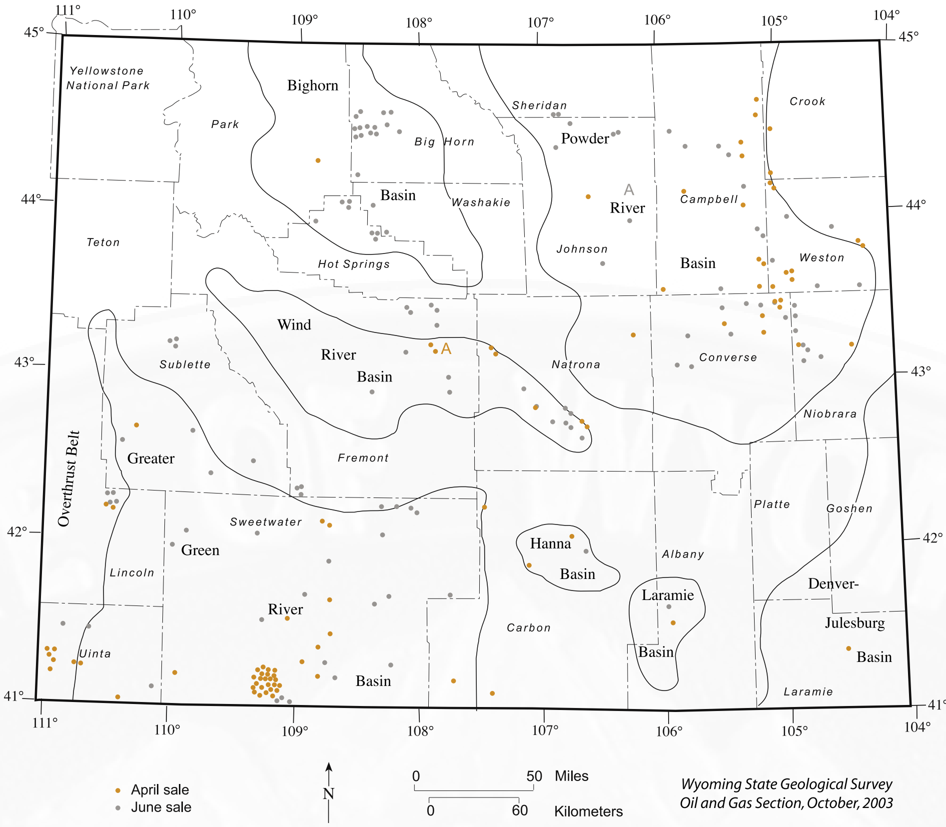

Figure 10. Locations of state oil and gas tracts leased by the Office of State Lands and Investments at its April, 2003 sale (locations in orange) and its June, 2003 sale (locations in gray). Locations are approximate and may represent more than one tract.

two different parcels, both in the northern WRB. One of the parcels covers 160 acres in SW section 23, T37N, R91W (**location A, Figure 10**) and the other comprises 164.06 acres in S NE and E NW section 25, T37N, R91W (**location A, Figure 10**). Sullivan also paid $340 an acre for 656.12 acres that covers all of section 36, T37N, R91W (**location A, Figure 10**). The leases are all about 1.5 to 3.5 miles southwest and west of the inactive Kanson Draw Field which produced over one BCF of gas from the Lance Formation. This sale generated over $800,000 in revenue and the per-acre bid averaged $26.96 (**Table 7**). There were 12 parcels at this sale that received bids of $50 or more per acre.

Leasing activity at the State Lands' June, 2003 sale was distributed fairly evenly throughout the state (**Figure 10**). The high per-acre bid of $575 was submitted by Emerald Operating Co. for a 40-acre parcel that covers SW NW section 35, T48N, R78W (**location A, Figure 10**). The lease is in the vicinity of CBM development in the Fort Union Formation. This sale generated over $580,000 in revenue and the average bid was $13.28 per acre (**Table 7**). There were nine leases at this sale that received bids of $50 or more per acre.

The slowdown in leasing for the last three BLM sales is mainly due to a lack of available parcels in prospective areas.

Leasing activity at the February, 2003 BLM sale was scattered throughout the state (**Figure 11**). The high per-acre bid of $56 was made by Yates Petroleum for a 400-acre lease that covers NW SE and SE SE section 9 and S section 10, T39N, R92W (**location A, Figure 11**). The lease is 3 to 4 miles east of a 1986 Frontier Formation gas discovery in the Steffen Hill Field area. The sale generated only $170,647 in revenue, only 27 of the 37 parcels offered were sold, and the average per-acre bid was only $8.64 (**Table 7**). Only one parcel at this sale received a bid of $50 or more per acre.

Leasing activity at the April, 2003 BLM sale was scattered throughout the state (**Figure 11**). The high per-acre bid of $310 was made by Kerr-McGee for a 1111.92-acre parcel that covers all of section 17 and parts of section 18, T37N, R90W (**location A, Figure 11**). The lease is in the Kanson Draw Field area and has an 18,834-foot-deep well that was completed in 1982 as a Shannon Sandstone gas well, but was never put into production. Kerr-McGee also purchased an adjacent 160-acre tract that covers the NW section 21, T37N, R90W, for $305 per acre. The sale generated over $1.4 million in revenue and the average per-acre price

Table 7. Federal and state competitive oil and gas lease sales in Wyoming (1999 through June, 2003).

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
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	1069	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
2002							
February	$5,137,024	219	164	271,248	177,117	$29.00	$345.00
April	$2,969,094	142	127	136,864	117,852	$25.19	$375.00
June	$1,183,222	91	63	82,958	55,808	$21.20	$185.00
August	$858,686	124	89	111,462	88,719	$9.68	$205.00
October	$578,597	117	86	122,962	72,039	$8.03	$46.00
December	$866,561	111	95	86,139	73,237	$11.83	$165.00
TOTAL	$11,593,184	804	624	811,633	584,772	$19.83	$375.00
2003							
February	$170,647	37	27	28,836	19,746	$8.64	$56.00
April	$1,455.295	98	71	49,521	33,304	$43.70	$310.00
June	$1,729,660	63	54	46,412	40,177	$43.05	$360.00

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
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	1190	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
2002							
April	$465,104	200	90	74,321	35,084	$13.26	$105.00
June	$517,143	200	124	74,608	46,841	$11.04	$525.00
October	$1,222,823	198	133	70,800	47,436	$25.77	$480.00
TOTAL	$2,205,070	598	347	219,729	129,361	$17.05	$525.00
2003							
April	$812,916	200	92	79,290	30,152	$26.96	$350.00
June	$583,950	200	121	76,433	43,966	$13.28	$575.00

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, April, 2003.*

was $43.70 (**Table 7**). There were 18 parcels at this sale that received bids of $50 or more per acre. This is a fairly high percentage of the 98 parcels that were offered and the 71 parcels that were sold.

Leasing activity at the June, 2003 BLM sale was concentrated in the PRB and WRB and in southwestern Wyoming (**Figure 11**). The high per-acre bid of $360 was made by Baseline Minerals for a 2120-acre lease that takes in all of sections 9, 10, and 11 and parts of section 15, T36N, R91W (**location A, Figure 11**). The parcel is 3 to 6 miles southwest of the inactive Kanson Draw Field. The sale generated over $1.7 million in revenue and the average per-acre price was $43.05 (**Table 7**). Only 54 parcels out of the 63 parcels offered for sale received bids. There were 10 leases at this sale that received bids of $50 or more per acre.

The slowdown in leasing for the last three BLM sales is mainly due to a lack of available parcels in prospective areas. The BLM withdrew a number of parcels that potentially could contain CBM in the PRB over the last six months because of a lawsuit brought by several environmental organizations. Overall in the five lease sales held during the first half of 2003, leasing activity increased in the WRB where four of the five sales had the high per-acre bid.

The slowdown in drilling permits last year and the first half of this year when compared to 2001 is due to a lack of CBM drilling locations on federal land.

Permitting and drilling

The WOGCC approved 3479 Applications for Permit to Drill (APDs) in the first half of 2003, which is 140 more than in the first half of 2002. The total for the first half of 2003 is more than the approvals for the full years of 1995 through 1998 (**Table 8** and earlier versions of this table). Campbell County again led with 36.8% of the total APDs that were approved in the first six months of 2003. Sheridan and Johnson counties combined for another 39.6%. Nearly all of the approved APDs in these three counties were for CBM tests. The slowdown in drilling permits last year and the first half of this year when compared to 2001 is due to a lack of CBM drilling locations on federal land. Even though the ROD for the PRB Oil and Gas Project Final EIS was signed in early 2003, the stringent requirements for drilling applications by the BLM shut down permitting on federal land until July. The BLM resumed permitting on July 14, 2003 and had only approved the drilling of 121 new CBM wells by August 20, 2003.

The WOGCC permitted 17 seismic projects in the first half of 2003. The number of permits is seven less than for the first half of 2002. The number of conventional miles permitted in the first half of 2003 was 707 lower than for the first half of 2002, but the total square miles of 3-D seismic is 464 more (**Table 9**). Geophysical activity is a good indicator of future exploration and production drilling.

The average daily rig count for the first half of 2003 was 44 (**Figure 12**). This average is four more than for the first half of 2002. The rig count does not include rigs drilling for CBM. The monthly averages for May and June were over 60, equaling monthly highs in 1993 and 2000.

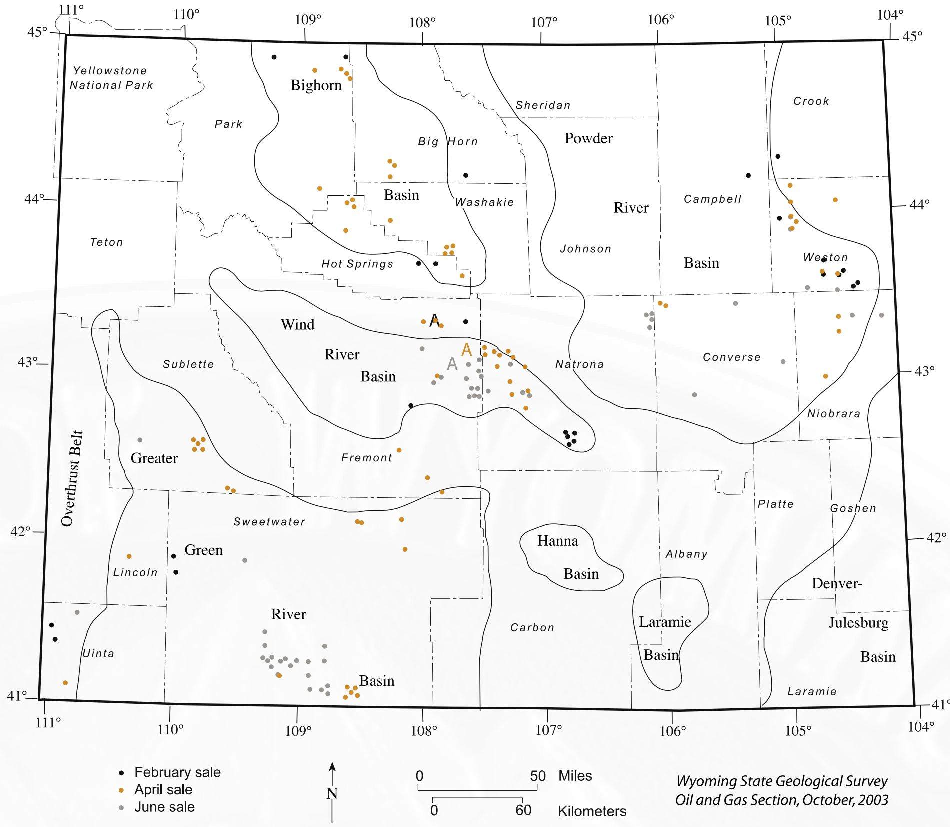

Figure 11. Locations of federal oil and gas tracts leased by the U.S. Bureau of Land Management at its February, 2003 sale (locations in black), its April, 2003 sale (locations in orange), and its June, 2003 sale (locations in gray). Locations are approximate and may represent more than one tract.

Exploration and development

Company data, news releases, and information compiled and published by Petroleum Information/Dwights LLC. are used to track oil and gas exploration and development activity in Wyoming. **Table 10** reports the most significant activities exclusive of CBM (see the **Coalbed Methane Update** for development in that industry) during the first half of 2003. The numbers correspond to locations on **Figure 13**.

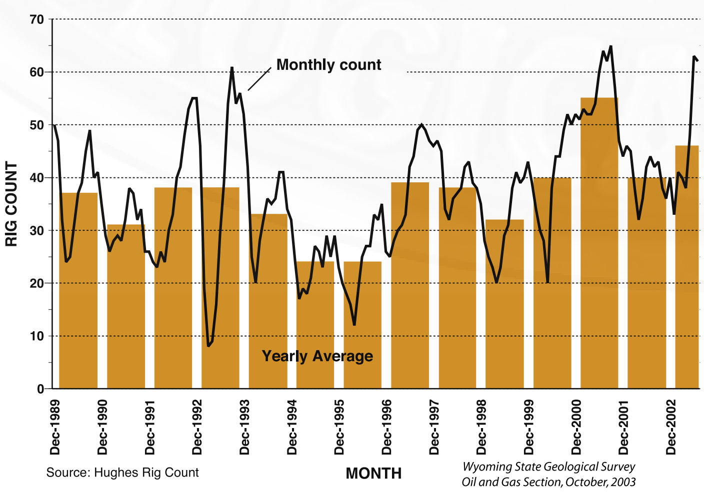

Figure 12. Wyoming daily rig count, exclusive of coalbed methane rigs, averaged by month and year (December, 1989 through June, 2003).

Table 8. Number of Applications for Permit to Drill (APDs) approved by the Wyoming Oil and Gas Conservation Commission (1997 through June, 2003).

County	1997 APDs	1998 APDs	1999 APDs	2000 APDs	2001 APDs	2002 APDs	2003 APDs
Albany	0	0	0	0	1	1	1
Big Horn	59	13	6	11	23	8	2
Campbell	941	1586	4461	5580	6204	2793	1281
Carbon	84	96	127	174	261	198	93
Converse	16	6	19	70	25	43	14
Crook	26	29	30	47	20	13	38
Fremont	58	76	67	136	149	62	59
Goshen	0	0	0	0	0	1	0
Hot Springs	42	1	8	6	2	9	2
Johnson	6	49	304	769	805	799	452
Laramie	3	2	0	2	3	3	0
Lincoln	122	105	51	70	87	51	30
Natrona	59	36	51	53	45	49	27
Niobrara	8	8	5	18	15	10	8
Park	25	11	12	18	45	23	37
Platte	0	0	0	0	0	0	0
Sheridan	2	35	416	891	1811	1531	924
Sublette	179	230	189	338	435	428	235
Sweetwater	210	181	124	335	534	379	269
Teton	0	0	0	0	0	0	0
Uinta	27	26	26	53	35	16	2
Washakie	36	9	0	7	10	1	0
Weston	5	6	4	20	7	2	5
Totals	**1908**	**2505**	**5900**	**8598**	**10,517**	**6420**	**3479**

Source: All data are from the Wyoming Oil and Gas Conservation Commission. *Wyoming State Geological Survey, Oil and Gas Section, August, 2003.*

Table 9. Number of seismic projects and miles permitted by the Wyoming Oil and Gas Conservation Commission (1999 through June, 2003).

	1999			2000			2001			2002			2003		
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	1	6	0	0	0	0
Big Horn	0	0	0	1	387	0	1	0	4	0	0	0	0	0	0
Campbell	4	4	10	14	64	132	5	38	3	10	49	3	2	5	0
Carbon	5	77	57	0	0	0	1	500	0	4	419	3	1	0	55
Converse	1	0	50	1	15	0	0	0	0	2	6	47	1	0	75
Crook	1	0	10	7	16	22	4	32	0	1	0	2	3	46	0
Fremont	1	0	88	4	25	116	2	70	15	1	160	0	4	12	717
Goshen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot Springs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Johnson	0	0	0	4	35	0	2	4	4	1	16	0	1	25	0
Laramie	0	0	0	0	0	0	0	0	0	1	0	18	0	0	0
Lincoln	1	0	32	0	0	0	1	0	25	0	0	0	0	0	0
Natrona	2	0	230	5	36	135	2	19	63	4	11	72	0	0	0
Niobrara	5	16	31	1	0	25	1	0	16	3	3	52	1	0	16
Park	3	25	32	1	13	0	4	21	20	0	0	0	0	0	0
Platte	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sheridan	0	0	0	0	0	0	2	0	81	0	0	0	0	0	0
Sublette	3	0	308	4	77	44	10	261	374	1	464	0	1	0	135
Sweetwater	9	0	530	13	54	1004	11	129	802	7	348	485	2	1	8
Teton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Uinta	1	0	26	0	0	0	1	259	0	2	196	0	1	0	47
Washakie	1	0	8	0	0	0	0	0	0	1	21	0	0	0	0
Weston	1	40	0	0	0	0	0	0	0	0	0	0	0	0	0
Totals	**38**	**162**	**1412**	**55**	**722**	**1478**	**47**	**1333**	**1407**	**39**	**1699**	**682**	**17**	**89**	**1053**

Source: All data are from the Wyoming Oil and Gas Conservation Commission. *Wyoming State Geological Survey, Oil and Gas Section, August, 2003.*

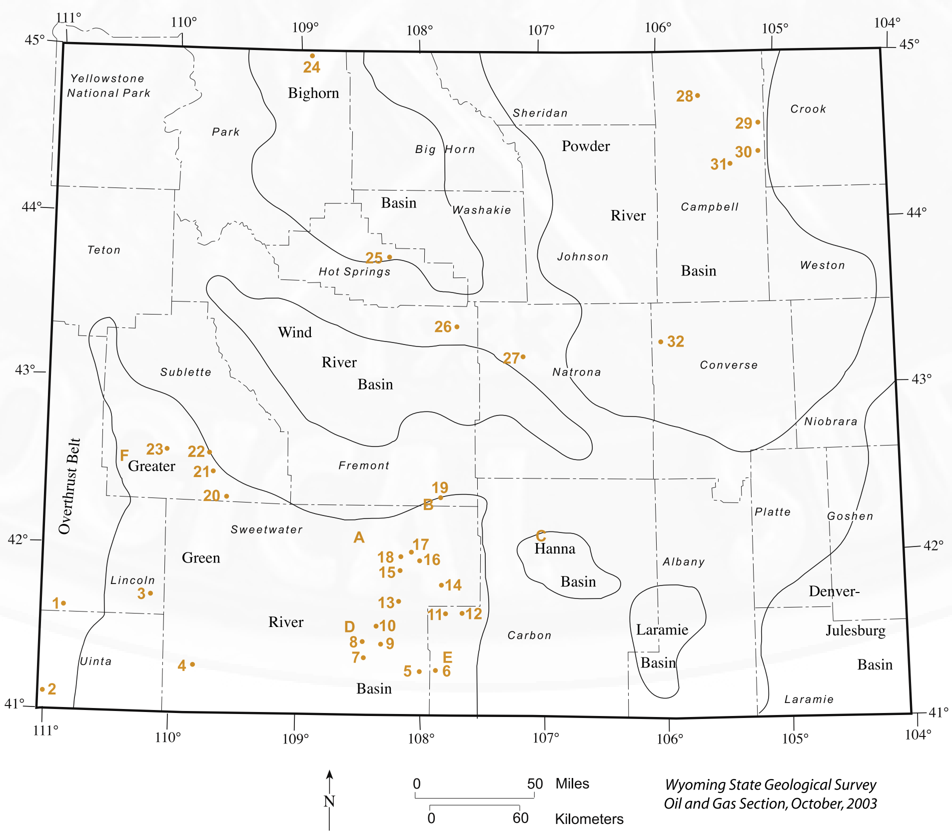

Figure 13. Oil and gas exploration and development activities in Wyoming during the first half of 2003. Letters indicate coalbed methane developments described in the Coalbed Methane Update. Locations are approximate and may represent more than one well location or project.

Table 10. Significant exploration and development wells in Wyoming, first half of 2003[1]. Number corresponds to location on Figure 13.

	Company name	Well name/number	Location	Formation tested	Depth(s) interval(s) tested	Tested prod. (per day)	Remarks
1	Chevron USA	2-20M Chevron-Federal	NW SW sec 20, T19N, R119W	Mission Canyon Ls.	14,676-15,373	2.5 MMCF 6.5 BBL cond 54 BBL H_2O	Northernmost producer in Whitney Canyon-Carter Creek Field
2	Anschutz Exploration	13-24ST Thief Creek	SW SE sec 24, T13N, R121W	Nugget Ss.	15,347-16,268	5.1 MMCF 681 BBL cond	Overthrust Belt discovery
3	EnCana Energy Resources	12 Reynard Unit	SE SE sec 3, T20N, R113W	Muddy Ss.	12,000-12,043	568 MCF 85 BBL cond 5 BBL H_2O	Wildcat discovery
4	EnCana Oil & Gas USA	2-17 Mary-Federal	NE NE sec 17, T15N, R110W	Ericson Ss.	10,136-10,176	357 MCF 21 BBL cond 4 BBL H_2O	Wildcat discovery
5	True Oil	33-6 Western-Federal	NW SE sec 6, T15N, R94W	Lewis Sh.	11,150-11,160	960 MCF 10 BBL cond 3 BBL H_2O	Wildcat discovery
6	Devon SFS Operating	8-4-15-93 Flat Top	SE NE sec 4, T15N, R93W	Mesaverde Gp.	9400-9635 9710-9728	1.0 MMCF 15 BBL cond 23 BBL H_2O	Wildcat discovery
7	BP America Production	9-1 Kennedy Springs	SE SW sec 9, T16N, R98W	Lance Fm. Lewis Sh. Mesaverde Gp.	9270-9340 9858-9951 12,044-12,160	447 MCF 94 BBL cond	Multiple zone wildcat discovery
8	BP America Production	35-2 Antelope Creek	SE SE sec 35, T17N, R98W	Lance Fm. Lewis Sh. Mesaverde Gp.	9480-9490 11,036-11,059 11,552-11,626	1.7 MMCF	Multiple zone wildcat discovery
9	BP America Production	29-2 NW Iron Pipe	NW NW sec 29, T17N, R97W	Lewis Sh. Mesaverde Gp.	two zones 10,914-10,933 seven zones 11,636-12,046	10.11.6 11 BBL cond	Multiple zone wildcat discovery
	BP America Production	19-1 NW Iron Pipe	NW SE sec 19, T17N, R97W	Lewis Sh. Mesaverde Gp.	two zones 10,206-10,845 five zones 11,220-11,545	696 MCF	Offset to the discovery well
	BP America Production	31-2 NW Iron Pipe	SE SE sec 31, T17N, R97W	Mesaverde Gp.	two zones 12,325-12,727	652 MCF 1 BBL cond	Offset to the discovery well
10	Anadarko Exploration & Production	35-3 Laney Rim	SE SE sec 35, T18N, R97W	Almond Fm.	10,670-10,690 10,896-10,996	800 MCF 41 BBL H_2O	Stepout discovery
11	Devon SFS Operating	1-22-19-92 East Echo Springs	E/2 NE sec 22, T19N, R92W	Lewis Sh. Almond Fm.	5 intervals 8187-8290 four intervals 8846-9142	1.4 MMCF 20 BBL cond 13 BBL H_2O	Northernmost producer in Echo Springs East Field
	BP America Production	25-1 High Point	NW SW sec 25, T19N, R92W	Mesaverde Gp.	8726-8731 8806-8816	2.7 MMCF 85 BBL cond	New producer near Echo Springs East Field
12	Nearburg Producing	4-19 Fillmore	SE NW sec 19, T19N, R91W	Lewis Sh. Almond Fm.	7853-7967 8665-9013	1.5 MMCF 34 BBl cond	New producer in Fillmore Field
	Nearburg Producing	2-20 Fillmore-Federal	C SW sec 20, T19N, R91W	Lewis Sh. Almond Fm.	7721-8593	600 MCF 4 BBL cond	New producer in Fillmore Field
	Devon SFS Operating	2 Eucker-Federal	SE SE sec 24, T19N, R92W	Lewis Sh.	7813-7815 7855-7860	1.3 MMCF 47 BBL cond 18 BBL H_2O	New producer in Fillmore Field
13	Devon SFS Operating	8-6-20-95 Red Desert	NE NE sec 6, T20N, R95W	Lewis Sh.	7360-7416	2.2 MMCF 8 BBL cond 81 BBL H_2O	New producer on the western flank of Wamsutter Field
	Yates Petroleum	5 Tipton-Federal	SW NE sec 12, T20N, R96W	Lewis Sh. Almond Fm. Ericson Ss.	two intervals 7157-7764 9028-9069 9150-9203	1.9 MMCF 204 BBL H_2O	New producer on the western flank of Wamsutter Field
14	Flying J Oil & Gas	4-28 Monument Lake	NW SE sec 28, T21N, R92W	Almond Fm.	three intervals 11,007-11,386	765 MMCF 27 BBL cond 22 BBL H_2O	Wildcat discovery
15	BP America Production	1-1 East Luman	SW SE sec 1, T22N, R95W	Mesaverde Gp.	11,228-11,450	1.1 MMCF 1 BBL cond	Wildcat discovery
16	BP America Production	35-1 Battle Springs	SW SW sec 35, T23N, R94W	Mesaverde Gp. Lewis Sh.	two intervals 11,879-12,209 10,131-10,141	457 MCF 156 BBL cond 1.8 MMCF 286 BBL cond	Wildcat discovery
17	BP America Production	19-1 Battle Springs	SE NW sec 19, T23N, R94W	Mesaverde Gp.	11,719-11,839 11,912-12,064	590 MCF 4 BBL cond	Wildcat discovery
18	BP America Production	35-1 Lost Creek	C SE sec 35, T23N, R95W	Mesaverde Gp.	11,127-11,260 11,350-11,392	2.2 MMCF 5 BBL cond	Wildcat discovery
19	Wold Oil Properties	1-27X Crooks Creek	NE SW sec 27, T27N, R92W	Frontier Fm.	13,678-13,692 13,775-13,848	451 MCF 20 BBL H_2O	Redrilled dry hole discovery
20	McMurry Oil	14-20 Sagebrush	SE SW sec 20, T27N, R107W	Lance Fm.	three intervals 7930-8817	330 MCF 2 BBL cond 30 BBL H_2O	Wildcat discovery
21	McMurry Oil	21-4 Stud Horse Butte	SE SE sec 34, T29N, R108W	Lance Fm.	12 intervals 8050-11,129	6.8 MMCF 79 BBL cond 43 BBL H_2O	New Jonah Field producer
	McMurry Oil	55-34 Stud Horse Butte	NE SE sec 34, T29N, R108W	Lance Fm.	10 intervals 8074-10,608	10.0 MMCF 100 BBL cond 75 BBL H_2O	New Jonah Field producer

Table 10. Continued. Significant exploration and development wells in Wyoming, first half of 2003[1]. Number corresponds to location on Figure 13.

