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Gary B. Glass, State Geologist

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WYOMING GEO-NOTES
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Cover: *Triceratops* (pronounced "try-sair-uh-tops"), designated the Wyoming State Dinosaur in 1994, roamed throughout Wyoming and North America about 75 million years ago. Named for its three large facial horns (*Triceratops* means literally "three-horned face"), *Triceratops* was one of the first dinosaurs discovered in Wyoming. *Triceratops* was a plant-eating dinosaur that may have traveled in herds, feeding on the lush vegetation that existed at that time. The animal may have attained a weight of 6 tons and a length of about 30 feet. (Reproduced from a painting by Phyllis A. Ranz, 1995).

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MINERALS UPDATE

OVERVIEW

Gary B. Glass
State Geologist, Wyoming State Geological Survey

This issue of Wyoming Geo-notes reflects the most recent production and price forecasts used by the State's Consensus Revenue Estimating Group (CREG). As suggested in the last issue, there have been some substantial changes in the forecasts, and most are downward at least for the short term.

Starting with production, the production forecasts for oil, methane, trona, and uranium have been lowered for all years in the forecast (**Table 1**). In regard to oil, the lowered forecast is a result of an oversupply of oil and the resulting low prices. While the decline in oil production is expected to accelerate over the next two years, it is felt that the decline will gradually taper off (**Table 1** and **Figure 1**). The rapid decline in the next two years is a function of the low prices now paid for a barrel of oil. Low prices are causing the shutting in or abandonment of low yield, higher cost wells and the potential bankruptcy of some operators.

The lowered forecast for methane production reflects a slower growth in demand for Wyoming's natural gas, but the estimate still reflects anticipated

Table 1. Wyoming mineral production (1985-1997) with forecasts to 2005[1].

Calendar Year	Oil[2,3]	Methane[3,4]	Carbon Dioxide[3,4]	Helium[4,5]	Coal[6]	Trona[7]	In-situ Uranium[7,8]	Sulfur[3,9]
1985	131.0	597.9	—	—	140.4	10.8	N/A	0.80
1986	122.4	563.2	23.8	0.15	135.4	11.9	0.05	0.76
1987	115.9	628.2	114.2	0.86	146.5	12.4	0.00	1.19
1988	114.3	700.8	110.0	0.83	163.6	15.1	0.09	1.06
1989	109.1	739.0	126.1	0.94	171.1	16.2	1.1	1.17
1990	104.0	777.2	119.9	0.90	184.0	16.2	1.0	1.04
1991	99.8	820.0	140.3	1.05	193.9	16.2	1.0	1.18
1992	97.0	871.5	139.2	1.05	189.5	16.4	1.2	1.20
1993	89.0	912.8	140.8	1.06	209.9	16.0	1.2	1.14
1994	80.2	959.2	142.6	1.07	236.9	16.1	1.2	1.10
1995	75.6	987.5	148.8	1.11	263.9	18.4	1.3	1.20
1996	73.9	1,023.4	149.0	1.10	278.4	18.6	1.9	1.22
1997	70.2	1,040.3	151.0	1.10	281.5	19.4	2.2	1.23
1998	63.2	1,052.9	151.0	1.10	301.7	18.5	2.5	1.20
1999	59.6	1,064.8	151.0	1.10	319.8	18.2	2.5	1.20
2000	54.0	1,089.1	151.0	1.10	339.0	18.2	2.5	1.20
2001	51.3	1,113.9	151.0	1.10	350.5	18.4	2.5	1.20
2002	48.8	1,139.2	151.0	1.10	354.0	18.6	2.5	1.20
2003	46.3	1,165.1	151.0	1.10	357.5	18.8	2.5	1.20
2004	44.0	1,191.4	151.0	1.10	361.1	19.0	2.5	1.20
2005	41.8	1,218.3	151.0	1.10	364.7	19.2	2.5	1.20

[1]Modified from CREG's Wyoming State Government Revenue Forecast, October, 1998; [2]Millions of barrels; [3]Wyoming Oil & Gas Conservation Commission, 1985-1997; [4] Billions of cubic feet; [5]Based on Exxon's estimate that the average helium content in the gas processed at Shute Creek is 0.5%; [