	Company name	Well name/number	Location	Formation tested	Depth(s) interval(s) tested	Tested prod. (per day)	Remarks
21	McMurry Oil	59-34 Stud Horse Butte	NW SW sec 34, T29N, R108W	Lance Fm.	11 intervals 8010-11,385	6.9 MMCF 110 BBL cond 28 BBL H_2O	New Jonah Field producer
	McMurry Oil	57-34 Stud Horse Butte	NE SW sec 34, T29N, R108W	Lance Fm.	12 intervals 8022-11,306	5.8 MMCF 100 BBL cond 45 BBL H_2O	New Jonah Field producer
22	Stone Energy	9-31 Rainbow	NE SE sec 31, T30N, R107W	Lance Fm. Mesaverde Fm.	nine intervals unreported depths	5.0 MMCF	New Pinedale anticline producer
	Stone Energy	5-4 Antelope	SW NW sec 4, T29N, R107W	Lance Fm. Mesaverde Fm.	eight intervals 10,648-12,604	2.8 MMCF 35 BBL cond 507 BBL H_2O	New Pinedale anticline producer
	Shell Rocky Mountain Production	11-14D Warbonnet	SW SW sec 14, T30N, R108W	Lance Fm Mesaverde Fm.	14 intervals 8400-12,436 12,614-12,738	7.9 MMCF 81 BBL cond 1192 BBL H_2O	New Pinedale anticline producer
	Shell Rocky Mountain Production	11-10 Warbonnet	NE SW sec 10, T30N, R108W	Lance Fm. Mesaverde Fm.	13 intervals 8484-12,200	7.7 MMCF 52 BBL cond 594 BBL H_2O	New Pinedale anticline producer
	Shell Rocky Mountain Production	2-6 Antelope	NW NE sec 6, T29N, R107W	Lance Fm.	five intervals 9926-12,054	6.4 MMCF 88 BBL cond 396 BBL H_2O	New Pinedale anticline producer
	Shell Rocky Mountain Production	14-4 Antelope	SE SW sec 4, T29N, R107W	Lance Fm. Mesaverde Fm.	five intervals 10,648-11,625 three intervals 11,839-12,604	2.8 MMCF 35 BBL cond 507 BBL H_2O	New Pinedale anticline producer
	Wexpro Co.	15-20D Stewart Point	SW SE sec 20, T33N, R109W	Lance Fm. Mesaverde Fm.	10 intervals 8816-12,832	19.4 MMCF 96 BBL cond 72 BBL H_2O	New Pinedale anticline producer Mesa Unit
	Questar Exploration & Production	15-20 Mesa	SW SE sec 20, T32N, R109W	Mesaverde Fm.	three intervals 12,626-14,040	4.5 MMCF 36 BBL cond 24 BBL H_2O	New Pinedale anticline producer
	Ultra Resources	13-24 Warbonnet	SW SW sec 24, T30N, R108W	Lance Fm.	16 intervals 8899-13,572	9.6 MMCF 74 BBL cond 1090 BBL H_2O	New Pinedale anticline producer
	Ultra Resources	7-23 Warbonnet	SW NE sec 23, T30N, R108W	Lance Fm. Mesaverde Fm.	14 intervals 8390-13,109	8.7 MMCF 82 BBL cond 1022 BBL H_2O	
	Anschutz Exploration	4-35 Mesa	NW NW sec 35, T32N, R109W	Lance Fm.	not reported	4.5 MMCF 24 BBL cond 109 BBL H_2O	New Pinedale anticline producer
23	Burlington Resources Oil & Gas	24-14 Muddy Creek	SE SW sec 14, T30N, R111W	Lance Fm.	three intervals 7794-8680	623 MCF 192 BBL H_2O	New Lance Fm. Discovery
24	Howell Petroleum	31-2 Howell-USA	NE SE sec 31, T58N, R99W	Sundance Fm.	3283-3298	2.1 MMCF 168 BBL cond 7 BBL H_2O	Second Sundance producing well in Elk Basin Field
	Howell Petroleum	25-17 Howell-USA	NE NE sec 25, T58N, R100W	Frontier Fm.	1797-1812	103 BBL oil 47 MCF	Development well in Elk Basin Field
25	Marathon Oil	90 Gebo	SE NW sec 23, T44N, R95W	Phosphoria Fm. Tensleep Ss.	4505-4530 4818-4837 4856-4878 4902-4944	440 BBL oil 1171 BBL H_2O	Development well in Gebo Field
26	Burlington Resources Oil & Gas	8-35 Bighorn	SE SE sec 35, T39N, R90W	Madison Ls.	24,562-24,812	46.6 MMCF 738 BBL H_2O	Madden Field ultra-deep development well
	Burlington Resources Oil & Gas	7-34 Bighorn	NW SW sec 34, T39N, R91W	Madison Ls.	below 23,900	37.4 MMCF 529 BBL H_2O	Madden Field ultra-deep development well
27	Bill Barrett	5-29 East Cave Gulch	NE SW sec 29, T37N, R86W	Lance Fm. Meeteetse Fm.	several intervals 6060-10,463	1.8 MMCF 117 BBL H_2O	Development well in Waltman Field
	Bill Barrett	9-30 North Cave Gulch	NW NW sec 30, T37N, R86W	Lance Fm. Meeteetse Fm.	several unreported intervals	1.1 MMCF 97 BBL cond 15 BBL H_2O	Development well in Waltman Field
28	Trend Exploration	1 Jayne Harris West	SE NW sec 1, T55N, R73W	Minnelusa Fm.	8732-8738	75-120 BBL oil 40-100 BBL H_2O	Wildcat discovery
29	Ballard Petroleum Holdings	22-21 Cundy	SE NW sec 21, T53N, R69W	Minnelusa Fm.	7354-7374	276 BBL oil	Wildcat discovery
30	Samedan Oil	44-7 East Kuehne Ranch Unit	SE SE sec 7, T51N, R69W	Minnelusa Fm.	7794-7854	237 BBL oil 9 BBL H_2O	Development well in Kuehne Ranch East Field
31	Ballard Petroleum Holdings	22-11 DW-State	SE NW sec 11, T50N, R71W	Minnelusa Fm.	9209-9232	DST recovered 31.7 BBL oil	Wildcat discovery
32	EOG Resources	3-1 Crotalus	SE NE sec 1, T38N, R76W	Frontier Fm.	12,540-12,560	140 BBL oil 318 MCF	Wildcat discovery
	12 BBL H_2O						
	EOG Resources	4-7 Crotalus	SE NW sec 7, T38N, R75W	Frontier Fm.	12,410-12,438	121 BBL oil 129 MCF 2 BBL H_2O	Extension well

[1]Abbreviations include: MCF=thousands of cubic feet of natural gas; MMCF=millions of cubic feet of natural gas; BBL=barrels; cond=condensate; H_2O=water; Ss.=Sandstone; Ls.=Limestone; Fm.=Formation; Sh.=Shale; Gp.=Group. *Wyoming State Geological Survey, August, 2003.*

Coal Update

Robert M. Lyman, Wyoming PG-656

Staff Geologist–Coal, Wyoming State Geological Survey

Halfway through 2003 and Wyoming coal production is apparently rolling to a new high for yet another year. Reported deliveries of coal in the first quarter of 2003 lagged behind those for the first quarter of 2002, but by the halfway point deliveries had matched last year's total. A surge in reported deliveries in July may indicate that our previous prediction of a 2% increase in annual production for 2003 may be correct, but to be on the conservative side, our new forecast calls for only a 1% increase over 2002's production, for a total of 376.8 million short tons.

The overall price of Wyoming coal for 2002 was $6.66 per short ton, up $0.76 per short ton from our earlier forecast, and we are predicting that coal prices will increase again in 2003 to $6.80 per short ton. Spot market prices for coal in the Powder River Basin (PRB) have apparently played a much larger role to influence overall prices than in the past—the much shorter terms for contract coal now closely follow the spot market prices. The spot market showed little activity for the first half of 2003, but flat prices with little change (none of the usual peaks and valleys) have surprised and frustrated many forecasters.

After a few years of relative stability, property acquisition in the PRB may be starting again, as Arch of Wyoming has reached a definitive agreement to purchase the coal holdings of Triton Coal. Some coal buyers are becoming a little nervous as more consolidation takes place in the Wyoming PRB.

Other Wyoming coal fields are showing signs of potential new mining activity. The New Stansbury mine project in Sweetwater County has received the Wyoming Business Council's endorsement and seems to be moving ahead on schedule. Arch of Wyoming appears to be going forward on their Carbon Basin project near the town of Elk Mountain. Bridger Coal has successfully completed a trial run using a highwall miner configuration at their Jim Bridger mine east of Rock Springs.

The coal industry as well as the Wyoming Mining Association and National Coal Association have been busy during the first half of 2003 watching and actively adding input to major regulatory and government policy issues. These include the Environmental Protection Agency's (EPA's) approach to mercury; the Bush Administration's Blue Sky Initiative; carbon sequestration; and use of the Abandoned Mine Land Fund, just to name a few.

Production and prices

New estimates of coal production for 2003 through 2008 were released in October by the State of Wyoming's Consensus Revenue Estimating Group (CREG). The estimates (**Tables 1** and **11**) are slightly more conservative than last year's estimates (see *Wyoming Geo-notes No. 77*, June, 2003): only a 1% increase in total state production is expected for 2003 rather than the 2% increase predicted earlier. Because the CREG estimates for 2004 through 2008 are based on a 1% annual increase, all the production for these years is slightly less than what was predicted a year ago.

The slope of the production curve for 2003 through 2008 remains the same as before, but at just a slightly lower level (**Figure 14**). Coal production from southern Wyoming coal fields is expected to remain static from 2003 through 2008 (**Table 11**) as new mines or new projects replace production that is phased out in other areas. All the projected statewide increases in coal production are from mines in the PRB, with Campbell County mines accounting for most of the annual increases. Almost 89% (or 334.8 million short tons) of Wyoming's 2003 production (376.8 million short tons) will be from Campbell County and 96% (or 360.8 million short tons) will be from the PRB. By 2008, Wyoming coal mines could be producing almost 400 million short tons per year.

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Wyoming coal delivered to the utility market for the first quarter of 2003 totaled about 89.8 million short tons compared to about 91.9 million short tons in the first quarter of 2002 (**Table 12**). This represented a decrease of 2.25% from the 2002 figure. Late winter blizzards were blamed for part of this lag as many coal mines lost one or two days of production and train movements were slowed. By the end of the second quarter of 2003, coal deliveries had nearly equaled deliveries for the same period in 2002. Coal deliveries were 90.9 million short tons in the second quarter of 2003 compared to 88.9 million short tons for the same period in 2002 (**Table 12**). July, 2003 coal deliveries surged, with the yearly total exceeding that for the total same period in 2002 by 3.3 million short tons (**Table 12**). With total deliveries in 2003 ahead of last year by 1.58%, the state's coal production is on track to show at least the 1% growth projected by CREG.

The trends in coal deliveries to power plants in 2003 become even more interesting when broken down by month

Table 11. Wyoming coal production by county[1,2] (in millions of short tons), 1997 through 2002 with forecasts to 2008.

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Powder River Basin												
Campbell County	246.3	274.1	294.3	299.5	329.5	332.8	334.8	337.6	340.4	343.3	346.1	350.0
Converse County	17.8	23.4	25.6	23.6	24.6	26.8	26.0	27.0	28.0	29.0	30.0	30.0
Sheridan County	M	M	M	M	0.0	0.0	M	M	M	M	M	M
Subtotal	264.1	297.5	320.0	323.1	354.1	359.6	360.8	364.6	368.4	372.3	376.1	380.0
Southern Wyoming												
Carbon County	5	3.5	2.7	2.0	0.5	0.7	2.0	2.0	2.0	2.0	2.0	2.0
Sweetwater County	7.8	9.2	9.4	10.0	9.5	8.6	9.0	9.0	9.0	9.0	9.0	9.0
Lincoln County	4.6	4.7	4.3	3.7	4.5	4.2	5.0	5.0	5.0	5.0	5.0	5.0
Subtotal	17.4	17.4	16.4	15.7	14.5	13.5	16.0	16.0	16.0	16.0	16.0	16.0
Total Wyoming[3]	**281.5**	**314.9**	**336.5**	**338.9**	**368.6**	**373.1**	**376.8**	**380.6**	**384.4**	**388.3**	**392.1**	**396.0**
Annual change	**1.1%**	**11.9%**	**6.9%**	**0.7%**	**8.8%**	**1.2%**	**1.0%**	**1.0%**	**1.0%**	**1.0%**	**1.0%**	**1.0%**

[1]Reported tonnage from the Wyoming State Inspector of Mines (1997 through 2002). [2]County estimates by the Wyoming State Geological Survey, October, 2003 for 2003 through 2008. Totals may not agree because of independent rounding. [3]Estimate from CREG's Wyoming State Government Revenue Forecast, October, 2003. M=minor tonnage (less than a million tons). *Wyoming State Geological Survey, Coal Section, October, 2003.*

Table 12. Estimated monthly coal deliveries from Wyoming's mines in short tons (January, 1999 through July, 2003).

	1999		2000		2001		2002		2003	
	Monthly	Cumulative	Monthly	Cumulative	Monthly	Cumulative	Monthly	Cumulative	Monthly	Cumulative
January	27,105,791	27,105,791	27,773,610	27,773,610	27,743,000	27,743,000	28,406,666	28,406,666	31,421,669	31,421,669
February	25,803,390	52,909,181	25,594,109	53,367,719	27,827,000	55,570,000	30,041,748	58,448,414	28,087,977	59,509,646
March	28,222,743	81,131,923	28,262,696	81,630,415	33,739,000	89,309,000	33,409,797	91,858,211	30,282,095	89,791,741
April	25,965,867	107,097,791	25,549,039	107,179,454	27,302,000	116,611,000	27,534,057	119,392,268	29,882,355	119,674,096
May	28,698,498	135,796,288	26,222,515	133,401,969	27,752,000	144,363,000	34,704,299	154,096,567	30,893,000	150,567,096
June	24,753,829	160,550,118	25,085,516	158,487,485	33,968,000	178,331,000	26,674,488	180,771,055	30,096,000	180,663,096
July	28,266,458	188,816,576	28,881,862	187,369,347	29,200,000	207,531,000	27,885,210	208,656,265	31,288,429	211,951,525
August	28,346,757	217,163,333	29,075,295	216,444,642	27,662,000	235,193,000	35,670,535	244,326,800		
September	27,373,417	244,536,749	25,865,389	242,310,032	35,369,000	270,562,000	32,234,471	276,561,271		
October	26,837,295	271,374,045	26,441,615	268,751,646	29,869,000	300,431,000	26,101,957	302,663,228		
November	26,843,021	298,217,066	27,400,245	296,151,892	29,308,000	329,739,000	32,767,619	335,430,847		
December	26,834,927	325,051,993	28,300,773	324,452,665	29,984,000	359,723,000	26,476,240	361,907,087		
Total Utility Tonnage[1]		**325,051,993**		**324,452,665**		**359,723,000**		**361,907,087**		
Total Tonnage Other [2]		**11,407,945**		**14,399,483**		**8,955,135**		**11,288,344**		
Total Tonnage Produced[3]		**336,459,938**		**338,852,148**		**368,678,135**		**373,195,431**		

[1]From Federal Energy Regulatory Commission (FERC) Form 423 for 1998; FERC Form 423 as modified by WSGS for 1999 through July, 2003. [2]Includes estimates of residential, industrial, and exported coal. [3]Wyoming State Mine Inspector's Annual Reports. *Wyoming State Geological Survey, Coal Section, August, 2003.*

and by contract coal versus spot coal. For example, monthly deliveries in 2003 have not shown the large variations experienced in 2001 and 2002 (**Figure 15**) but are similar to monthly deliveries in 2000. Contract coal deliveries reflect the same pattern (**Figure 16a**), but spot coal deliveries (**Figure 16b**) are worth further discussion. All of this is somehow related to coal prices, which seem to be driving Wyoming production trends.

To say spot coal prices in the Wyoming PRB for the first half of 2003 have been flat would be an understatement (**Figure 17**). While some market watchers are very uneasy about this, the author believes it is a healthy sign. Most of our coal producers are evidently content to service their contract coal customers and hold firm on their spot market sales. The high spot coal prices in 2001 and 2002 (see *Wyoming Geo-notes No. 76*, April, 2003, Figure 14, p. 15) have certainly influenced average coal prices for Wyoming. The average price for Wyoming coal in 2002 was $6.66 per short ton (**Tables 2** and **13**), an increase of $0.91 per short ton over the average price in 2001 and $0.76 per short ton higher than our earlier estimate (see *Wyoming Geo-notes No. 77*, June, 2003, Table 2, p. 1). A

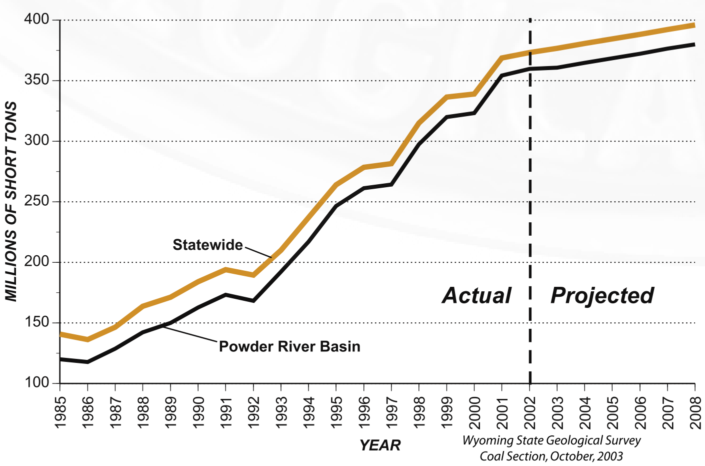

Figure 14. Annual coal production from Wyoming and the Powder River Basin (1985 through 2002) with forecasts to 2008. Sources: Wyoming State Inspector of Mines (1985 through 2002), CREG (2003 through 2008), and the Wyoming State Geological Survey.

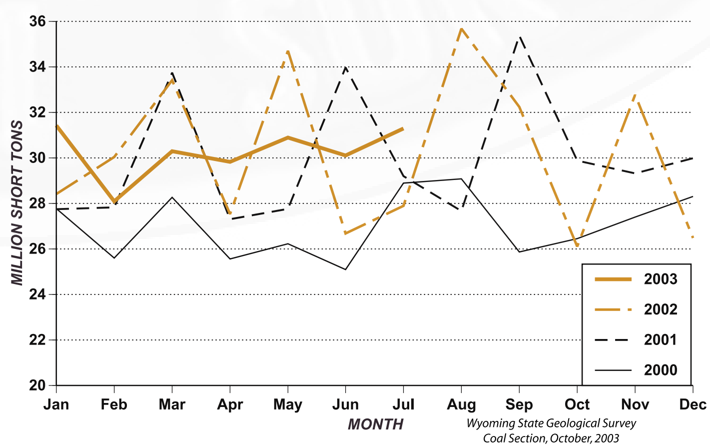

Figure 15. Reported monthly deliveries from Wyoming coal mines (2000 through July, 2003). From Form 423 of the Federal Regulatory Commission (FERC) as modified by the Wyoming State Geological Survey for 2000 through July, 2003.

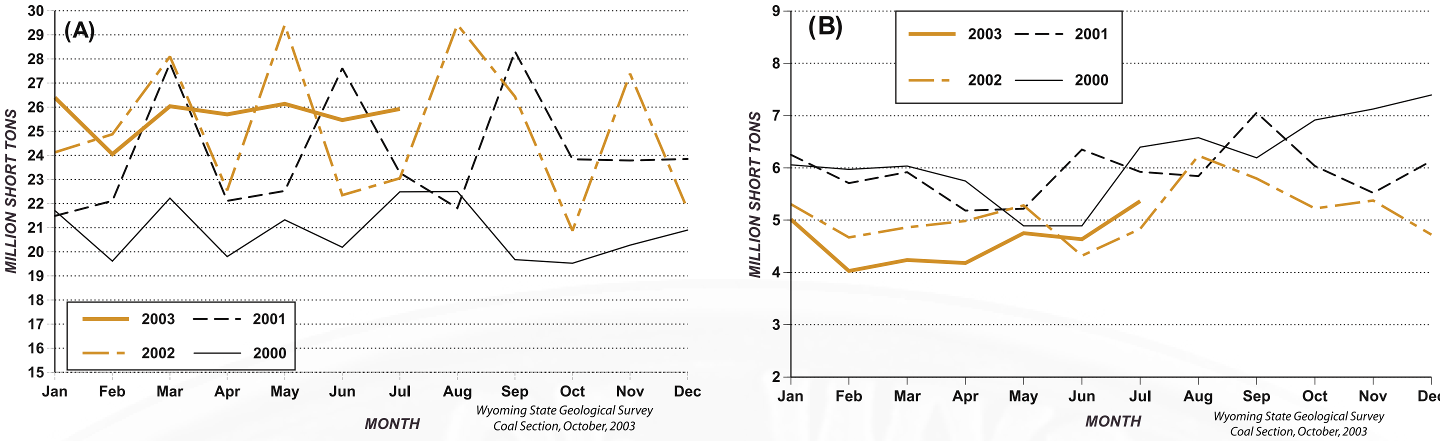

Figure 16. Monthly coal deliveries from Wyoming (2000 through July, 2003). (A) Coal sold on contract and (B) coal sold on the spot market. From Form 423 of the Federal Regulatory Commission (FERC) as modified by the Wyoming State Geological Survey for 2000 through July, 2003.

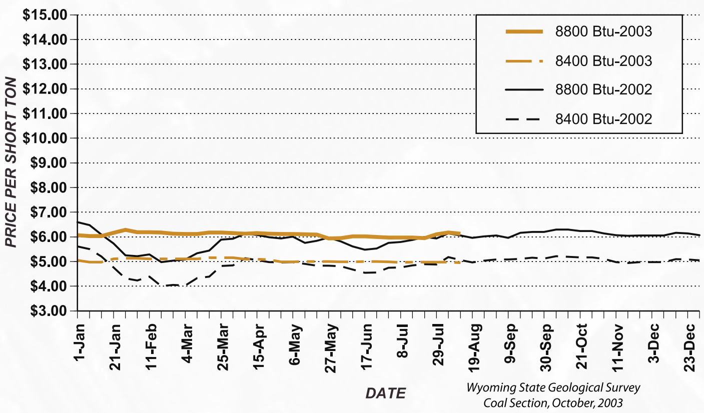

Figure 17. Wyoming Powder River Basin coal spot price watch (January 1, 2002 through August 12, 2003). Modified from COAL Daily's spot market index and Coal Week's short-term spot market price index.

Table 13. Breakdown of average prices paid for coal from northeastern Wyoming, southern Wyoming, and Wyoming as a whole (1988 through 2002) with forecasts to 2008.

	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
	2001	$5.36	$16.50	$5.75
	2002	$6.28	$16.50	$6.66
FORECAST	2003	$6.37	$16.50	$6.80
	2004	$5.54	$16.50	$6.00
	2005	$5.58	$16.50	$6.03
	2006	$5.67	$16.50	$6.12
	2007	$5.80	$16.50	$6.24
	2008	$5.97	$16.50	$6.40

Statewide data for 1988 through 1990 are from reports by the U.S. Department of Energy's Energy Information Administration; data for 1991 through 2002 are derived from Wyoming Department of Revenue information; estimates for 2003 through 2008, and all regional breakdowns by the *Wyoming State Geological Survey, Coal Section, October, 2003.*

number of short-term contracts were signed for the higher prices in 2001 and 2002, and as these higher-priced coal contracts expire in 2004 and 2005, CREG estimates that average prices will decrease (**Table 13** and **Figure 18**). CREG estimates that average prices will then increase slightly in 2006 through 2008. These predicted fluctuations in price are all related to prices for coal from the PRB, as shown in **Table 13**.

The biggest question for the next six months is how the PRB spot market will behave. During the first half of 2003 electric utility companies have drawn down their existing coal stockpiles to historical lows. A weak economy and suspected cash flow pinches at merchant plants may have delayed some power producers from getting into the PRB spot arena in expectation of softer pricing later in the year. However, spot prices have remained at the upper limit of last year's spot price range (**Figure 17**). With utility companies needing additional coal to build stockpiles for the coming winter, we may instead see second half price gains in the spot market. Will the spot coal be available, and if the coal buyers need it this year, can the railroads deliver the coal at new record tonnages?

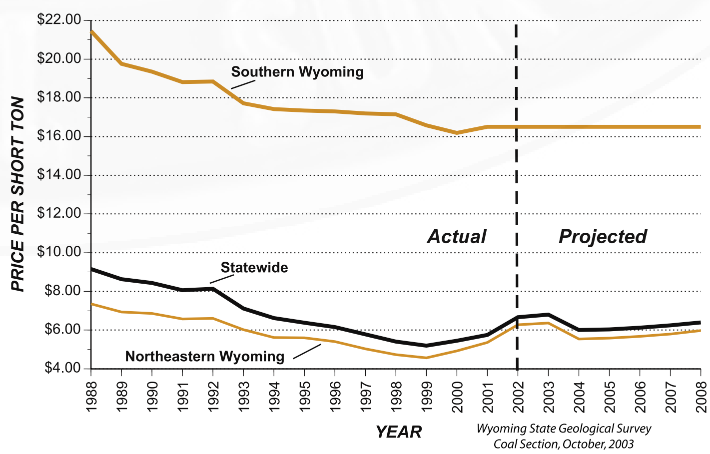

Figure 18. Average prices paid for Wyoming coal by producing area (1988 through 2002) with forecasts to 2008. Sources: U.S. Energy Information Administration (1988 through 1990); Wyoming Department of Revenue (1991 through 2002); and CREG (2003 through 2008).

Developments in the Powder River Basin

As mentioned in *Wyoming Geo-notes No. 77*, June, 2003, p. 16, Arch of Wyoming announced signing a definitive agreement to acquire Vulcan Coal Holdings, which owns all the equity of Triton Coal. The price of the acquisition was reported to be $364 million. Triton Coal consists of two Wyoming PRB mines, the Buckskin mine north of Gillette, and the North Rochelle mine near Wright. Triton produced 42,217,946 short tons of coal from the two mines in 2002 (Stauffenberg, 2002). The acquisition increases Arch's reserve base in the PRB by about 50%, from 1.4 to 2.1 billion short tons. On reserve basis alone, Arch appears to have paid $0.52 per ton for the Triton reserves, much lower than nearly $0.72 per short ton paid at the most recent federal lease sale in the PRB. Final closing on the transaction awaits federal review and approval (U.S. Coal Review, 6/2/2003).

Arch is also contemplating reviving their Coal Creek mine in 2004. Arch has held initial talks with the Land Quality Division, Wyoming Department of Environmental Quality (WDEQ) toward that end. To reopen Coal Creek, Arch will have to take the mine's permit off inactive status, update the mine plan, and do some earth moving operations in the old pit. The mine was mothballed in 2000 and at that time was operated by a contract miner. If the mine is reactivated, Arch will do the mining themselves (Coal Outlook, 5/12/2003). However, in light of Arch's recent Triton acquisition, the Coal Creek reopening may be delayed until the newly acquired Triton mines are incorporated into Arch's mining and marketing plans.

In February, the U.S. Bureau of Land Management (BLM) released a draft Environmental Impact Statement (DEIS) regarding five tracts of federal coal nominated for leasing by four neighboring mines in the PRB. Under BLM's Lease by Application (LBA) process, Peabody Coal applied for 4503 acres of coal land believed to contain approximately 564 million short tons of reserves in the NARO North and South LBAs. Kennecott Energy applied for 3542 acres in the West Antelope LBA containing 274 million short tons; Arch applied for 3449 acres in the Little Thunder LBA containing 479 million short tons; and Triton applied for 1871 acres in the West Roundup LBA containing 173 million short tons (Coal Trader, 5/14/2003). Wyoming currently has seven LBAs pending; they cover 17,873 acres of federal coal lands and contain 2.04 billion short tons of coal (**Table 14**).

The BLM has released the DEIS for the West Hay Creek LBA, which is located adjacent to the northwest corner of the Buckskin mine. Triton Coal applied for the tract in August, 2001. The LBA consists of approximately 840 acres containing 145 million short tons of in-place coal. If Triton is successful in acquiring the tract, Buckskin's life-of-mine would be extended an additional five years (U.S. Coal Review, 3/31/2003).

Peabody Energy has applied for an exploration license for 5426 acres of PRB property located between their North Antelope mine complex and Kennecott Energy's Antelope mine. Peabody plans to delineate burn lines for the upper and lower splits of the Wyodak-Anderson coal seam and further fine tune coal structure and coal quality data for the area (COAL Daily, 5/13/2003).

Kfx Inc. reached an agreement with Arch to pursue development of a 700,000-ton-per-year K-Fuel Plus plant to be constructed and operated at Arch's Black Thunder mine. The new enhanced coal plant will be financed by Kfx and built and operated together with Kfx affiliate, Lurgi South Africa Limited. Under the agreement, Black Thunder will provide the facility site, utilities, coal transportation, equipment infrastructure, and the coal feedstock. Arch Coal Sales would purchase the new plant's product and could blend it into the company's run-of-mine coal per specific customers' fuel needs. The technology to be used at the plant has been shown to significantly enhance the Btu content of PRB coal

Table 14. Federal Coal Lease By Applications (LBAs) in the Powder River Basin, Wyoming.

LBA Tract Name	Date	Applicant's Mine Name	Acres	Millions of Short Tons	Auction Status	Acceptance Date	Bid Price	Bid Per Ton
North Jacobs Ranch	10/2/98	Jacobs Ranch	4,821	519	Sold	1/16/02	$379,504,652.00	$0.706
Horse Creek	2/14/97	Antelope	2,838	357	Sold	9/7/00	$91,220,120.70	$0.330
Thunder Cloud	4/14/95	Jacobs Ranch	3,396	427	Sold	10/1/98	$158,000,008.50	$0.384*
Powder River	3/23/95	North Antelope/Rochelle	4,023	515	Sold	6/30/98	$109,596,500.00	$0.206
North Rochelle	7/22/92	North Rochelle	1,440	144	Sold	9/25/97	$30,576,340.00	$0.194
Antelope	12/29/92	Antelope	617	60	Sold	9/18/96	$9,054,600.00	$0.150
Eagle Butte	7/25/91	Eagle Butte	915	150	Sold	4/5/95	$18,470,400.00	$0.111
West Rocky Butte	12/4/90	Rocky Butte	390	50	Sold	1/7/93	$16,500,000.00	$0.291
West Black Thunder	12/22/89	Black Thunder	3,225	400	Sold	8/12/92	$71,909,282.69	$0.168
North Antelope/Rochelle	3/9/90	North Antelope/Rochelle	2,150	270	Sold	9/28/92	$86,987,765.00	$0.216
Jacobs Ranch	10/10/89	Jacobs Ranch	1,465	123	Sold	9/26/91	$20,114,930.00	$0.136
West Roundup	7/28/00	North Rochelle	1,868	173	Pending	na	na	na
West Antelope	9/12/00	Antelope	3,501	293	Pending	na	na	na
Little Thunder	3/23/00	Black Thunder	2,710	384	Pending	na	na	na
NARO (North & South)	3/10/00	North Antelope/Rochelle	4,501	564	Pending	na	na	na
Hay Creek	8/31/00	Buckskin	840	130	Pending	na	na	na
EGBT West Extension	12/28/01	Eagle Butte	1,643	200	Pending	na	na	na
Maysdorf (Mt. Logan)	9/20/01	Cordero-Rojo	2,810	296	Pending	na	na	na
New Keeline	5/13/96	proposed new mine	7,841	675	Rejected	na	na	na
Belle Ayr	3/20/97	Belle Ayr	1,336	171	Case Closed	na	na	na
State Section	1/31/00	proposed new mine	3,753	193	Withdrawn	na	na	na
Belle Ayr 2000	7/28/00	Belle Ayr	244	29	Bid Rejected	na	na	na
Big Thunder	9/12/01	Jacobs Ranch	5,634	715	Withdrawn	na	na	na

*LBA won by ARCH COAL (Black Thunder). Note: na = not applicable. Source: Bureau Of Land Management Wyoming website updated as of 7/18/2003. *Wyoming State Geological Survey, Coal Section, August, 2003.*

while lowering the fuel's SO_2, NOx, and mercury emissions (U.S. Coal Review, 2/3/2003).

North American Power Group's (NAPG's) Two Elk power plant has received a second chance. After WDEQ pulled their construction permit late last year, the company has now been granted a new permit. The company now has 24 months to reach specific construction goals (U.S. Coal Review, 6/9/2003).

In another matter, NAPG has asked the Wyoming Public Service Commission (WPSC) to require Cheyenne Light, Fuel and Power Co. (CLFP) to purchase power from the proposed 300-megawatt (MW) coal-waste-fired plant. NAPG claims that under federal rules regarding the Two Elk plant as a qualifying small-power producing facility, CLFP should be required to buy their power. The WPSC has in turn asked CLFP to file a research plan outlining how it intends to supply future power needs of its customers (U.S. Coal Review, 5/19/2003).

Peabody Energy announced that their North Antelope mine complex shipped a North American monthly record amount of coal in May, 2003. The company moved 7,076,658 short tons of coal from the mine complex, loading 476 unit-trains consisting of 60,113 coal cars. To put this in a layman's perspective, if you placed the trains end to end they would make a line approximately 625 miles long (U.S. Coal Review, 6/9/2003).

Developments in southern Wyoming

Bridger Coal Co. has tested a highwall miner configuration (**Figure 19**) at their Jim Bridger operation in Sweetwater County and reportedly is very pleased with the unit's performance and in-coal availability rates (a measure of its reliability and efficiency). The trial was to be completed sometime in late July and then results would be closely analyzed by the mine's engineering staff. Based on initial comments from Bridger mine employees during a recent Wyoming State Geological Survey (WSGS) mine visit, we expect to see much more highwall mining here. The highwall mining process allows for coal to be recovered that would be lost in a conventional surface-mining operation. No operators actually enter the workings, as the miner is operated remotely. Coal seams from 5 to 14 feet thick can be mined and the highwall miner can penetrate up to 1600 feet into the seam.

The WDEQ has started processing Arch of Wyoming's application for a permit to mine coal in Carbon County north of the town of Elk Mountain. The Carbon Basin mine permit was applied for in December, 2002 and covers 13,309 acres of land. The company believes that approximately 23.3 million short tons of recoverable coal is present at the mine site. The current mine plan calls for Arch to use both surface and underground mine methods to produce the coal. The coal reserves are in the Johnson seam, which is estimated to have the following as-received quality specifications: 11,255 Btus per pound, 9.7% moisture, 8.17% ash, and 0.57% sulfur (U.S. Coal Review, 3/3/2003).

The Wyoming Business Council has endorsed the reopening of the Stansbury mine (see *Wyoming Geo-notes No. 77*, June, 2003, p. 16), recommending that the State of Wyoming help fund what would become Wyoming's only active underground coal operation. New Stansbury Coal Co. has requested $12 million in State bonds to reopen the mine near Rock Springs. New Stansbury has signed a purchase and sale agreement with Rock Springs Royalty Co. for the mine. The company hopes that mining will begin by the fourth quarter of 2003 and be at full production of 3 million short tons per year within three years (U.S. Coal Review, 2/17/2003).

Anadarko Petroleum Co., the successor to Union Pacific Resources and Rocky Mountain Resources, is working to get the old Stansbury mine permit renewed. When that is accomplished, the permit then will be transferred to New Stansbury Coal Co. The two companies are hoping to have the permit ready for transfer by October, 2003 (U.S. Coal Review, 4/28/2003).

The Eastern Shoshone and Northern Arapaho Business Council has criticized the BLM's proposal to open the Jack

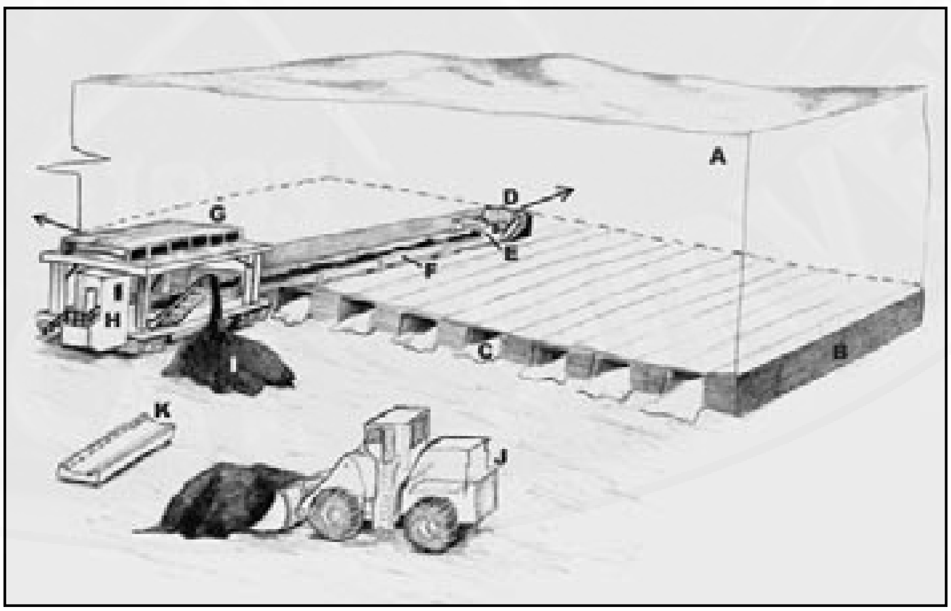

Figure 19. A 3-D perspective of the highwall mining system at the Jim Bridger mine. The face of the highwall (A), which can be up to 300 feet high, exposes a 10- to 14-foot-thick coal bed (B) and previous cuts (C) made by the system. The cutting head (D) on the continuous miner (E) shears coal as it advances into the coal bed. The mined coal is transported out of the mine via wheel-mounted conveyer cars (F) driven by the track-mounted highwall miner (G) which advances parallel to the mine face. At the operator's station (H), movement of the continuous miner is controlled remotely, and the mined coal (I) leaves the miner via conveyer and either loaded directly into coal haulers or stockpiled and then loaded later (J). Additional conveyer car sections (K) are added as the miner advances. Original pencil sketch by Nicholas R. Jones.

Morrows Hills to energy development which could include coal mining and coalbed methane (CBM) activities. The BLM wants to allow for 115 exploration wells and 90 development wells to be drilled in the area of their Jack Morrow Hills Coordinated Activity Plan. Along with several other groups, the Tribes have asked for complete closure of the area to oil and gas and mining exploration for the protection of wildlife, and preserving the area's historical and cultural wealth for the benefit of future generations. Complaints against the BLM include the Tribes' concern that there would be less protection for North American cultural and spiritual sites and that BLM would not provide the support necessary to study and identify these sites (U.S. Coal Review, 6/9/2003).

The BLM has initiated a review of their Kemmerer Resource Management Plan (RMP). The agency is calling for the submission of coal and other resource information as part of its review of the 1.4-million-acre region in Lincoln, Sweetwater, and Uinta counties. The BLM is seeking details about the interest in future areas of coal leasing along with substantiated coal data to help them address development potential during their RMP revision process (COAL Daily, 6/17/2003).

The BLM released an Environmental Assessment (EA) on a proposed reclamation plan for the abandoned Gebo-Crosby coal mining district in Washakie and Hot Springs counties. The EA recommendations were targeted to remedy hazards related to the five Priority 1 mine safety hazards located at the site, which is approximately 12 miles north of Thermopolis in the southern part of the Bighorn Basin Coal Field. After the proposed reclamation work, no Priority 1 sites would remain in the district. The plan also calls for the development, in coordination with the Wyoming State Historic Preservation Office (SHPO), of a plan for a multi-year program to enhance the public's understanding, awareness, and appreciation of the historical mining district. Toward this end, the plan would preserve important features related to historical coal mining on public lands, such as coal refuse piles, powder magazines, tipple and load-out features, concrete foundations, and housing structures. The plan also calls for the installation of two interpretive signs on the public land. One would be at the Miller Mine load-out (**Figure 20**), and the other at an overlook above the Gebo town site (Casper Star-Tribune, 5/11/2003).

Transportation developments

Wyoming Attorney General Pat Crank said he will not appeal the April 22, 2003 ruling by Federal Judge Alan Johnson that struck down Wyoming's coal transportation tax on railroads. The judge ruled that the tax, authorized by the 2000 Wyoming Legislature, violated the 1976 federal Railroad Revitalization and Regulatory Act. The tax would have generated from $6 to $7.5 million in revenue for the state (Coal Trader, 5/13/2003).

Rail transportation experts at the April, 2003 meeting of the National Coal Transportation Association's Rapid Response Team expressed concern that the PRB joint railroad line would be tested in the second half of this year. Increased demand is anticipated from traditional customers as well as new demand from eastern customers experiencing shortfalls in Central Appalachian coal production. Because many electric utility companies have waited until late in 2003 to begin moving large supplies of coal, "its not an absolute guarantee" that all of the coal needed will be delivered despite the significant investment to improve the rail structure in the area. The Wyoming PRB is heading for another record production year and we will soon see what the railroads can do (U.S. Coal Review, 4/28/2003).

The Dakota, Minnesota, & Eastern Railroad's (DM&E's) PRB expansion plan is being challenged in a federal appeals court. Environmental groups, businesses, and communities who have raised opposition to the project, stating fears of noise and traffic, claim that the EA was poorly done. The 8th Circuit Court of Appeals will hear arguments from lawyers for the federal Surface Transportation Board (STB). The lawyers will be defending the STB's EA and approval of the DM&E project. The Court of Appeals ruling on the matter is expected by the end of this year (Coal Outlook, 4/28/2003).

Entergy Services has acquired 120 Bethgon II coal gondola cars from Johnson America. The company will add the new 122-ton-capacity cars to their fleet of 3000 cars moving PRB coal to Entergy Arkansas' two 850 MW units and one Entergy-Gulf States' 400 MW unit (COAL Daily, 2/21/2003).

Regulatory developments

Some experts have expressed concern that new mercury regulations for the power generation sector may have a large negative effect on Wyoming's PRB coal industry. A study released by Hill & Associates shows utilization of coal from the PRB may fall by nearly 100 million short tons per year once the regulations take place in 2010. Representatives of

Figure 20. The abandoned coal loadout at the Miller Mine, ca. 1987. This structure, located west of the Gebo/Crosby mine area, is one of the few coal mining structures preserved in the area. Photograph by Richard W. Jones.

major Wyoming coal producers and the National Mining Association have told the EPA that PRB coals, which are low in mercury, should not be held to the same standards as those in other parts of the country. Some coal company officials have noted that the EPA is receptive to the idea of taking regional differences into account when setting guidelines. The small amounts of mercury in PRB coals are in elemental form and thus more difficult to remove from coal-fired power plants. In other coals around the nation, mercury is present as particulate and ionized species which are easier to remove. The EPA's draft mercury proposal is expected by the end of this year with the final rule due by December 15, 2004 (U.S. Coal Review, 4/28/2003).

By the end of the year, the State of Wyoming will have to choose the path it will take to comply with federal regional haze rules. It has the choice of submitting an implementation plan under either the "National rule" or under a "Grand Canyon rule" that is available for use by a group of western states. Under the National rule, the implementation plan would not have to be finished until 2007. Under the Grand Canyon rule, the State's implementation requirement would not have to be met until 2018. Regardless of the path taken, the State would have to prove that their plan is actually improving its seven Class One areas protected under the Regional Haze Rule (U.S. Coal Review, 6/30/2003).

Wyoming surface mine operators pay an AML tax of 35 cents per short ton on their produced coal. . .

The EPA, concerned about coal-dust releases in Campbell County, has decided not to intervene with more strict air quality controls. Instead, EPA is taking a wait-and-see approach as county and WDEQ officials get their local dust control plan into shape. County and coal company officials hope the State's improved dust control plan will prevent the federal government from implementing tougher regulations that could limit growth of the area's coal mining industry. In a related move, Campbell County has dedicated $2.2 million this year to road resurfacing and other improvements to address the dust issue (U.S. Coal Review, 4/21/2003).

The U.S. Department of Energy (DOE) has released its "Carbon Sequestration: Technology Roadmap and Program Plan." The 22-page roadmap indicates that DOE is placing more emphasis on measuring, monitoring, and verifying carbon capture and storage. The report is available at: www.netl.doe.gov/whatsnew/whatsnew.html (Coal Outlook, 3/24/2003).

In February of this year, the Bush Administration proposed a 14% cut in the Abandoned Mine Land (AML) reclamation program for fiscal year 2004. This would be the third straight reduction for the program, which is designed to clean up abandoned coal mine sites. Under the proposed budget, the U.S. Office of Surface Mining (OSM) spending for actual reclamation projects would be cut from $203 million to $174 million in 2004. An estimated $2.5 billion in high-priority AML cleanups are waiting for federal money. At the end of 2002, the AML trust fund had an unspent balance of $1.54 billion. Wyoming surface mine operators pay an AML tax of 35 cents per short ton on their produced coal (U.S. Coal Review, 2/10/2003).

The OSM released a special report entitled "Surface Coal Mining Reclamation: 25 years of progress, 1977-2002." The non-technical report provides case studies of successful reclamation projects, and includes abandoned mine land statistics. A copy of the report can be found at: www.osmre.gov/25th anniversaryreport.htm (COAL Daily, 5/12/2003).

The OSM in the first quarter of 2003 awarded funds to several states to aid them in regulating the surface effects of coal mining. The State of Wyoming received $10.98 million, North Dakota received $1.64 million, Colorado received $0.9 million, and Utah received $0.6 million (COAL Daily, 2/26/2003).

Senator Mike Enzi (Republican-Wyoming) and Senator Robert Byrd (Democrat-West Virginia) have worked out an agreement to transfer $34 million in AML trust fund interest into the federal Combined Benefit Fund Plan to maintain the health benefits of retired coal miners. This is aimed at a temporary solution for the Miner's Health Fund, which has slowly been going broke. The deal would protect the heath benefits of retired coal workers in the Senators' two states through September, 2004. The agreement is part of the Omnibus Appropriations Conference Report, a $396 billion spending bill that would fund all of the federal government (except for the Department of Defense) for fiscal year 2003 (U.S. Coal Review, 2/24/2003).

Legislation designed to change the Wyoming State Department of Revenue's method of valuing coal consumed at a power plant adjacent to a mine was defeated in the Wyoming State Legislature's House of Representatives by a vote of 50-9. The bill was crafted in an attempt to help define the value of coal not sold on the open market, but instead consumed by a power plant owned by the same company that owns the mine. This situation often results in a coal price lower than the current market value. Known as a captive mine or captive market situation, there are two such mines in Wyoming that would have been affected: the Jim Bridger mine in Sweetwater County and the Wyodak mine in Campbell County (U. S. Coal Review, 2/17/2003).

Market developments and opportunities

NRG Energy is planning to burn substantial volumes of PRB coal in New York, backing down their use of Northern Appalachian coal. Citing "superlative reductions in Nox," the power company is burning 80% or more PRB coal at their Dunkirk and Huntley generating stations (U.S. Coal Review, 6/9/2003).

Dynegy is moving their Wood River plant toward a 100% burn of PRB coal by the end of 2003. Having tested PRB coal over the past few years, the company is weaning the plant off Colorado and Illinois Basin coals that it has previously burned. The plant consumes about 160,000 short tons of coal per month (U.S. Coal Review, 1/20/2003).

Southern Co. announced that it would begin to shift two more of its coal-fired units at the Georgia Power's Scherer generating station to PRB coal this year. The two units had been using coal from sources in the Central Appalachian Coal Field. By 2004, the units are earmarked to burn 100% PRB coal. The plant's other two units are already fired by PRB coal (U.S. Coal Review, 2/3/2003).

The Powder River Basin Coal Users' Group selected Westar Energy's Jeffrey Energy Center (JEC) in northeastern Kansas as its 2002 PRB plant of the year. JEC was chosen due to its high standards of safety related to handling and burning PRB coal (U.S. Coal Review, 3/10/2003).

Holcim Cement is involved in discussions with PRB suppliers about possibly expanding the use of PRB coal at many of the company's U.S. cement plants. Holcim currently only burns PRB coal at its Trident, Montana plant. The key issue as to whether or not they expand the use of the low-sulfur coal seems to be logistics (U.S. Coal Review, 3/17/2003).

Ontario Power Generation is obtaining rail-delivered PRB coal as a hedge to ice-caused delays through the Great Lakes system. Because of this consideration, PRB coal supplies will continue to be an important component of their fuel mixture (U.S. Coal Review, 3/24/2003).

City Public Service of San Antonio is considering construction of a new coal-fired power plant. In preparation for future electricity needs of the area, the utility's planning department believes coal may be its best fuel option. Although no proposal has been brought forward, a target start-up date between 2009 and 2010 has been mentioned in-house (U.S. Coal Review, 4/28/2003).

Empire District Electric said they may test additional southern PRB coal in 2004 at their Asbury, Missouri plant. Last year, the plant envisioned going to 100% PRB coal by phasing out the non-PRB portion of their burn. Currently the plant's burn consists of coals from Wyoming's PRB plus some tonnage from Utah, Missouri, and Oklahoma (Coal Trader, 4/4/2003).

Table 15 tabulates some of the contract, spot sales, test burns, and solicitations for Wyoming coal announced during the first half of 2003.

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Table 15. Marketing activities for Wyoming coal producers during the first half of 2003*.

Utility	Power Plant	Coal Mine/Region	Activity	Tonnage	Comments
Alliant Energy	System	PRB	So	Up to 2 mt/y	Up to five years; delivery to begin in 2004
Ameren Energy	System	PRB	So	3 to 5 mt/y	Delivery to begin in 2004 for various periods of supplier's choosing for 1 to 7 years
Consumers Energy	Cobb	PRB	So	Up to 350,000 t	Delivery in 2003
FirstEnergy	System	PRB	So	0.5 to 2 mt/y	8,800 Btu/lb. for delivery through 2007
Fremont Department of Utilities	System	North Antelope/PRB	Sp	4 unit trains	Delivery in 2003
Grand River Dam Authority	System	Caballo/PRB	C	1.6 mt/y	Delivery to begin in 2004 for 8 years
Lansing Board of Water & Light	Eckert and Moores Park	PRB	Sp	335,000 t	Delivery in 4th quarter of 2003
Lansing Board of Water & Light	System	PRB	So	2.1 mt/y	Delivery to begin in 2004 for 3 years
LG&E Energy	Ghent	PRB	So	unspecified spot coal	Delivery in 2003 and 2004
Lower Colorado River Authority	Fayette Power Project	PRB	Sp	750,000 t	Delivery in 2003
MidAmerican Energy	System	PRB	So	1 mt	Delivery in 2004
Northern Indiana Public Service	Michigan City & Schahfer	Kennecott/PRB	C	3 mt/y	Delivery to begin in 2003 for 3 years
Omaha Public Power District	North Omaha & Nebraska City	PRB	So	2.5 mt/y	Delivery to begin in 2004 over 5 years
Portland General Electric	Boardman	Buckskin/PRB	Sp	Up to 2.3 mt	Delivery in 2004
Southern Company	Scherer	Kennecott/PRB	C	7 mt	Delivery to begin in 2003 over 3 years
Southern Company	Scherer	PRB	So	Up to 1 mt/y	Delivery in 2003
Southern Company	Scherer	PRB	So	Up to 3 mt/y	Delivery in 2004
Southern Company	Scherer	PRB	So	Up to 3 mt/y	Delivery to begin in 2004 through 2006
Springfield City Utilities	Springfield (MO)	Peabody Energy/PRB	C	1.5 mt/y	Delivery to begin in 1st quarter of 2003 for 3 years
Tennessee Valley Authority	System	PRB	So	8 mt/y	8,800 Btu/lb. and 0.8 lb. SO_2/mm Btu for up to 10 years
Texas Genco	Limestone	PRB	So	560,000 t	Delivery in 2003
Texas Municipal Power Agency	Gibbons Creek	PRB	So	Up to 2 mt/y	Delivery to begin in 2004 for five years
Western Fuels Association	Basin Electric	PRB	So	1 to 1.5 mt/y	Delivery to begin in 2004 for 3 years
Western Fuels Association	Laramie River	PRB	So	3.5 mt	Delivery from 2004 to 2006
Western Fuels Association	Quindaro	Jacobs Ranch/PRB	Sp	5 unit trains	Purchased thrugh Kennicott Direct and DTE Coal Services
Wisconsin Electric Power Corp.	Oak Creek	Peabody Energy/PRB	C	3 to 3.5 mt/y	3 to 5 years beginning in 2004
Wisconsin Electric Power Corp.	Presque Isle	Kennecott/PRB	C	1.25 mt/y	3 to 5 years beginning in 2004

*Data obtained from: Coal Outlook, COAL Daily, U.S. Coal Review, FERC database, and personal contacts. Note: Btu = British Thermal Units; C = contract; lb. = pound; mm = million; mt = million short tons; mt/y = million short tons per year; PRB = Powder River Basin; Sp = spot coal; So = solicitation; and t = short tons. *Wyoming State Geological Survey, Coal Section, August, 2003.*

Coalbed Methane Update

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Coalbed methane (CBM) production in Wyoming for the first half of 2003 was 169.7 billion cubic feet (BCF), with all but 0.9 BCF from the Powder River Basin (PRB) Coal Field. Almost one-fifth of Wyoming's natural gas production is now from CBM wells. Because of delays in permitting CBM wells on federal leases, there has been a large decline in applications for permit to drill in Wyoming during the last year and a half when compared to 2001. This has had an effect on CBM production rates, which have fallen nearly every month since December, 2002. Besides the resumption of permitting for new projects in the PRB (that occurred in July, 2003), a number of CBM exploration projects for southern Wyoming coal fields were announced in the second half of 2003, including projects in the Great Divide, Washakie, Hanna, and Green River basins.

Production and drilling

CBM production reported by the Wyoming Oil and Gas Conservation Commission for the first six months of 2003 was 169.7 BCF (**Table 16**). Although nearly all of this CBM production was from the PRB, 0.9 BCF came from other areas of the state. The total CBM production from the PRB was 19.1% of Wyoming's total natural gas production for the first six months of 2003, and all CBM production in the state made up 19.2% of the total. There were 11,158 producing wells and 3140 shut-in wells in June of 2003, compared to 10,974 producing wells and 3405 shut-in wells in January of 2003. CBM production rates have declined every month since peaking in November, 2002 when production averaged slightly more than 970 million cubic feet (MMCF) per day. In June, 2003, the average production rate was around 920 MMCF per day.

Dudley & Associates LLC. plans to drill up to 1240 CBM wells on up to 785 well pad sites about 15 miles north of Sinclair, Wyoming

The slowdown in production rates was primarily due to no new drilling permits being issued by the U.S. Bureau of Land Management (BLM) because of the hold up in the issuance of the record of decision (ROD) for the environmental impact statement (EIS). The ROD was eventually submitted in early May, 2003; the BLM resumed permitting on July 14, 2003; and permits were issued for the drilling of 121 new CBM wells by August 20, 2003.

Activities

The BLM approved an exploratory CBM pilot project proposed by Kennedy Oil in Ts24 and 25N, R98W (**location A, Figure 13**) approximately 35 miles north-

Table 16. Monthly and cumulative Wyoming coalbed methane production[1] in MCF[2] (1999 through June, 2003).

	1999		2000		2001		2002		2003	
	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative
January	3,660,434	3,660,434	8,461,780	8,461,780	18,201,908	18,201,908	25,565,938	25,565,938	29,572,337	29,572,337
February	3,462,685	7,123,119	8,706,458	17,168,238	16,892,486	35,094,394	23,307,520	48,873,458	26,454,713	56,027,050
March	4,110,431	11,233,550	9,872,362	27,040,600	19,707,066	54,801,460	25,906,264	74,779,722	29,035,427	85,062,477
April	4,040,989	15,274,539	10,565,807	37,606,407	19,541,037	74,342,497	25,261,800	100,041,522	28,098,995	113,161,472
May	4,422,581	19,697,120	11,831,227	49,437,634	20,620,560	94,963,057	27,147,588	127,189,110	28,835,574	141,997,046
June	4,605,167	24,302,287	12,199,486	61,637,120	20,411,571	115,374,628	26,315,894	153,505,004	27,678,437	169,675,483
July	4,877,924	29,180,211	13,024,856	74,661,976	21,418,942	136,793,570	28,123,520	181,628,524		
August	4,793,060	33,973,271	14,180,161	88,842,137	22,250,477	159,044,047	28,844,705	210,473,229		
September	5,125,811	39,099,082	14,390,965	103,233,102	21,550,038	180,594,085	28,451,541	238,924,770		
October	5,961,192	45,060,274	15,393,978	118,627,080	23,996,891	204,590,976	29,474,971	268,399,741		
November	5,947,893	51,008,167	15,220,163	133,847,243	23,768,106	228,359,082	29,183,514	297,583,255		
December	7,180,697	58,188,864	16,852,924	150,700,167	25,622,941	253,982,023	29,876,270	327,459,525		
Total		**58,188,864**		**150,700,167**		**253,982,023**		**327,459,525**		

[1]Data from the Wyoming Oil and Gas Conservation Commission. Totals for 2002 now include production in the Powder River Coal Field plus production from other fields in Wyoming. [2]MCF=thousands of cubic feet. *Wyoming State Geological Survey, August, 2003.*

west of Wamsutter. The Lower Bush Creek Coal Bed Methane Exploratory Pilot Project is designed to evaluate coal zones in the Fort Union Formation using 10 exploratory wells with 160-acre spacing on each of two pods.

Patina Oil & Gas Corp. proposes development of three exploratory CBM pilot projects of five wells each in the Pappy Draw area 40 to 50 miles northwest of Rawlins. The company notified the BLM of its plans to explore in T26N, R93W; T27N, R93W; and T26N, R92W (**location B, Figure 13**). The projects are designed to evaluate the quantity of methane in Fort Union coals, the permeability and productivity of the coals, the quality of the coals and the water, the quantity of water, and the dewatering characteristics of the coals. Patina plans to core the target coal seam in the first well drilled in each pilot project.

. . .plans to allow CBM development in the Jack Morrow Hills area are under protest. This area contains nearly 3 trillion cubic feet (TCF) of CBM. . .

Dudley & Associates LLC. plans to drill up to 1240 CBM wells on up to 785 well pad sites about 15 miles north of Sinclair, Wyoming (**location C, Figure 13**). The Seminoe Road Project EIS analysis area covers about 137,000 acres and involves a checkerboard land ownership of mainly private and federal. Associated facilities include roads, gas and water collection pipelines, compressor stations, water disposal systems, and a power supply system. The targeted coals are the shallower coals in the Medicine Bow Formation and Fox Hills Sandstone and the deeper coals in the Mesaverde Group. Dudley originally drilled 16 wells for a pilot project in 2001 and is beginning to see small amounts of gas from many of those wells. The analysis of natural gas from the pilot project indicates that there will be no need for nitrogen or carbon dioxide extraction facilities. Dudley plans to initiate field development in 2004 or as soon as possible once National Environmental Protection Act (NEPA) analyses are completed and local, state, and federal regulations are satisfied. Field development of the Mesaverde coals is expected to take six to eight years with secondary objectives in the Medicine Bow and Fox Hills requiring another three to four years.

Yates Petroleum Corp. plans to drill four CBM tests in Mesaverde Group coals approximately 30 miles southeast of Rock Springs in T18N, R99W (**location D, Figure 13**). Yates also has plans to drill five additional Mesaverde tests 2 1/2 miles to the northwest on its Bicycle lease, which is 1 mile east of Infinity Inc.'s Pipeline CBM project.

Double Eagle Petroleum Co. increased its production for the first quarter of 2003 partly as a result of successful drilling of CBM wells in the Cow Creek Field of T16N, R92W (**location E, Figure 13**). The company plans to drill five additional CBM wells in the field in 2003.

Infinity Oil & Gas and Williams Production RMT are planning a drilling program in the South Piney area about 10 to 16 miles west of Big Piney, Wyoming (**location F, Figure 13**). The companies want to drill from 100 to 210 natural gas wells in the project area. Infinity will drill wells to a maximum depth of 5000 feet to test interbedded coals in the Mesaverde Formation; Williams will be drilling wells to a maximum depth of 10,000 feet to test the Frontier Formation's potential.

As mentioned in the **Coal Update** (above), plans to allow CBM development in the Jack Morrow Hills area are under protest. This area contains nearly 3 trillion cubic feet (TCF) of CBM that could be recovered from Tertiary and Upper Cretaceous coal beds (Cook and others, 2002).

Western Gas Resources added net natural gas reserves of 64 BCF during 2002. The company controls about 515,000 net acres in the PRB CBM play; the majority of Western's proved reserves of 588 BCF are in that basin. The company drilled 909 gross CBM wells in 2002 with a success rate of 98%.

Regulatory issues

The BLM's Wyoming and Montana state offices concurrently issued RODs regarding oil and gas (particularly CBM) development in the PRB of both states. The ROD comes at the end of a three-year process that started with an EIS that analyzed exploration and development of oil and gas (including CBM) in the basin and the anticipated impacts and environmental consequences. The EIS updated the scope and analysis of effects of oil and gas development originally presented in the 1985 Buffalo and Platte River Resource Management Plans. The BLM's reasonable foreseeable development scenario for the area forecasts the drilling of up to 51,000 CBM wells over the next 10 years. About 25 TCF of CBM may be recoverable in the Wyoming part of the basin, according to the BLM.

Key elements in BLM's preferred alternative in the PRB EIS include the use of compressors powered by natural gas and an emphasis on infiltration for water handling. The BLM once again began issuing permits to drill for CBM in the PRB on July 14, 2003 and had issued 121 such permits by August 20. The BLM revised its guidebook on how to prepare applications for permit to drill and plans of development for coal bed natural gas wells, which is available online at http://www.wy.blm.gov/bfo/.

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Industrial Minerals and Uranium Update

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Production of the major industrial minerals in Wyoming remained mostly steady in the first half of 2003, continuing as it did in 2002. Wyoming's only dimensional stone quarrier, Raven Quarries, ceased operations. A major glass manufacturer, Owens-Illinois (O-I), announced that it had received a contract from Budweiser to construct a plant to manufacture beer bottles near Budweiser's brewery north of Fort Collins, Colorado. Owens-Illinois will contract for a silica sand source and may prefer one nearby.

Wyoming maintained its national ranking of 15^{th} in the value of nonfuel minerals produced in the state in 2001. It ranked first in per capita production of nonfuel minerals (U.S. Geological Survey, 2003). The major nonfuel minerals produced in the state in order of value are trona, bentonite, helium, limestone reported as cement (U.S. Geological Survey, 2003), construction aggregate, and gypsum.

Uranium continues to be produced at two *in situ* localities in Wyoming. The price of yellowcake increased from $9.90 per pound at the end of the fourth quarter of 2002 to $10.90 per pound at the end of the second quarter of 2003.

> **Raven Quarries ceased production of Mirage® and Wyoming Raven® stone and abandoned their operations. . .in northern Albany County.**

Bentonite

Bentonite production in the first half of 2003 continued at a level about the same as in 2002. Seven companies operate thirteen plants in Wyoming (**Figure 21**). At each operation, bentonite of different properties is mined from separate pits and hauled to a mill, where it is blended (if necessary) into products of consistent quality. Because the natural weathering process is important in the quality and characteristics of the bentonite, many pits remain inactive for a number of years before the bentonite is finally taken to the mill.

Construction aggregate

Construction aggregate production in Wyoming is mainly seasonal and peaks during the summer highway and outdoor structure construction season. Construction during the summer of 2003 seemed strong, so the production of construction aggregate should remain high for 2003.

Decorative and dimensional stone

Raven Quarries ceased production of Mirage® and Wyoming Raven® stone and abandoned their operations at the quarry on the Vale Ranch in northern Albany County (**Figure 21**). The owner, Toby SerVoss, is locating and selling fieldstone and moss rock as an independent operator. According to SerVoss, the quarry site is for sale. Wyoming is again without dimensional stone production.

Vermont Quarries has not yet conducted exploration for dimensional stone this year, except for the drilling of two test holes in the Blue Eyes anorthosite northeast of Laramie in Albany County (**Figure 21**) in early January. Due to inclement weather, only 15 feet of core were recovered. Vermont is bidding on a government contract to supply white marble for military tombstones and is concentrating on that project. Vermont maintains an interest in the Blue Eyes deposit and other projects for the future.

Cumberland Gap Hearthstone operates a flagstone and fieldstone quarry south of Kemmerer in Lincoln County (**Figures 21** and **22**). Over 50 people were employed by Cumberland in 2002. This year, less than ten are working at the company due to permitting uncertainties for quarry expansion. However, the stone produced continues to enjoy a large market and steady sales. Cumberland quarries a sandstone in the upper part of the Frontier Formation.

The market for moss rock, flagstone, and fieldstone remains strong. These products from Wyoming are sold regionally to markets along the Wasatch front of Utah, the Front Range, and developing ski towns of Colorado. Also, some stone has been sold as far away as California and Chicago. There are about 12 producers in Wyoming as of summer, 2003.

Silica sand

Silica sand is the primary ingredient in the manufacture of glass. Soda ash, the primary product refined from Wyoming's natural trona deposits (see below) is the second ingredient. Silica sand occurs as high-silica (SiO_2) sandstone or windblown or beach sand deposits. In Wyoming, sandstones in the Cretaceous Cloverly Formation in northern Platte County (Harris, 1988b) (**Figures 21** and **23**) and the Pennsylvanian Casper Formation in central Albany County (Harris, 1988a) (**Figure 21**) may qualify as silica sand. So far, Wyoming's extensive sand dune fields have not been found to contain silica in sufficient grades. Other factors such as the presence of certain impurities (especially chromium) and grain

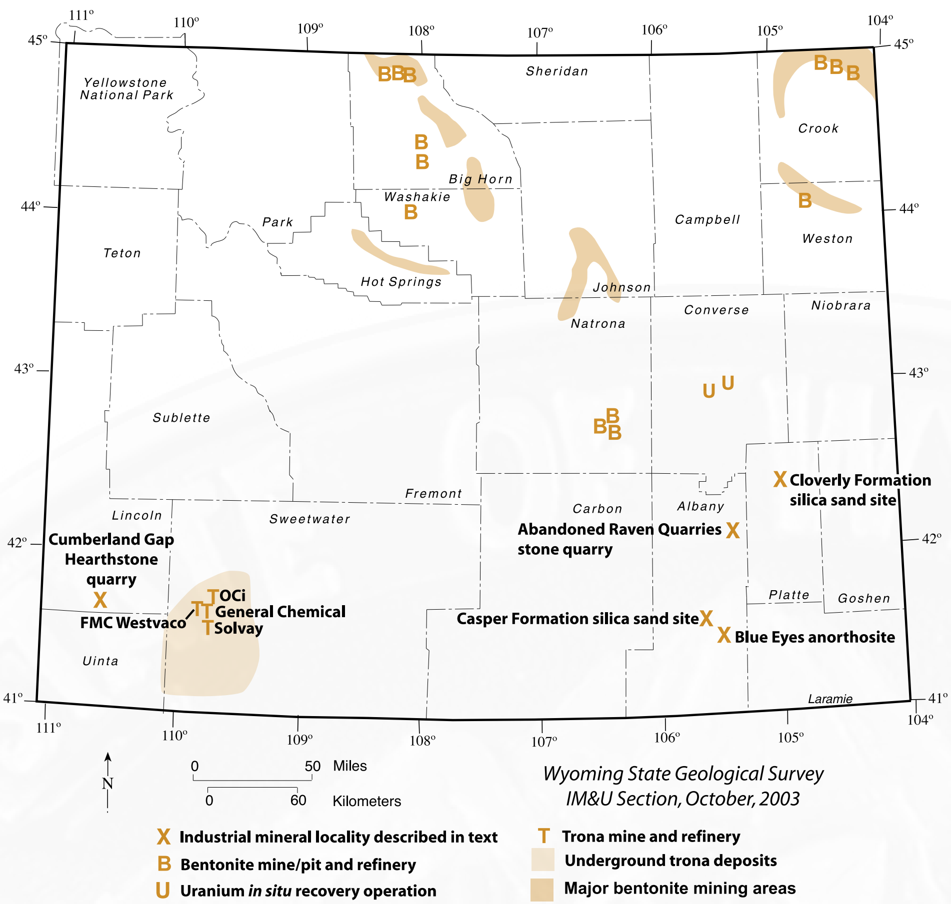

Figure 21. Index map of Wyoming showing the location of industrial mineral sites, selected mining areas, and uranium sites mentioned in the text. Locations are approximate and may represent more than one site.

size distribution affect a particular sandstone's use in glass manufacture.

In early 2003, O-I, a major manufacturer of glass, announced that it had obtained a contract with Budweiser to manufacture beer bottles for Budweiser's brewery north of Fort Collins, Colorado. O-I has selected a site in Windsor, Colorado. It has been reported that O-I was going to request a local source for silica sand. Inquiries have been received by the Industrial Minerals and Uranium Section of the Wyoming State Geological Survey from glass manufacturers and others regarding silica sand sources in Wyoming. This interest should continue regardless of when O-I begins plant design and construction, and announces specifications for raw material sources. Wyoming's trona industry should benefit from the construction of this plant, as most of the nation's major soda as manufacturers are in southwestern Wyoming. O-I would like to complete the bottle plant by mid-year 2005.

Trona

Trona is mined in Wyoming at four underground mines and refined into soda ash and other sodium compounds at mine-mouth plants. Four companies (FMC, General Chemical Soda Ash Partners, OCi, and Solvay Minerals) operate the mines and refining plants (**Figure 21**). FMC closed their trona mine and soda ash refining plant at the Granger site in late 2002. They continue to keep the mine accessible for possible reopening, but by mid-year 2003, had not made a decision regarding permanent closure. FMC operates the larger mine and refining plant at Westvaco.

Trona mining and soda ash production in Wyoming in 2003 should be slightly more than that in 2002. According to the State of Wyoming's Consensus Revenue Estimating Group (CREG) report released in October, 2003, actual trona production of 17.2 million short tons in 2002 (**Table 1**) was slightly less than the 17.6 million short tons forecast last year (see *Wyoming Geo-notes No. 77*, June, 2003, Table 1). Trona production in April and May, 2003 was slightly more than for the same period in 2002, according to the U.S. Geological Survey (Kostick, 2003),

Figure 22. Cumberland Gap Hearthstone quarry in sandstones of the upper Frontier Formation, Lincoln County, Wyoming.

Figure 23. Outcrop of the silica sand zone in the Lower Cretaceous Cloverly Formation, Platte County, Wyoming.

and should help attain the 18 million short tons predicted for this year by CREG.

The CREG forecast for the price of mined trona changed only slightly from last year's forecast (see *Wyoming Geo-notes No. 77*, June, 2003, Table 2), with the actual price of mined trona for 2002 remaining as predicted at $38.00 per short ton. CREG predicts that the price will then drop slightly to $37.50 per short ton from 2003 through 2008 (**Table 2**).

Solvay began operating a longwall mining system early in 2003. Solvay joins FMC Westvaco in operating a longwall. In this method, trona is continuously removed from a face several hundred feet wide. The unit advances towards the face, supporting the roof near the face with hydraulic covers. Following the passage of the longwall, the roof is allowed to collapse behind it. This method results in a higher rate of recovery than other methods of mining. All four producers also mine by a room-and-pillar method using conventional mining equipment and one producer operates an *in situ* operation to recover trona from abandoned mine workings.

Uranium

The spot market price of yellowcake (oxidized uranium—the product of Wyoming's uranium mills) increased during the first half of 2003 from $9.90 per pound of yellowcake to $10.90 per pound, according to the Ux Consulting Company, LLC., The Uranium Exchange Company: (http://www.uxc.com/review/uxc_prices.html), and the Rocky Mountain Minerals Scout. Yellowcake is uranium oxide with a varying amount of other elements, having no definite chemical formula.

Uranium is produced in Wyoming at two *in situ* recovery sites, Smith Ranch and Highland/Morton Ranch by Power Resources, a subsidiary of CAMECO (**Figure 21**). CAMECO, of Saskatoon, Saskatchewan, also owns the only other current uranium production in the U.S. at Crow Butte, Nebraska. The new CREG forecast released in October, 2003 shows that 1.4 million pounds of yellowcake will be produced in Wyoming in 2003 and beyond (**Table 1**), slightly less than predicted last year by CREG.

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Metals and Precious Stones Update

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During this field season, Wayne M. Sutherland and W. Dan Hausel of the Metals and Precious Stones Section of the Wyoming State Geological Survey (WSGS) continued to compile a geologic map of the Saratoga 1:100,000-scale Quadrangle as part of a STATEMAP 2003 project. Much of the previous geologic mapping on this quadrangle was completed by Robert Houston, Karl Karlstrom, and Paul Graff while they were at the University of Wyoming. This area is significant not only because it provides geologists with a model for cratonic boundaries, but it also has excellent potential for the discovery of commercial gemstone and base-, precious-, and strategic-metal deposits.

Interest in colored gemstones continued in 2003 with the WSGS identifying several regions having potential for discovery of colored gemstones, based on geology. One Atlanta-based company was investigating the possibility of exploring for new deposits, testing old deposits, and marketing the colored gemstones. Diamonds were on the agenda of the 8th International Kimberlite Conference. The WSGS took part in a field trip to the kimberlites and lamproites of Colorado and Wyoming. The attendees all recognized the untapped diamond potential of the Wyoming province and some announced plans to budget for exploration in this region for next year. Precious metals continued to attract interest in Wyoming. A group of deposits that potentially could host a million ounce+ gold resource has been identified.

During the past fiscal year, the Metals and Precious Stones Section, which consists of the author (Hausel) and a part-time contract geologist, responded to more than 1300 inquiries in the office. Hausel also lectured and led field trips for several groups resulting in at least 1400 additional contacts. During the past year, (September, 2002 through September, 2003) the Section's homepage on the WSGS web site has averaged 2462 hits per month.

Precious metals

Wyoming has several potentially economic gold deposits. These are found at South Pass, Rattlesnake Hills, Copper King, Dickie Springs-Oregon Gulch, Bear Lodge Mountains, Mineral Hill, Seminoe Mountains, Douglas Creek, Purgatory Gulch, and others (Hausel, 1989). Based on geological models, others remain to be discovered. In addition, economic silver deposits were identified in the Kirwin district (Absaroka Mountains) by AMAX nearly three decades ago.

Gold continued to attract attention in the first half of 2003. A few deposits have been reported with potential to host a million-ounce gold resource. The Carissa gold mine at South Pass potentially hosts more than 1 million ounces of unmined gold. The Copper King mine west of Cheyenne has a drilled resource of 770,000 ounces of gold with some copper (estimated gold-equivalent resource of 1 million ounces). The Sandy Mountain prospect in the Rattlesnake Hills continued to attract interest as a probable million-ounce+ resource, where gold has been identified associated with a breccia.

South Pass

Historically, South Pass was Wyoming's principal gold district, and based on earlier mapping by the WSGS, the geology of the district suggests a good possibility for discovering several major gold deposits. Mapping by the WSGS in the 1980s showed favorable conditions for the presence of several hidden gold deposits along a well-defined lithologic and structural zone running from South Pass City to Miners Delight (Hausel, 1991).

Through a sale to the State of Wyoming, the Carissa gold mine at South Pass is scheduled to be incorporated into the South Pass City historic site. Historically, the Carissa was Wyoming's largest gold producer and the data indicate that the ore body still contains considerable gold resources. Past work had identified significant gold resources within and below the mine workings. In addition, preliminary sampling by the WSGS identified a major unevaluated shear zone (as much as 1000 feet wide) enclosing the mine workings that could potentially host significant gold resources.

Copper King mine, Silver Crown district

The WSGS mapped this mine (Hausel and Jones, 1982a; Hausel, 1997) and described a large-tonnage, low-grade gold-copper porphyry. Drilling by several companies (including the U.S. Bureau of Mines) confirmed a large-tonnage ore deposit. More than 80 drill holes on the property identified an *in situ* resource of 770,000 ounces of gold with associated copper values. Mineralization open in at least two directions suggested the resource could be increased with additional drilling. A gold mining company leased the property from the State of Wyoming in 2003.

Rattlesnake Hills

Gold was initially identified in the Rattlesnake Hills by the WSGS (Hausel and Jones, 1982b). Follow-up work in the district led to the discovery of dozens of additional gold anomalies by the WSGS, American Copper and Nickel Company, Canyon Resources, and Newmont Gold Company (Hausel, 1996). During the past year, the WSGS received several inquiries on the Rattlesnake Hills.

The available drill data suggests one of the gold anomalies in the district may enclose an *in situ* resource of more than 1 million ounces (Dave Miller, personal communication; Hausel and others, 2000). Near the end of 2003, Bald Mountain Mining Company reported that they had leased the Sandy Mountain-Antelope Basin disseminated gold prospect.

Encampment district

A significant gold anomaly was identified by the WSGS in the Purgatory Gulch area of the Encampment district, Sierra Madre, 15 years ago (Hausel, 1988). Quartz specimens with visible gold were found in Purgatory Gulch (Hausel, 1992). One company initiated exploration in this region during 2003.

Dickie Springs-Oregon Gulch

Work by the U.S. Geological Survey (USGS) in the Dickie Springs-Oregon Gulch and Twin Creek paleoplacers, located along the margin of South Pass, indicated that at least two major (possibly world-class) hidden gold deposits exist in those areas. The USGS estimated that the Dickie Springs-Oregon Gulch paleoplacer could host as much as 28.5 million ounces ($10 billion resource) of gold (Love and others, 1978). Hecla Mining Company had identified a distinct magnetic – Induced Polarization (IP) anomaly in the immediate region of the gold paleoplacer, suggesting a source adjacent (and at depth) to the paleoplacer. Hecla's interpretation of their data was that the anomaly was generated from a Homestake-type deposit and could potentially represent a world-class gold deposit based on the size of the anomaly and the amount of gold in the adjacent paleoplacer.

Other inquiries

During the year, several other inquiries were received from geological consultants and prospectors looking for information on gold in Wyoming. A few of the companies included Eleven Point Exploration, Norwest, Bald Mountain Mining, Paso Rico Resources, Nevada Contact, and Nevada Pacific Gold. The latter company indicated that the Canadian market is favorable for companies to search for gold in the U.S.

Platinum group metals

Wyoming is one of only a few states in the U.S. with potential for the discovery of significant platinum-group metals (PGMs). An overview on the state's potential for PGMs was published by the WSGS (Hausel, 2000) and placed on the WSGS website (http://wsgsweb.uwyo.edu/metals/platinum.asp). Areas of highest potential include Lake Owen, Mullen Creek, Puzzler Hill, Wood Mountain, and Blackhall Mountain, all located within the Medicine Bow Mountains and Sierra Madre. A few small peridotite bodies within the

Laramie Range may also host some PGMs, but occurrences in these peridotites would be limited in size. The layered complexes in the Medicine Bow and Sierra Madre Mountains rival the Stillwater, Montana complex in size.

Encampment Resources is exploring two target zones for PGMs in Wyoming. In the southern Medicine Bow Mountains, conductors were identified beneath 100 feet of gravel cover and the company planned to drill the target. A second target to the west contained highly anomalous PGMs in a zone from 16 to 70 feet wide. The company trenched the latter anomaly in the past year and identified mineralized zones within layered (and apparently hydrothermally altered) gabbro. Nearby, they sampled two abandoned mines driven into a magnetite gabbro. Samples from the mines yielded anomalous platinum, gold, and copper.

It should be noted that in addition to PGMs, the rock types in the Medicine Bow Mountains and Sierra Madre may host significant resources in other strategic metals, including chromium, titanium, iron, vanadium, and nickel.

Barnhart Drilling recently contacted the WSGS and indicated that they have found a series of breccia pipes near Riverton that intrude Tertiary sedimentary rocks.

Diamonds

During the past several years, the WSGS identified more than 300 targets for diamond exploration. Most of the targets have never been examined except for recovering nearby kimberlitic indicator minerals (and/or diamond stability minerals) panned from stream sediments. The data collected to date implies that the Wyoming craton is highly anomalous and has been intruded numerous times by kimberlites, lamproites, and lamprophyres, all potential host rocks for diamond. Mineralogical, geochemical, geophysical, geological, and remote sensing data generated by the WSGS and others all indicate major geologic events that led up to the intrusion of these rocks in Wyoming. In one study by the WSGS, more than 300 of 1600 stream sediment-samples (19%) contained kimberlitic indicator minerals.

Only a few of these samples were ever tested for chemistry, but those that were tested provided a high ratio of diamond-stability to graphite-stability indicator minerals. In other words, the physical data indicates the presence of several undiscovered diamond pipes in Wyoming, and only a very small percentage of Wyoming has been explored for diamonds! Only about $100,000 has been spent by the WSGS exploring for diamonds in Wyoming over 20 years. For comparison, more than $1 billion has been spent in exploration and development of diamond deposits in Canada.

It is important to realize that these indicator minerals, collected in streams from the Laramie, Medicine Bow, Sierra Madre, and Seminoe mountains, were eroded from hidden kimberlites (or related mantle-derived rocks) and provide physical evidence for a major swarm of potentially diamondiferous host rocks. In addition, various companies and prospectors have identified similar kimberlitic indicator mineral anomalies in the Greater Green River Basin, Hartville uplift, Owl Creek Mountains, and Bighorn Mountains. The WSGS also identified a wide spread indicator mineral anomaly in the southern Bighorn Basin. Diamonds have been reported in the Powder River and Wind River basins, Granite Mountains, Sierra Madre, and Gros Ventre Range in addition to the known diamond occurrences in the Greater Green River Basin and Medicine Bow and Laramie mountains. Wyoming hosts the two largest kimberlite districts in the U.S. (both of which have yielded diamonds) and the largest lamproite field in North America, where work by the WSGS indicates some potential for diamonds in the Leucite Hills near Rock Springs (Hausel, in preparation).

Mapping and sampling in the Iron Mountain kimberlite district 45 miles north of Cheyenne showed it to be the second largest field of kimberlites in the U.S. (Hausel and others, 2003). The report suggested a high probability for discovering additional kimberlites along the northern edge of the district (which remains unmapped for kimberlites) as well as in the Indian Guide area 5 to 10 miles to the west. It is probable that buried kimberlite exists within the mapped area. Undiscovered kimberlite probably exists immediately north of the mapped area. Geochemical data show that many Iron Mountain kimberlites have similar diamond potential to kimberlites in the State Line district to the south.

This summer, the WSGS completed a grid magnetic survey over the IG-3 diamondiferous kimberlite pipe at Iron Mountain to determine the potential size of this pipe. Data from this survey are still being analyzed. A sample collected from this pipe by Cominco American Inc. in the early 1980s yielded a 0.3-carat octahedral diamond (Howard Coopersmith, personal communication).

In June, the Metals and Precious Stones Section assisted in a field trip for a group of diamond company geologists during the 8th International Kimberlite Conference (Coopersmith and others, 2003). The overall consensus from field conference attendees was that Wyoming is amazingly unexplored for diamonds, and that road access is incredibly easy compared to diamond areas in Canada.

Barnhart Drilling recently contacted the WSGS and indicated that they have found a series of breccia pipes near Riverton that intrude Tertiary sedimentary rocks. Samples were sent to the WSGS for examination and are now being prepared.

The Kelsey Lake mine in the Colorado part of the State Line district recently installed new crushers and an x-ray Sortex® diamond sorter, and they predicted recovery of larger diamonds in the near future. This is based on both sampling the tailings from earlier mining, which shows that about 40% of the diamonds were rejected by the old mill, and the recovery of an octahedral fragment from an estimated 80-carat diamond (Howard Coopersmith, personal communication, 2003).

Colored gemstones

Research by the WSGS over the past decade has resulted in several discoveries of colored gemstones, some of which were described by Hausel and Sutherland (2000) and on the WSGS website (http://wsgsweb.uwyo.edu/metals/gemstones.asp).

One of the more significant discoveries was made by the WSGS in Palmer Canyon west of Wheatland (Hausel, 2002a, 2002b). This deposit was claimed by Eagle-Hawk Mining and has produced some attractive sapphire and iolite gemstones. The geology of the area suggests that similar deposits will be found elsewhere in the state. Currently, the WSGS is attempting to gain access to the Owen Creek, Grizzly Creek, Elk Park, and Horse Creek areas to search for similar occurrences, and is also looking in the Granite Mountains.

Recently, a company from Atlanta initiated discussions with the WSGS to examine colored gemstone markets. Their analysis indicates that Wyoming iolites have a very good potential to corner the market for iolite gemstones of more than one carat. The WSGS has already found iolite gemstones in the 1000- to 3000-carat range at Palmer Canyon. State leases for colored gemstones were taken by the company based on reports by the WSGS.

During the past year, the WSGS sent some Wyoming gemstones to be faceted. These included peridot, pyrope garnet, ruby, opal, and a few other stones. Photographs of many of the specimens were placed on the Section's website at http://wsgsweb.uwyo.edu/metals/gemstones.asp.

Eagle-Hawk Mining cut more Palmer Canyon sapphires and iolites during 2003. The finished stones included a pinkish-red 2.5-carat sapphire and a 3.5-carat ruby. Some other cut stones included a pinkish-brown sapphire cabochon (1.4 carat), a reddish pink sapphire marquise (1.1 carat), three deep-blue iolites (0.5, 1.0, and 1.49 carats), and two large faceted cordierites (3.4 and 3.9 carats).

The WSGS examined an opal discovery in central Wyoming in the first half of 2003. It appears there could be several thousand tonnes of common opal exposed in the White River Formation, and the WSGS hopes to investigate the property in the future to search for possible precious opal. The opal occurs in nodules ranging from inches to boulders that are a few feet in diameter. Several opals were cut into cabochons and produced some nice semi-precious stones.

During mapping of the Barlow Gap 1:24,000-scale Quadrangle along the southern margin of the Rattlesnake Hills, Wayne Sutherland of the WSGS identified a large jasperoid area (about 10 acres) in the Wagon Bed Formation (Sutherland and Hausel, 1999). Barnhart Drilling from Riverton filed claims on the jasperoid.

Other news

During the past year, the section completed 22 papers for publication—nearly all were submitted to outside publishers. In addition, the section presented 23 talks and led a group of field trips during the past year. In total, W. Dan Hausel has now presented more than 300 lectures on minerals and Wyoming geology. For contributions to the advancement of knowledge of Wyoming geology and mineral resources, Hausel was recognized by some international institutions during the year including: the International Biographical Center's 1st Edition of *Living Science*, the 58th Edition of *Who's Who in America*, the 7th Edition of *Who's Who in Science and Engineering*, and the 21st Edition of *Who's Who in the World*.

Under the STATEMAP 2004 program proposed by the WSGS, the Section will apply for funds to map the Rock River 1:100,000-scale Quadrangle in the Laramie Mountains. Hausel is currently working on a Geology of Gemstone Deposits book as well as chapters on colored gemstones and diamond for a book to be published by the Society of Mining Engineers.

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GEOLOGIC MAPPING AND HAZARDS UPDATE

Geologic Mapping, Paleontology, and Stratigraphy Update

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The Wyoming State Geological Survey (WSGS) submitted four map products as deliverables for STATEMAP 2002 to the U.S. Geological Survey (USGS) at the end of July. The Mapping Section at the WSGS completed work on the Kaycee and Reno Junction geologic maps as subproject 1 of STATEMAP 2002. The Publications Section digitized these two maps and the Rattlesnake Hills geologic map as subproject 2 and the Metals and Precious Stones Section completed the Keystone geologic map and report as subproject 3.

In a related note, the Mapping Section initiated work to complete the mapping and compilation of the Casper 1:100,000-scale STATEMAP 2003 project. John Hunter, a mapping volunteer, began work on this map in 1996; the map was 75% completed, with work remaining on the northeast and southwest quadrants.

Two new articles relating to Wyoming geology were released recently. The articles include topics relating to sequence stratigraphy of the Pahasapa Formation (Madison Group) in the northeastern Black Hills and a discussion of geology and gas production associated with Stagecoach Draw field in southwestern Wyoming.

STATEMAP 2002 projects completed

The Mapping Section completed geologic maps of the Kaycee and Reno Junction 1:100,000-scale quadrangles as subproject 1 of STATEMAP 2002 (**Figure 24).** GIS personnel in the Publications Section digitized these two maps, along with a geologic map of the Rattlesnake Hills 1:100,000-scale Quadrangle as subproject 2. The Metals and Precious Stones Section completed a geologic map and report of the Keystone 1:24,000-scale Quadrangle as subproject 3 for STATEMAP 2002 (**Figure 24**). These four geologic maps were submitted to the USGS at the end of July as deliverables fulfilling this STATEMAP contract.

The Kaycee Quadrangle is located in northeastern Wyoming and includes bedrock ranging in age from Precambrian to Oligocene. The eastern flank of the southern Bighorn Mountains and the adjacent western side of the Powder River Basin (PRB) are interrupted by a series of northwest-trending anticlines, which are asymmetrical with the steep limbs on the west. These structural features and the Bighorn uplift itself were created by a Laramide-age, northeast-oriented (N40-65°E) compressional event. These features cover

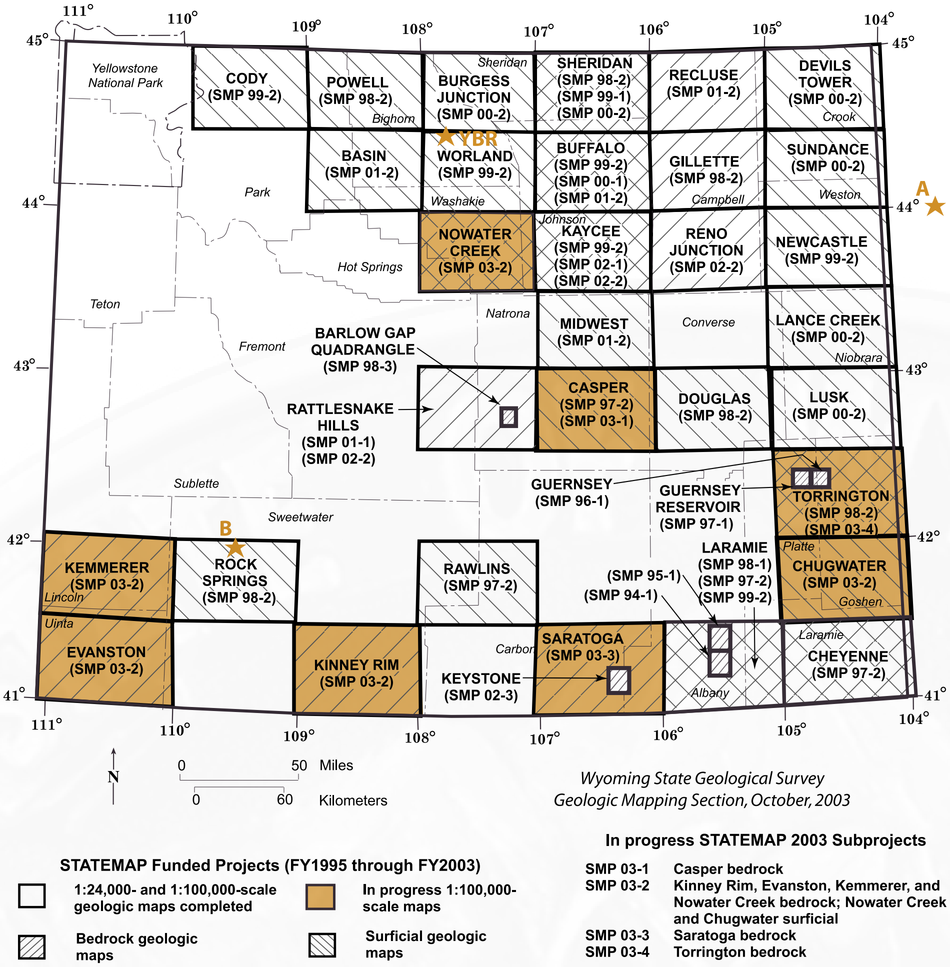

Figure 24. Index to in-progress and completed STATEMAP projects in Wyoming, locations of new published studies on Wyoming geology (letters and orange stars), and location of the Yellow Brick Road Dinosaur Tracksite (YBR) (orange star).

the western one-fourth of the map. The remainder of the quadrangle includes Cretaceous and Tertiary outcrops dipping toward the east/northeast. The axis of the PRB runs northwest to southeast through the northeastern corner of the quadrangle.

The quadrangle contains geology favorable to hosting petroleum and mineral occurrences. Structural oil and gas traps including the Sussex and Meadow Creek complexes, Tisdale Field, and North Fork Field have produced significant amounts of oil in the southeastern quadrant of the map. Stratigraphic traps including Heldt Draw, Jepson Draw, and Table Mountain produce oil in the northeastern quadrant. Bentonite production continues west of Kaycee from outcrops of the Frontier Formation and Mowry Shale. Uranium production has occurred in the northeastern part of the map from the Wasatch Formation, but the mines are currently inactive. Quaternary terrace deposits along the North Fork and Middle Fork of the Powder River serve as a source for sand and gravel in the area.

The Mapping Section compiled the geology for the Kaycee 1:100,000-scale Quadrangle using existing geologic mapping along with some aerial photo interpretation where no detailed geologic map coverage existed. The Section previously completed 1:24,000-scale geologic maps of the Packsaddle Canyon, Fraker Mountain, Barnum, Poker Butte, Hole-in-the-Wall, Red Fork Powder River, and Mayoworth quadrangles, which make up the western quarter of the map. That mapping project was funded through the USGS' COGEOMAP Program in the mid- to late-1980s. These seven quadrangles were first digitized at 1:24,000 scale, edited down to 1:100,000 scale, and then seamed together to complete the western quarter of the Kaycee map. The remaining three-quarters of the Kaycee map, which includes bedrock from Cretaceous through Tertiary in age, was compiled from USGS publications dating from the 1950s, 1960s, and 1990s. The completed maps include an index map and list of references for all sources used in compilation. The individual quadrangle maps will also be released as 1:24,000-scale color digital maps as a spin-off of this project. The Hole-in-the-Wall Quadrangle map will include a complete explanation and cross-section and is the first of this group that will be published in the WSGS map series.

The Reno Junction 1:100,000-scale Quadrangle is located immediately east of the Kaycee Quadrangle (**Figure 24**). Tertiary bedrock ranging in age from Paleocene to Oligocene crops out on the quadrangle. The structural axis of the PRB cuts diagonally across the southwestern corner of the quadrangle.

The geologic units within the Reno Junction Quadrangle also serve as hosts for petroleum and minerals. The petroleum traps are all stratigraphic in nature and significant oil production continues from such fields as Hartzog Draw, Hilight, House Creek, and Porcupine. Coalbed methane production is becoming significant in the quadrangle. Coal is another very significant resource for the area with thick Fort Union Formation coal beds mined at the Jacobs Ranch, Black Thunder, and North Antelope mines. As with the Kaycee Quadrangle, uranium has been an important resource, especially in the Pumpkin Buttes area where Wyoming roll-front-type deposits were first discovered in the early 1950s. Sand and gravel resources occur in the Quaternary terraces along the larger streams within the map area. Another important resource is the baked shale or clinker (used extensively for road cover and light-weight aggregate) associated with burned coal outcrops in the eastern half of the quadrangle.

The geology of the quadrangle was compiled from published surficial and bedrock geologic maps (1:100,000-scale and 1:24,000-scale) produced by the USGS in the early 1990s. As with the Kaycee Quadrangle, the completed map includes an index map and list of references used in compilation.

The completion of the above maps is essential to expanding the Northern Powder River Basin geologic, hydrologic, and water quality database project to the south. In addition, these maps continue our goal of completing the geologic mapping of the PRB (basically the northeast quadrant of the state) at a scale of 1:100,000.

Following (and even coincident with) compilation of both Kaycee and Reno Junction quadrangles, Geographic Information Systems (GIS) personnel in the Publications Section digitized the maps, creating digital coverages that can be used in the database project as well as in preparing the final published maps. Final editing will be completed on the digital coverages and the maps will be offered for sale in both hard copy (a color, plotted map) and in digital form on a CD-ROM in the WSGS Map Series (MS). The Kaycee Quadrangle is designated MS-63 and the Reno Junction Quadrangle is designated MS-62. Both maps are expected to be released in late 2003 or early 2004.

All the completed STATEMAP projects and the in-progress STATEMAP 2003 projects are shown in **Figure 24**. The STATEMAP Program, part of the USGS National Cooperative Geologic Mapping Program, has significantly expanded and driven the mapping efforts of the WSGS, contributing $419,549 in funding through the recently funded STATEMAP 2003 projects (**Table 17**). Counting the four maps submitted for STATEMAP 2002, the WSGS has completed 39 maps using funding from the STATEMAP program since it began involvement in 1994. An additional 11 maps were completed by the WSGS independent of the program's funding.

STATEMAP 2003 project begins

The Mapping Section, with funding from STATEMAP 2003, initiated efforts to complete mapping and compiling the geology for the Casper 1:100,000-scale Quadrangle in early August, 2003. Completing this map will augment southward expansion of the Northern Powder River Basin geologic, hydrologic, and water quality database project and will also satisfy the priority of mapping the populated areas in the state. A project to complete the Casper geologic map was initiated in 1996 by John Hunter, a mapping volunteer then employed by Power Resources in Casper. John compiled about 75% of the map before returning to England with his family. The map was turned over to the Mapping Section and it was proposed (and later funded) as subproject 1 of STATEMAP 2003. The Section will complete work on the northeastern corner of the map and the southwestern quadrant in the Shirley Basin area. In addition, the geology on the west side of the map needs to be reconciled with the adjacent, recently completed Rattlesnake Hills 1:100,000-scale Quadrangle. Some field checking of the map will be required.

The Casper Quadrangle is located in central Wyoming (**Figure 24**) and includes bedrock ranging in age from Precambrian to Oligocene. The dominant structural features included in the map area are the Casper arch and the Casper Mountain uplift, with their associated structures. The Casper uplift includes Precambrian, Paleozoic, and Mesozoic outcrops which cover the south half of the map. Much of the remainder of the quadrangle includes Cretaceous rocks dipping toward the east/northeast, capped by Tertiary rocks in the southwestern and southeastern corners. The axis of the PRB trends northwest to southeast and is located approximately 25 miles northeast of the quadrangle.

New publications on Wyoming geology

In a recently published article, Petty (2003) examined and compared the sequence stratigraphy of the Pahasapa Formation via regional correlations with the Mississippian Madison Group and the Madison Limestone. Comparisons are made with sections in the northern Bighorn Mountains, Wyoming and various locations in the Williston Basin in South Dakota, North Dakota, and eastern Montana. The Pahasapa Formation in the northeastern Black Hills area (**location A, Figure 24**) can be subdivided into three third-order stratigraphic sequences informally designated as the Woodhurst-Paine sequence, Frobisher-Alida sequence, and the Ratcliffe sequence. These sequences can then be correlated to other parts of the Williston Basin and the northern Bighorn Mountains.

Kovach and others (2003) recently published the results of a comprehensive study on the geology and gas production of Stagecoach Draw Field, located northwest of the Rock Springs uplift and south of Jonah field in the northwestern Green River Basin (**location B, Figure 24**). The field, discovered in 1993, produces from the Upper Cretaceous Almond Formation and represents the only Almond production between the Rock Springs uplift and the Moxa arch. The authors discussed the tectonic setting, regional stratigraphy, and the discovery and production phases of this structural/stratigraphic trap. The techniques used to find and develop this field will aid in finding and developing similar traps in this part of the Green River Basin.

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Table 17. Summary of the STATEMAP-funded geologic mapping program in Wyoming.

Fiscal Year	Project description and map scale	State dollars	Federal dollars	Total project dollars
1995	Geologic map of the Laramie Quadrangle, 1:24,000-scale STATEMAP94	**$12,000**	**$12,000**	**$24,000**
1996	Geologic map of the Howell Quadrangle, 1:24,000-scale STATEMAP95	**$10,000**	**$10,000**	**$20,000**
1997	Geologic map of the Guernsey Quadrangle, 1:24,000-scale STATEMAP96	**$8,499**	**$8,499**	**$16,998**
1998	1-Geologic map of the Guernsey Reservoir Quadrangle, 1:24,000-scale STATEMAP97			
	2-Digital geologic map of the Cheyenne Quadrangle and digital surficial geologic maps	$14,000	$14,000	$28,000
	of the Casper, Cheyenne, Laramie, and Rawlins Quadrangles, 1:100,000-scale STATEMAP97	$17,000	$17,000	$34,000
	Total 1998 Funds	**$31,000**	**$31,000**	**$62,000**
1999	1-Geologic map of the Laramie Quadrangle, 1:100,000-scale STATEMAP98	$18,500	$18,500	$37,000
	2-Digital geologic map of the Gillette Quadrangle and surficial geologic maps of the Douglas,			
	Powell, Rock Springs, Sheridan, and Torrington Quadrangles, 1:100,000-scale STATEMAP98	$20,000	$20,000	$40,000
	3-Geologic map of the Barlow Gap Quadrangle, 1:24,000-scale STATEMAP98	$18,650	$18,650	$37,300
	Total 1999 Funds	**$57,150**	**$57,150**	**$114,300**
2000	1-Geologic map of the Sheridan Quadrangle, 1:100,000-scale STATEMAP99	$19,500	$19,500	$39,000
	2-Digital geologic map of the Laramie Quadrangle and digital surficial geologic maps of the			
	Buffalo, Cody, Newcastle, Kaycee, and Worland Quadrangles, 1:100,000-scale STATEMAP99	$20,000	$20,000	$40,000
	Total 2000 Funds	**$39,500**	**$39,500**	**$79,000**
2001	1-Geologic map of the Buffalo Quadrangle, 1:100,000-scale STATEMAP00	$20,500	$20,500	$41,000
	2-Digital geologic map of the Sheridan Quadrangle and digital surficial geologic maps of the Burgess			
	Junction, Devils Tower, Lance Creek, Lusk, and Sundance Quadrangles, 1:100,000-scale STATEMAP00	$24,500	$24,500	$49,000
	Total 2001 Funds	**$45,000**	**$45,000**	**$90,000**
2002	1-Geologic map of the Rattlesnake Hills Quadrangle 1:100,000-scale STATEMAP01	$24,133	$24,133	$48,266
	2-Digital geologic maps of the Buffalo and Recluse Quadrangles and digital surficial geologic maps			
	of the Midwest and Basin Quadrangles 1:100,000-scale STATEMAP01	$24,796	$24,796	$49,592
	3-Entering map data in National Geologic Map Database STATEMAP01	$6,500	$6,500	$13,000
	Total 2002 Funds	**$55,429**	**$55,429**	**$110,858**
2003	1-Geologic map of the Kaycee Quadrangle 1:100,000-scale STATEMAP02	$23,500	$23,500	$47,000
	2-Digital geologic maps of the Kaycee, Reno Junction, and Rattlesnake Hills Quadrangles			
	1:100,000-scale STATEMAP02	$18,437	$18,437	$36,874
	3-Geologic map of the Keystone Quadrangle 1:24,000-scale STATEMAP02	$28,976	$28,976	$57,952
	Total 2003 Funds	**$70,913**	**$70,913**	**$141,826**
2004	1-Geologic map of the Casper Quadrangle 1:100,000-scale STATEMAP03-in progress	$21,889	$21,889	$43,778
	2-Digital geologic maps of the Kinney Rim, Evanson, Kemmerer, and Nowater Creek quadrangles;			
	digital surficial geologic maps of the Nowater Creek and Chugwater quadrangles			
	1:100,000-scale STATEMAP03-in progress	$16,745	$16,745	$33,490
	3-Geologic map of the Saratoga Quadrangle 1:100,000-scale STATEMAP03-in progress	$27,532	$27,532	$55,064
	4-Geologic map of the Torrington Quadrangle 1:100,000-scale STATEMAP03-in progress	$23,892	$23,892	$47,784
	Total 2004 Funds	**$90,058**	**$90,058**	**$180,116**
	TOTALS	**$419,549**	**$419,549**	**$839,098**

Research Assistantships Help Compile New Geologic Map of Wyoming

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In the fall of 2002, the Wyoming State Geological Survey (WSGS) began a four-year project to compile and publish a digital geologic map of Wyoming at a scale of 1:250,000. The idea for this project was originally conceived and initiated by the late, renowned Wyoming geologist, Dr. J. David Love, author of two previous geologic maps of Wyoming. The Department of Geography and Recreation, University of Wyoming, and the WSGS (through the efforts of Joseph M. Huss, GIS Coordinator) agreed to fund a research assistant (RA) each year to map a quadrant of the state. Each assistantship would last one year, commencing in the fall of 2002, with planned project completion in 2006. Following the conclusion of each assistantship, the WSGS would then publish the map in their Map Series (MS) the year following.

Using published and unpublished geologic maps, the RA develops and builds a Geographic Information System (GIS) database and cartographic map of the bedrock geology for one of four quadrants in Wyoming. Each quadrant map encompasses 2 degrees of latitude and 4 degrees of longitude, containing four 1:250,000-scale source maps (**Figure 25**). Some of the source maps have been published as color, printed maps from the U.S. Geological Survey (USGS) or the WSGS or as USGS open file reports (OFRs); some maps were compiled in the process of preparing the 1985 *Geologic Map of Wyoming* (Love and Christiansen, 1985), but were never released. The WSGS will be using these unpublished maps for this compilation. In some cases, the quadrant maps will use newer published and digitized 1:100,000-scale maps to augment the unpublished maps.

The northeastern Wyoming quadrant is scheduled for the first year of the program, followed by the southwestern, northwestern, and southeastern quadrants. These mapping priorities were established primarily by need rather than availability of data. Once all four quadrants are completed, additional mapping in Wyoming will be incorporated into each quadrant map and a new digital map of Wyoming at 1:500,000-scale will then be compiled to replace the 1985 version.

Work began on the first quadrant map in September, 2002 by the first graduate RA at the WSGS, Justin T. Carreno. The work was successfully completed this summer and the final cartographic product (GIS database, layout, and draft paper map) is now in review. A second map, of the southwestern quadrant, began this fall, 2003 by the second RA at the WSGS, David W. Lucke. The final maps will be published in the WSGS Map Series and will include both a printed map and the digital data on CD-ROM.

The northeastern quadrant consists of the Sheridan, Gillette, Arminto, and Newcastle 1:250,000-scale quadrangles (**Figure 25**). This map is the first of its kind to synthesize the four quadrangles into a contiguous bedrock geologic map of northeastern Wyoming. Each map was edge-matched to the adjoining quadrangle and mappable units were preserved wherever possible across map boundaries. Both the GIS data and the cartographic map cover the area from 43° to 45°N and 104° to 108°W. The map includes slivers of bordering Montana and South Dakota.

The GIS database provides information on the bedrock geology, faults, and associated geologic information. In addition, it includes other essential information necessary for proper and / or more extensive uses of the database. This information consists of layers of hydrography, roads, public land survey boundaries, county boundaries, lake boundaries, and hypsography (topography) with associated annotation linked to these layers.

The GIS database and map will ultimately serve the needs of the general public, industry, government, non-government groups, and academia. Potential functions of the map are varied. A primary function is for natural resource management, in particular, geology-related interests including coalbed methane, oil, natural gas, coal, uranium, groundwater, and a number of other minerals and materials. With the recent success of the first map, the WSGS looks forward to completion of the other maps on the project and eventually, a new geologic map of Wyoming.

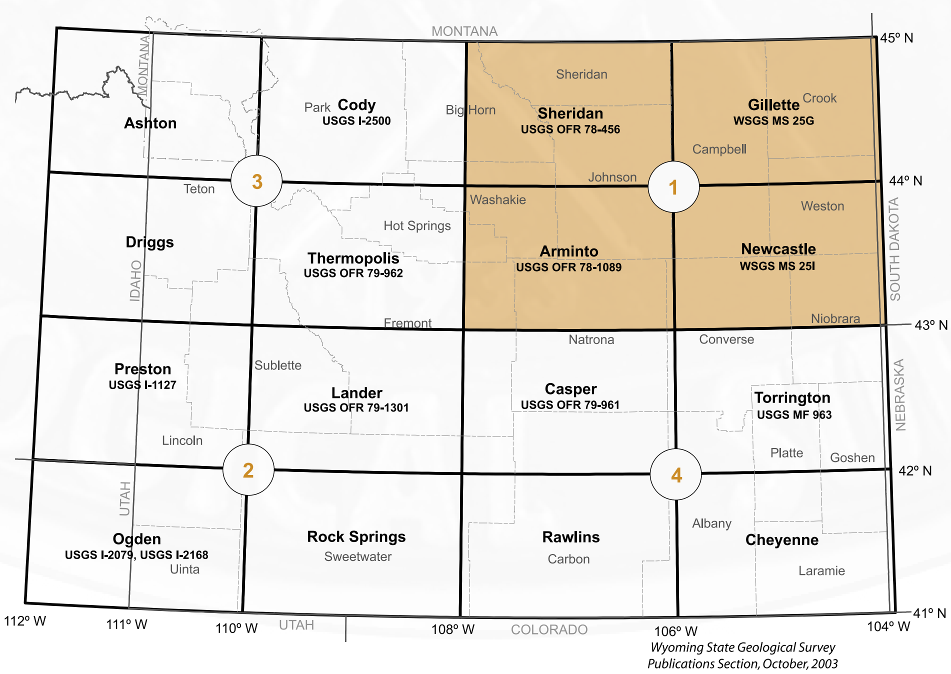

Figure 25. Index to 1:250,000-scale mapping projects and priorities (numbered quadrants) at the Wyoming State Geological Survey (WSGS) showing quadrangles being compiled to publish a new geologic map of Wyoming. The U.S. Geological Survey (USGS) maps are published as an Open-File Report (OFR), Miscellaneous Field Studies Map (MF), or Miscellaneous Investigations Series Map (I). WSGS maps are published as a Map Series (MS).

Hazards, Infrastructure, and Related Databases

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The Wyoming Office of Homeland Security–Emergency Management Agency and the Federal Emergency Management Agency (FEMA) has provided funding to the Geologic Hazards Section at the Wyoming State Geological Survey (WSGS) to generate natural hazards analyses for the entire state of Wyoming. The analyses include the effects of hazards on all State buildings and infrastructure. In addition, potential effects of hazards on counties and municipalities must be refined from previously generated county analyses (see *Wyoming Geo-notes No. 77*, June, 2003). To efficiently generate the hazards analyses, current digital data and layers from Geographic Information Systems (GIS) are required. The data are used directly or are utilized in software, such as HAZUS, in order to generate damage scenarios.

HAZUS is loss estimation software developed for FEMA by the National Institute of Building Sciences. The Section recently received an advanced version of the latest HAZUS called HAZUS MH, which stands for HAZUS Multi-Hazard. Wyoming is a pilot-project state for HAZUS MH. The new HAZUS can run simulations on earthquakes, floods, and high-wind events. A previous article on HAZUS (see *Wyoming Geo-Notes No. 73*, April, 2002) discussed weaknesses in the program and with supplied databases. Previous versions of HAZUS ran simulations at the census tract level, using tract centroid values for ground acceleration as the basis for earthquake analysis. This was inadequate for Wyoming, as most census tracts are very large. HAZUS MH for Wyoming runs simulations at the census block level, which provides for a more precise analysis. In addition, the Section is working with FEMA on a variable grid–size analysis.

The Section has been correcting or completely rebuilding many of the databases required to properly run HAZUS, HAZUS MH, or independent analyses. Many of the HAZUS-supplied databases were inadequate, and many other databases that are readily available were found to be incomplete or inaccurate. Presented below is a summary of databases and GIS layers that the Section is working on or has completed.

Natural hazards data updates

A complete discussion of the natural hazards data was presented in *Wyoming Geo-notes No. 77*, June, 2003.

Landslides

All 850 7.5-minute quadrangle-based landslide maps generated by the Section have been scanned and digitized. A statewide landslide map has been generated from the individual quadrangle maps. The maps will be served through the University of Wyoming's Water Resources Data System (WRDS) at http://www.wrds.uwyo.edu/wrds/wsgs/hazards/landslides/lshome.html.

Flood Insurance Rate Maps (FIRMs)

As mentioned previously, all of the FIRMs produced by FEMA were individually scanned and digitized. They have now been merged into a statewide coverage. Some of the maps were found to be inconsistent with recent 7.5-minute topographic maps or with 1994 digital orthophoto quarter quadrangles (DOQQs) and were brought to FEMA's attention.

Severe weather

Severe weather data includes hail, tornado, snow, rain, high wind, and lightning. The primary sources of the data are the National Oceanic and Atmospheric Administration (NOAA) (http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwevent~storms) and WRDS (http://www.wrds.uwyo.edu). The severe weather events are located by latitude and longitude, and include damage estimates.

Infrastructure data

This section contains data on essential facilities, banks, transportation, public health and health related facilities and organizations, dams, law enforcement facilities, energy-related facilities, State buildings and laboratories, and media. Other databases are being generated, and will be addressed in future issues of Geo-notes.

Methodology

It is as important to properly locate buildings, offices, transportation systems, and other elements related to a state's infrastructure as it is to map and properly locate hazards. Properly located facilities can then be analyzed in regards to hazards vulnerability. Many of the databases below are associated with physical addresses tied to roads and streets. Nationally, one of the primary sources for roads and streets is Topologically Integrated Geographic Encoding and Referencing system (TIGER) data from the U.S. Census Bureau. TIGER data include roads, streams, railroads, and many other types of features that are generally used to define boundaries of census blocks and tracts. TIGER roads have addresses assigned to most road segments and, as a result, the TIGER roads can be used for geocoding. Geocoding is a process of assigning geographic coordinates (latitudes and longitudes) to street or road addresses in ESRI's® ArcGIS®.

Current TIGER roads were derived from digitizing roads shown on 1:100,000-scale topographic maps. As a result, TIGER road segments shown at a scale of 1:24,000 may be mislocated by hundreds of feet compared to actual locations. Most buildings and offices described below were initially located using the geocoding process. Because of the error currently associated with the TIGER road data, we refined the following facility locations using DOQQs.

Banks

We obtained bank addresses and contacts from current phone books and from the Wyoming Department of Audit—Division of Banking (http://audit.state.wy.us/banking). Addresses that were not consistent between sources were checked through personal contact.

County, State, and Federal Courts and associated Courthouses

We obtained Circuit and District Court addresses and contacts from the State of Wyoming Judicial Branch (http://courts.state.wy.us/). Circuit and District Courts are usually, but not always, located at county courthouses. Federal Court addresses and contacts were obtained from the Tenth Circuit Court of Appeals (http://www.ck10.uscourts.gov/wyoming/district/index.html). Federal Courts are located within federal buildings in Casper and Cheyenne.

County coroners and health officers

We obtained county coroner addresses and contacts from the Wyoming Board of Coroners Standards contact sheet (as modified by the Natrona County Coroner's Office), current phone books, and through personal contact. County Health Officer addresses and contacts were obtained from the Wyoming Department of Health—County Health Officers contact sheet and through personal contacts.

Dams

The Wyoming State Engineer's Office provided the Section with a database of potentially hazardous dams in Wyoming. The only dams in the state included in the database are those that have enough dam height (20 feet or more) and water (at least 15 acre-feet of water behind the dam) to pose a downstream threat if they fail. The latitude and longitude of the dams in the database were plotted on DOQQs, and corrected as needed.

Essential facilities

Schools, health care facilities, fire stations, police stations, American Red Cross offices, and county/state emergency operations centers are all considered to be essential facilities in HAZUS. The Section acquired a database of all schools, associated facilities, and daycares from the Wyoming School Facilities Commission. The latitude and longitude of schools, school administration offices, and associated buildings derived from geocoding were plotted on DOQQs to confirm or modify locations.

Hospital, nursing home, medical clinic, assisted living facility, boarding home, surgical center, renal dialysis center, home health center, hospice, mental health center, psychiatric hospital, rehabilitation center, and public health agency locations and descriptions were acquired from the Wyoming Department of Health in paper format. We entered the names and addresses into a digital database, generated latitudes and longitudes using geocoding, and confirmed hospital locations using DOQQs and personal contacts.

Fire station addresses and contacts were modified from Wyoming Department of Fire Prevention and Electrical Safety online databases: http://wyofire.state.wy.us/training/2r.pdf, http://wyofire.state.wy.us/training/3r.pdf, and http://wyofire.state.wy.us/training/8863.pdf.

We derived police station addresses and contacts from a paper database at the Wyoming Peace Officers Standards and Training Division of the Wyoming Attorney General's Office and from current phone books. We entered the data into a digital database, and confirmed geocoded locations using DOQQs and personal contacts.

American Red Cross addresses and contacts were derived from the American Red Cross of Wyoming online database (http://www.wyomingredcross.org). The addresses and phone numbers were then confirmed with the State Red Cross office.

We derived addresses and contacts for County and State emergency operations centers from data made available by the Wyoming Office of Homeland Security–Emergency Management Agency. The names and addresses were entered into a digital database, and locations were confirmed with personal contacts.

Federal law enforcement agencies

Federal buildings and agencies included in the Federal Law Enforcement database include the Bureau of Alcohol, Tobacco, and Firearms (ATF); the Drug Enforcement Administration (DEA); the Defense Security Service; various offices of the Federal Aviation Administration (FAA); the Federal Bureau of Investigation (FBI); the Internal Revenue Service (IRS); the U.S. Customs Service; the U.S. Department of the Army–Reserve Training Center; the U.S. Department of Agriculture–Wyoming Farm Service Agency: the National

Weather Service: the U.S. Department of Energy (DOE); the U.S. Department of the Navy–Naval Reserve Center; the U.S. Marshals Service; and the U.S. Secret Service. Addresses for the above entities were obtained from online phone directories and individual agency web sites, and confirmed through personal contacts.

Media

Radio stations and transmission towers, television stations and transmission towers, and print media are in a media database and in individual databases. We obtained radio and television station addresses and contacts from the Wyoming Association of Broadcasters and current phone books, and confirmed them through personal contact. The transmission tower locations, in latitudes and longitudes, and technical specifications were obtained from the Federal Communications Commission (FCC). We obtained print media addresses and contacts from the Wyoming Press Association and current phone books, and confirmed them through personal contact.

Oil and gas wells

Oil and gas wells are derived from the Wyoming Oil and Gas Conservation Commission (WOGCC) at http://wogcc.state.wy.us. The WOGCC web site allows for the download of latitudes and longitudes of all wells in Wyoming. Some of the location data have been modified in the northern part of the Powder River Basin as part of an interactive geologic, hydrologic, and water quality database for that area.

Pharmacies

Pharmacy addresses and contacts were obtained from the Wyoming State Board of Pharmacy and through current phone books. Addresses that were not consistent between sources were checked through personal contacts.

Pipelines

Pipeline locations are from WSGS Map Series 55, *Oil and gas fields map of Wyoming*. The locations are not precise, and are intended to be used at a scale of 1:500,000. The WSGS generated a more precise GIS layer of pipelines, part of which is based upon proprietary data from pipeline companies, but the layer cannot be publicly released.

Power plants

Power plant locations and additional data for coal-, natural gas-, oil-, hydro-, and wind- powered electrical generating plants were obtained from the Wyoming Geographic Information Science Center (WyGISC) web site (http://www.wygisc.uwyo.edu), paper reports from the Wyoming Public Service Commission, historical data at the WSGS, the DOE–Energy Information Administration (http://www.eia.doe.gov), and the American Wind Energy Association (http://www.awea.org). The power plants are currently being located on DOQQs.

Refineries and gas plants

Refinery and natural gas plant locations, operator, type, and capacity are being obtained from historical data at the WSGS (including WSGS Map Series 55), the WOGCC, and the Wyoming Department of Environmental Quality–Air Quality Division. The refineries are being located on DOQQs, as are most gas plants.

Transportation

Transportation data include airports, runways, railroads, highways, roads, bridges, and tunnels. Data for 120 public and private airports and runways were acquired from the National Imagery and Mapping Agency (http://www.nima.mil) and the Bureau of Transportation Statistics (http://www.bts.gov). Airports are an important database as many disaster response activities will require an airport or runway. The newest airport in Wyoming, Hulett Municipal Airport recently opened on October 3, 2003. Although information on this airport has not yet been released to the public, Armstrong Consultants, Inc. in Grand Junction, Colorado provided the WSGS with the airport specifications. Airport and runway locations for public airports were confirmed using DOQQs and personal contacts.

There were two sources of railroad data for Wyoming, TIGER data and Wyoming Department of Revenue data. Upon comparing both datasets, we determined that the latter dataset was more complete and accurate. As a result, railroads were downloaded from http://revenue.state.wy.us.

There are two sets of road data that have been acquired. TIGER road data are described above. The Wyoming Department of Transportation has supplied the WSGS with a GIS layer of State-maintained highways, bridges, and tunnels. The locations are precise, but the roads do not have addresses associated with them.

Wyoming State buildings and laboratories

We acquired the Wyoming State Buildings database from the Risk Management Section at the Wyoming Department of Administration and Information (DAI). The database included street addresses for all State buildings. The geocoded addresses were confirmed on DOQQs. We will run specific hazards analyses on each State building starting in January, 2004. The addresses and contacts for State of Wyoming laboratories were obtained from the Wyoming State Laboratories web site (http://wyolabs.state.wy.us/) and confirmed through personal contacts.

Additional data

There are additional sets of data that are crucial to hazards analyses. These data are described below.

Census block data

FEMA provided the WSGS with census data by block and tract. The data are building values by type of building at the block level. In addition, the Census Bureau (http://www.census.gov) and Wyoming DAI provided boundaries of census blocks and tracts.

County and municipal boundaries

There are a number of county and municipal boundary GIS layers that are available for the State of Wyoming. After comparing all available layers, the Hazards Section selected the county and municipal boundary layers served by the Wyoming Department of Revenue (http://revenue.state.wy.us).

Streams and lakes

Streams and lakes are from the National Hydrologic Dataset (NHD), which is a comprehensive set of digital spatial data that contains information about surface water features. The NHD is currently designed to be used at a scale of 1:100,000, although a 1:24,000-scale update is underway by WyGISC. The GIS layer currently used in this dataset is from WyGISC (http://www.wygisc.uwyo.edu) and U.S. Geological Survey/U.S. Environmental Protection Agency (http://nhd.usgs.gov/data.html).

Summary

In order to conduct a reliable hazards and vulnerability assessment for the state, a county, a city, or an individual facility, it is necessary to have reliable data. A facility mislocated by a few hundred feet may be mistakenly plotted on a landslide or in a floodplain during digital analysis. The Geologic Hazards Section will continue to generate databases on facilities and structures that may be affected by hazards.

The data above will be provided to all counties in Wyoming on a Pocket PC. The Pocket PCs will have an attached Global Positioning System (GPS) unit that can be used to check and/or modify locations of facilities.

Middle Jurassic Dinosaurs of Northern Wyoming: Evidence from the Yellow Brick Road Dinosaur Tracksite, Bighorn Basin, Wyoming

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Dinosaur tracks preserved at the Yellow Brick Road Dinosaur Tracksite (YBR) in limestone exposures of the Middle Jurassic in the northeastern Bighorn Basin, Wyoming are a unique paleontological resource for student research. This is the second in a two-part series dealing with our research on the dinosaur tracks at the YBR. In the first report, we described the history of discovery, general geology and stratigraphy of the area, and discussed the methodologies used to document these tracks (see Adams and Breithaupt, 2003a). In this paper we present our results, interpretations and conclusions on this previously unknown Middle Jurassic dinosaur population. The YBR provides new information to our understanding of the Jurassic Period in Wyoming and is adding to the limited knowledge of North America's Middle Jurassic dinosaur fauna. As can be seen in this installment, estimations on dinosaur sizes, speeds, and activity patterns can be determined from the fossil record.

Introduction

The YBR (UW Locality V-2001-001) contains thousands of footprint impressions preserved in limestone exposures of the lower parts of the Sundance Formation, making it the largest track locality known within the Bighorn Basin. This tracksite, located on public lands owned by the State of Wyoming (section 16, T52N, R91W) in Big Horn County (**Figure 24**), represents a lateral equivalent of the unit occurring at the Red Gulch Dinosaur Tracksite (RGDT), which is one of the most extensively studied dinosaur track localities in the world (Breithaupt and others, in review; in press; 2002; 2001). At YBR, hundreds of previously unrecorded tridactyl pes impressions of theropod dinosaurs were surveyed and studied. Tracks were located, measured, mapped, photographed, and described as part of an undergraduate independent study project at the University of Wyoming (UW) (Adams and Breithaupt, 2003a, 2003b; Adams, 2001). Tracks and trackways were studied to determine possible behavioral implications and to try to interpret the paleoecology of the tracksite. The track surface and surrounding rock layers were analyzed to help establish the depositional environment and paleoenvironmental aspects of the site.

Within the YBR research area, four members of the Sundance Formation are present (**Figure 26**): the Canyon Springs, Stockade Beaver Shale, and Hulett members of the Lower Sundance, and the Redwater Shale Member of the Upper Sundance (Schumde, 2000). The Lak and Pine Butte members of the Lower Sundance and the Windy Hill Member of the Upper Sundance, which occur in eastern Wyoming, are not present at YBR. The three Lower Sundance members are found within the Third Marine cycle (Pipiringos and O'Sullivan, 1978). The dinosaur track-bearing layer at YBR is located in the upper part of the Canyon Springs Member. It is an oolitic grainstone, which lies stratigraphically above the upper Claystone Member of the Piper, the J-2 unconformity, and the Gypsum Spring Formation. The Stockade Beaver Shale Member overlies the Canyon Springs, and is composed of an olive-green, calcareous shale with abundant remains of marine invertebrate fossils, including *Gryphaea nebrascensis*, which can be used as a biostratigraphic marker. Schmude (2000) placed the J-4 unconformity above the Hulett Member. Above the J-4 unconformity is the Redwater Shale Member of the Upper Sundance, which contains fossil belemnitids and *Camptonectes* (Schumde, 2000; Imlay, 1980).

During the Third Marine cycle, the Sundance Sea was a shallow to relatively deep marine environment with normal salinity (Brenner and Peterson, 1994). Tectonic highs, along with variations in sea level change, possibly resulted in shoaling and tidal features throughout the basin. Schmude (2000) pointed out that the tracks within the study area are located at the northern end of a tectonic feature called the Black Mountain High which developed during the J-2 unconformity. Polar wander data places the Bighorn Basin between 20° and 25° north latitude during the Middle Jurassic, as the continent drifted north with a clockwise rotation (Kocurek and Dott, 1983; Steiner, 1983). Paleoclimate indicators (i.e., evaporites and oxygen isotope analysis) suggest a tropical climate with some aridity and little seasonal variation (Keller, 2001; Frakes, 1979).

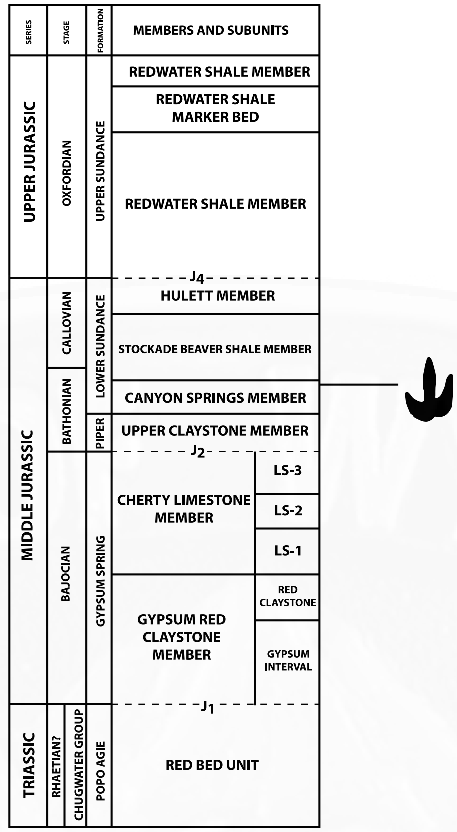

Figure 26. Stratigraphic location of the track-bearing Canyon Springs Member of the Sundance Formation (from Schmude, 2000).

Methodology

Once the data had been collected (see Adams and Breithaupt, 2003a), interpretations and comparisons were made. All data were entered into a spreadsheet and statistical analyses were performed using the Statistical Package for Social Sciences (SPSS). A frequency distribution was done for each measurement on each track, as well as descriptive statistics. Correlations were performed on measurements of tracks from the YBR and tracks from the RGDT. By using established mathematical formulas and measurements taken of the tracks, estimates were made on the sizes and speeds of the individual dinosaurs. The foot length (FL) measurements were used to estimate the hip height (h) of the trackmaker (see Wright and Breithaupt, 2002): FL<25 cm: $h = 3.06FL^{1.14}$; FL>25 cm: $h = 8.60FL^{0.85}$; and for Theropods in general: $h = 3.14FL^{1.14}$.

Thulborn (1990) derived a set of equations, based on foot length, that can be used to make hip height determinations (using the equation for tracks less then 25 cm). Once the sizes of the dinosaurs were determined, calculations were made of the speed at which they were traveling, utilizing the following formula (Alexander, 1989) which yields results (speeds) in meters per second: $V = 0.25g^{0.5} \times L^{1.67} \times H^{-1.17}$, where V= velocity, g = gravity constant, L = stride length, and H = hip height, all in meters.

To determine the gaits of the dinosaurs, it is necessary to calculate the relative stride length. Thulborn (1990) defined relative stride length as L/h, where L is the average stride length and h is the hip height (calculated above) of the trackmaker. Relative stride length is then related to gaits for bipeds: $L/h<2.0$ = Walking; $L/h \sim 2.0 - 2.9$ = Trotting; and $L/h>2.9$ = Running.

Orientation of the tracks was studied by plotting the azimuth of each track on a Grapher 3® program creating a rose diagram. This will help to determine if there were dinosaurs with parallel trackways, which will assist in the determination of community dynamics.

To better understand relationships between the substrate and tracks, samples of the footprint-bearing limestone were collected and made into thin sections. The thin sections are being used to study micro-stratigraphy and lithology of the bedding sequences. These bedding sequences may provide clues to depositional environments during formation of the limestone layers. Thicknesses of the micro-stratigraphic sections at YBR were measured on freshly exposed rock layers and used to create a detailed lithologic description and stratigraphic column of the YBR tracksite (**Figure 27**). Study of the limestone package, as well as the clastic units above and below it, will assist in interpreting paleoenvironmental settings of the tracksites.

Results

Lithology

The limestone fabric of the four layers studied in thin section demonstrates similar textures and features that have undergone various stages of alteration. Early sparry calcite cement rims the oolites as bladed to fibrous crystals, with secondary, coarse-grained, calcite-filled voids between grains. The calcite cement has been replaced by dolomite, possibly resulting from tidal pumping and/or subaerial conditions and evaporation of sea water (Boggs, 1992). Peloids and oncolites are also found in all four sampled limestone layers, along with recrystalization of altered invertebrate fossil fragments.

The 45 cm-thick limestone package represents four time-transgressive layers (**Figure 27**). Lithology of each layer was described using thin sections and hand sample observations. Layer two (L2), the lowest limestone layer, is a gray, coarse-grained, oolitic grainstone. This layer is fossiliferous, with

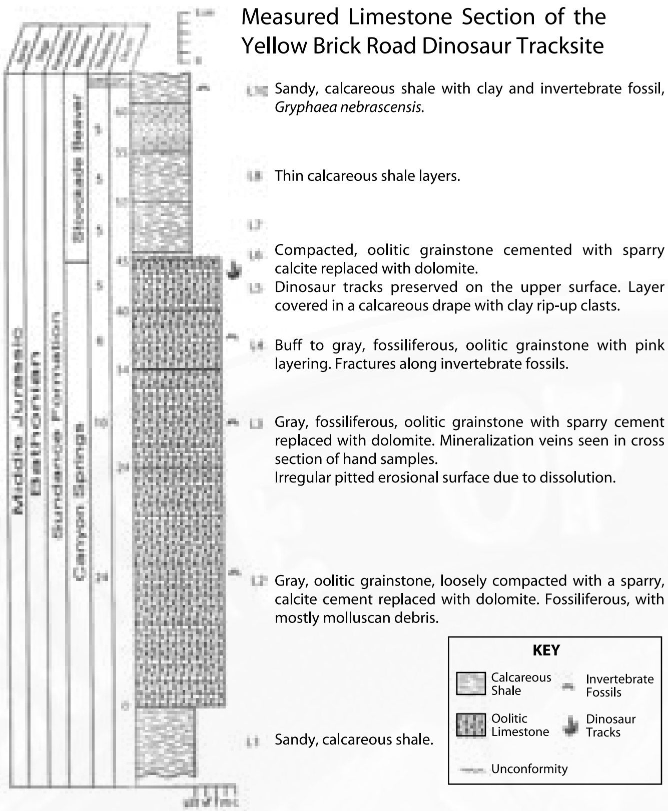

Figure 27. Measured limestone section of the Yellow Brick Road.

mostly molluscan fossil debris. The oolite grains and fossils are loosely compacted with a sparry calcite cement. Layer three (L3) is also a gray, fossiliferous, oolitic grainstone, with mineralization veins seen in cross section of hand samples. The erosional surface of this layer has an irregular pitted surface due to dissolution. The grains are also cemented with sparry calcite. Layer four (L4) is a buff to gray, fossiliferous, oolitic grainstone, with pink layering throughout the hand samples. This layer tends to fracture along the invertebrate fossils. Layer five (L5), the top layer, has dinosaur tracks and salt casts preserved in the uppermost part of the layer. This layer is a compacted, oolitic grainstone, cemented with sparry calcite. This layer is covered in a thin, calcareous drape with occasional clay rip-up clasts preserved in its under layer. The limestone package is topped by four thin shale layers (L6, L7, L8, and L10), with a total thickness less than fifteen centimeters. Ripple marks occur only in a few areas and do not cover the surface at YBR in the same manner as seen on the RGDT surface. The presence of invertebrate trace fossils, seen at the RGDT, is also relatively absent on the main track surface of YBR. The unconformity between the Canyon Springs and Stockade Beaver members can be seen at RGDT from the presence of truncated invertebrate vertical burrows (i.e., *Diplocraterion*).

Paleoichnology

At YBR, more than 600 tracks were mapped within five study areas, with 213 of these tracks measured and documented, resulting in over 2500 individual measurements. Tracks are tridactyl, digitigrade impressions in concave epirelief with the majority of the tracks showing sharp claw impressions (**Figure 28**). Tracks have narrow toe marks with S-shape curvature of the middle digit and with a foot length longer than foot width. Foot lengths vary in size from 7.3 to 25.4 cm with the majority of the tracks falling in the 12 to 17 cm ranges (**Table 18** and **Figure 29**). Foot width of the tracks varies from 5.2 to 21.6 cm, with an average of 14 cm (**Table 18** and **Figure 30**). Interdigital angles (IDA) between the digits of the tracks show a larger angle between digits II and III than between digits III and IV: the average angle between II and III is 47º and between III and IV is about 38º.

Thirty-four trackways have been identified, with 22 of these having three to five steps, due to limited track surface exposure (**Figure 31**). Determining traveling speeds is done by using the foot lengths and stride lengths of those tracks that occur in trackways with three steps or more. Hip heights ranging from 30 cm to 99 cm indicate small-to-medium sized dinosaurs (**Table 19**). Absolute speeds range from 4.7 kilometers per hour (kph) or 2.9 miles per hour (mph) to 11.9 kph (7.4 mph). Relative stride lengths for YBR trackways show that most of the dinosaurs were walking or trotting (L/h = 1.4 to 2.7). One individual appears to have a running gait (L/h = 3.1).

Azimuths of footprints were plotted for 22.5º intervals on a rose diagram to show track orientations (**Figure 32**). Orientations of the majority of tracks show trends to the northwest

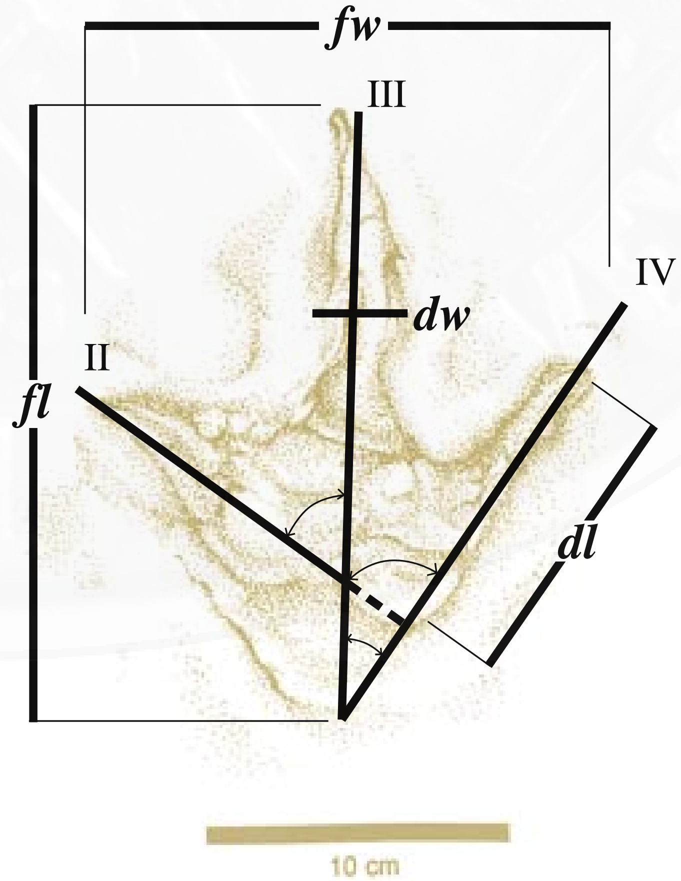

Figure 28. Example illustration of a track from Yellow Brick Road with track measurements; fl=foot length, fw=foot width, dl=digit length, dw =digit width, angles between digits also indicated.

Table 18. Summary of track measurements (in centimeters) from the Yellow Brick Road Tracksite.

	N	Minimum	Maximum	Mean	Std. Deviation
foot length	180	7.3	25.4	16.65	2.99
foot width	184	5.2	21.6	14.32	2.83
digit 2 length	188	2.6	11.4	7.17	1.54
digit 2 width	186	0.3	3.6	2.13	0.61
digit 3 length	204	3.6	21.6	11.83	2.54
digit 3 width	206	0.4	4.8	2.61	0.71
digit 4 length	168	3.4	14.1	9.33	1.94
digit 4 width	161	0.4	3.8	2.23	0.59
angle between 2 & 3	197	30.0	70.0	47.00	8.45
angle between 3 & 4	185	22.0	68.0	38.24	7.12
angle between 2 & 4	177	57.0	123.0	83.63	8.92
track depth	212	0.4	2.5	1.32	0.41
Valid N (listwise)	124				

Table 19. Summary of trackway measurements and estimated speeds of trackmakers from the Yellow Brick Road Tracksite.

	N	Minimum	Maximum	Mean	Std. Deviation
foot length (cm)	61	7.3	21.2	16.78	3.29
stride length (m)	30	0.8	183.9	56.66	74.54
average foot length (cm)	22	7.4	20.6	16.65	3.27
average stride (m)	22	0.8	1.9	1.42	0.25
hip height (m)	22	0.3	0.9	0.76	0.16
meters per second	22	1.3	3.3	2.06	0.50
kilometers per hour (kph)	22	4.7	11.9	7.38	1.84
miles per hour (mph)	22	2.9	7.4	4.62	1.13
relative stride length	22	1.4	3.1	1.92	0.40
Valid N (listwise)	22				

and to the southeast. This is not the case at RGDT, where the majority of trends of parallel to subparallel groupings are to the south and southwest (Breithaupt and others, in review; 2002).

Underprints or undertracks (a distinct style of track preservation) were discovered while conducting field research at YBR (**Figure 33**). These underprints suggest the existence of the preservation of individual footprints superimposed within multiple layers of sedimentary rock. The recognition of underprints has been used to explain the lack of fine detail observed in some fossilized tracks (Lockley, 1991). The absence of such details as skin imprints, digital pad impressions, and claw marks, is interpreted as being lost when the foot impression is transmitted progressively through the sequence of deeper, thinly-layered sediments as the animal stepped down (Lockley, 1991; Thulborn, 1990; Brand and Kramer, 1996). However, Nadon (2001) asserted that some reported undertracks are actually true tracks and their lack of detail is not due to underprinting. Rather, they are due to poor preservation of the substrate, track morphology, and erosion of the track casts (during the infilling of the track by sediment). The best evidence for underprints is the presence of tracks and trackways that are exposed in multiple sedimentary layers (that are) deeper than the original track surface (Brand and Kramer, 1996). YBR demonstrates both true track and undertrack preservation, with several areas showing excellent preservation of multiple layers deep to the track surfaces (which vary in thickness from 2 mm to 3 cm). These underprints allow better opportunity for preservation, since the layers of sediment they are found in are already buried and not as susceptible to erosion or cracking through desiccation. The presence of underprints also provides information on the substrate the dinosaurs were walking across. The transmission of track imprints through successive layers of substrate suggests a certain amount of plasticity to the sediment, due to cohesiveness from water saturation, microbial film, and early rim cement.

Interpretations

Depositional environment

The limestone unit in the Canyon Springs Member at YBR represents a tidal flat environment that evolved from rising tectonic highs during Middle Jurassic time, which influenced fluctuating sea levels. The tracks are preserved on a tidally influenced near-shore, intertidal environment. The basal unit of the Lower Sundance, in which the tracks are found, has typically been interpreted to be a transgressive phase of the Sundance Sea (Brenner and Peterson, 1994; West, 1985; Imlay, 1980). Schmude's (2000) Black Mountain High provides the uplift needed to cause a minor regressive (emergent) event that would help explain the presence of dinosaurs in what is traditionally thought of as a totally marine sequence within

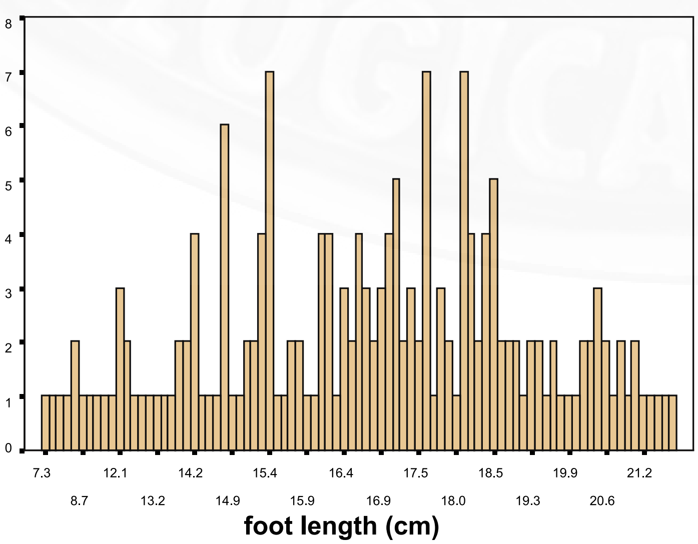

Figure 29. Size-frequency distribution of track foot lengths from Yellow Brick Road (cm), N = 180.

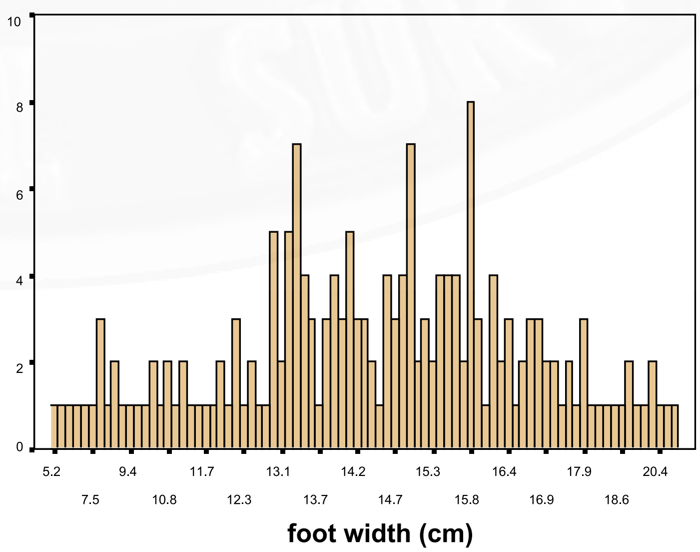

Figure 30. Size-frequency distribution of foot widths from Yellow Brick Road (cm), N = 184.

Figure 31. Example of a trackway at Yellow Brick Road. Arrows indicate locations of tracks in middle of photograph.

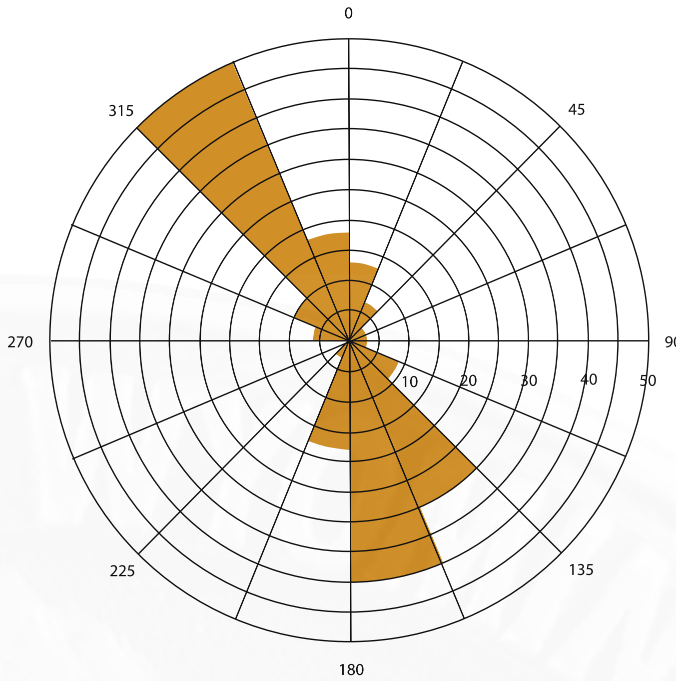

Figure 32. Rose diagram of track azimuths at Yellow Brick Road, N = 213.

the Bighorn Basin. As the epicontinental sea was regressing, the former area of deposition became more exposed. Later, the track horizon was buried and even later subaerially exposed, allowing evaporative, cubic salt crystals to form within the track layer. The overlying shales of the Stockade Beaver Member represent the transgressive event within the Bighorn Basin; the Stockade Beaver was deposited in an open marine environment (Newsome, 1999).

Paleoenvironment/paleoecology

Knowing that there was a regressing seaway at the time of the Canyon Springs Member, we can now make interpretations as to the paleoenvironment in which these dinosaurs were interacting. It has been stated that the limestone surface was subaerially exposed at the time the dinosaurs were walking across the tidal flat (Keller, 2001; Kvale and others, 2001). The lack of micrite within the track substrate suggests that the track surface was still tidally dominated and may represent the regressive interval between being entirely submerged to being subaerially exposed. The wide range of morphology and preservation of track features may be due to substrate consistency and plasticity, a factor of early cementation, microbial film, and cohesiveness from water saturation. The limestone substrate in the process of being partially lithified before complete exposure would explain the excellence preservation of the footprints and the development of undertracks. With this in mind, it is possible that the footprints were generated under very shallow subaqueous conditions or just after high tide has receded. This subaqueous condition does not need to be very deep and may simply represent an interval of high tide.

The correlation of tracks between YBR and RGDT suggest that they are part of a single, larger ichnofaunal province (Breithaupt and others, 2003). Statistical analysis of track measurements (**Table 18**), along with an independent research project to determine the number of dinosaur taxa represented in the Bighorn Basin tracksites (Sizemore, 2000), demonstrate that the trackmakers were small- to medium-sized theropod dinosaurs, representing a single ichnotaxon of possible different ages (**Figure 34**). Based on the evidence collected and the criteria set by Farlow (1987), identification of the trackmaker can only be stated to be a theropod (bipedal, carnivorous) dinosaur. Since there are essentially no records of Middle Jurassic dinosaur skeletal fossils being discovered in North America, no further identification can be made as to genera (Weishampel, 1990). The wide range of morphology and preservation of track features may be due

Figure 33. Example of undertrack preservation at Yellow Brick Road, with tracks preserved on both the upper and lower layers of the limestone surface.

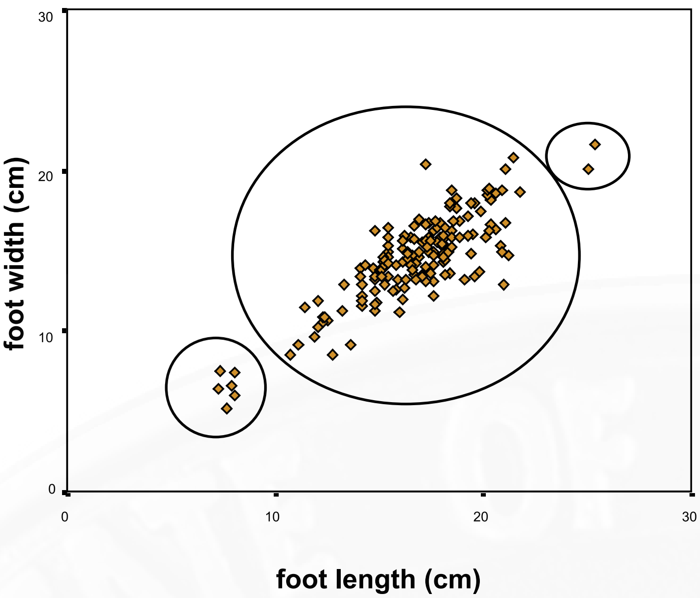

Figure 34. Scatter diagram correlating foot length and foot width. Distribution falls into three size classes, possibly representing age classes, N = 180.

to substrate consistency and plasticity. Faint heel impressions and variation of interdigital angles on some tracks can be contributed to plunging tracks, where the foot moves forward and downward as the track impression is being created. Faint heel impressions can also be explained by the observation that some tracks are underprints, where the heels are poorly preserved.

Ostrom (1972) showed that parallel to near-parallel trackway orientations most likely represented a single event—a result of trackmaker gregariousness, as opposed to random behavior. The majority of trackways at RGDT indicate gregarious behavior of the trackmakers, with preferred orientations like those discussed above (Breithaupt and others, in review; 2002). Nevertheless, Coombs (1990) pointed out that many present day social animals show strong internal cohesion while moving randomly within their environment. With the multiple orientations of individual dinosaur trackways at YBR representing a single ichnotaxon occupying a particular area, gregarious behavior has been inferred to this unique population of carnivorous dinosaurs (**Figure 35**).

We propose that the dinosaurs (**Cover**) were possibly involved in foraging behavior on a nutrient rich, ancient tidal flat, as opposed to migrating. Evidence from invertebrate fossils found within the limestone suggests that this type of environment would supply an abundant source of food for theropod dinosaurs (Molles, 1999). The monospecific ichnocoenoses (a single assemblage of tracks, preserved at a single horizon) of the tracksite may represent individuals ranging from adults to juveniles, providing additional evidence for gregarious behavior (**Figure 36**) (Lockley and others, 1994; Coombs, 1990). The number of Middle Jurassic tracks present in the Bighorn Basin may represent three possible scenarios for gregarious dinosaurs: (1) a small group of theropods foraging over a longer period of time; (2) a large group foraging over a short time span; and (3) the presence of multiple track layers representing multiple intervals. Thus, the preserved activity of dinosaurs in the Bighorn Basin provides a unique glimpse of a Middle Jurassic dinosaur community with possible family structure (Breithaupt and others, in review; 2003).

Summary

The YBR is an important, new vertebrate paleontological locality in northern Wyoming. At this site, thousands of dinosaur footprints are known, making this site the largest track locality within a newly defined "Sundance Vertebrate Ichnofaunal Province" (Breithaupt and others, 2003). The tracks are attributed to theropod (bipedal, carnivorous) dinosaurs representing a single and possibly new ichnotaxon. They are found in the approximately 167-million-year-old Canyon Springs Member of the Sundance Formation during a minor regressive event. They are preserved in an oolitic, gray limestone that has undergone alteration with dolomite replacement. The dinosaur tracks were probably developed on an ancient, sub-tropical intertidal zone under tide-dominated conditions. This interpretation suggests that the near-shore environment could possibly provide a nutrient-rich source for a large group of theropod dinosaurs. The tracks within the Bighorn Basin represent a family grouping of adults and juveniles, demonstrating gregarious behavior.

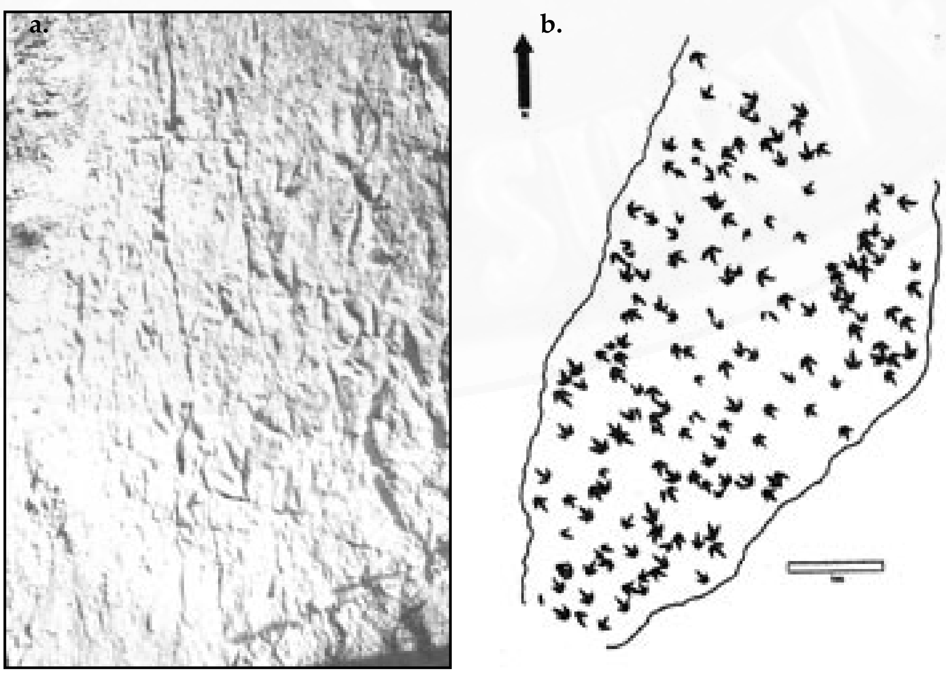

Figure 35. (a) Limestone surface of Yellow Brick Road with numerous tracks (YBRC5crp) and (b) track map showing track density and orientation.

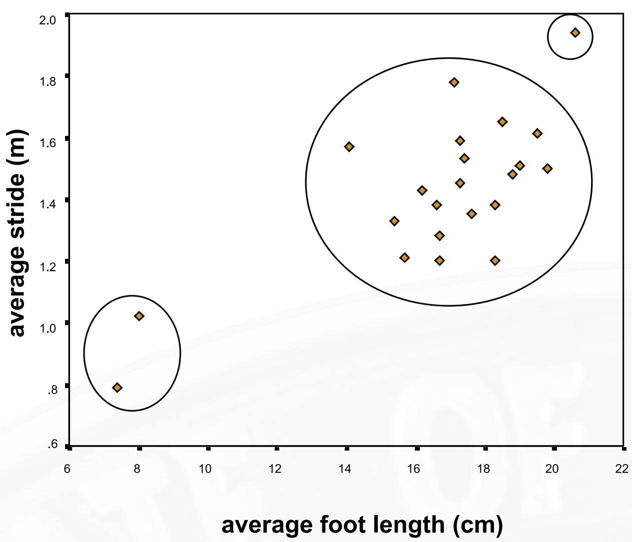

Figure 36. Scatter diagram correlating average foot length and average stride. Distribution falls into three size classes, possibly representing age classes, N = 22.

This study has provided a better understanding of the activity patterns and behavior of a previously unknown Middle Jurassic dinosaur fauna, the environment, and the geological setting in which their tracks were preserved. This undergraduate research study has provided valuable experience in setting up research projects, collecting data in the field, and interpreting these data. The research project illustrates the educational potential for paleontological resources on State lands in Wyoming.

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To facilitate the thorough documentation of the YBR, the authors utilized a diversity of volunteers to assist in investigating the site and documenting the paleontological resources. Appreciation is extended to all of the students and volunteers who devoted hundreds of hours of their time to assist us in the research. In particular, Neffra Matthews, Beth Southwell, Jana Sizemore, Don Hopkins, Terry Lumme, Bob Wallin, and Pat Monaco were instrumental in the documentation of the YBR. Funding for this project was made possible by EPSCoR, the Jurassic Foundation, the Geological Museum, and a Chevron Research Scholarship through the Department of Geology and Geophysics at UW. This project is dedicated to the memory of Donald L. Adams.

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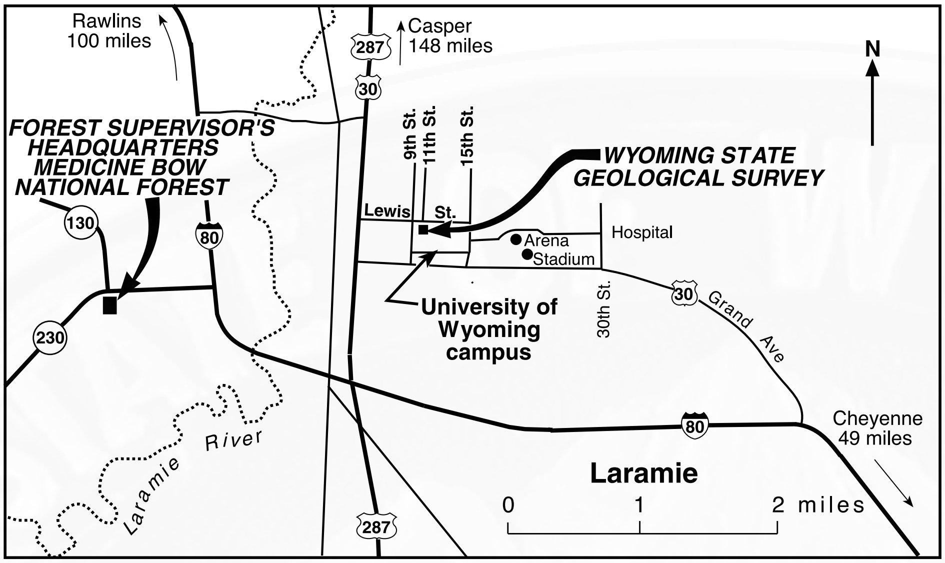

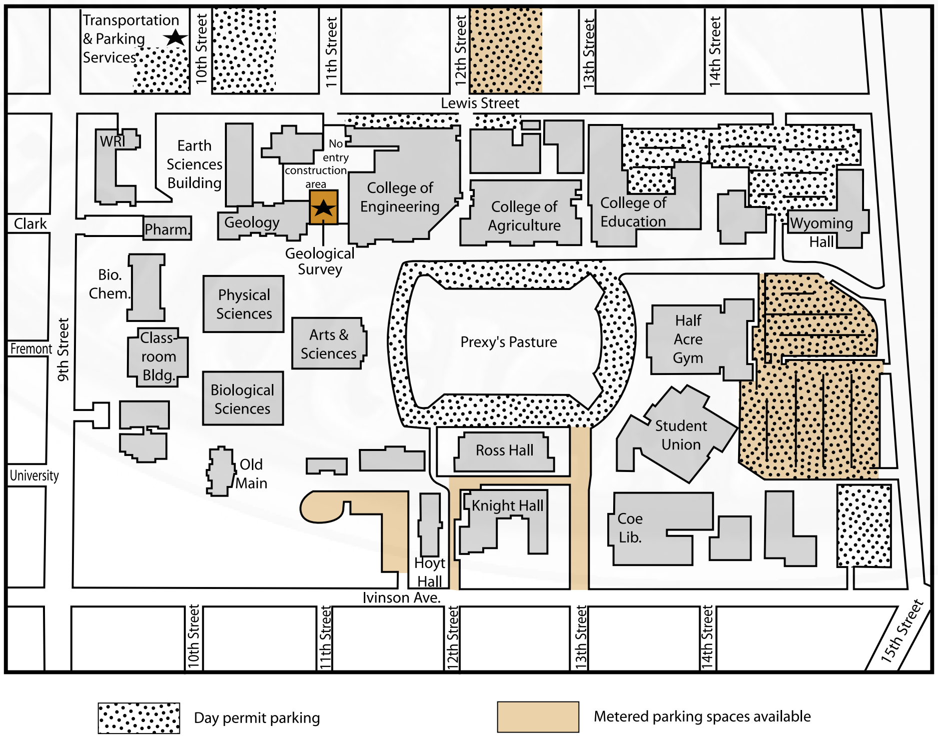

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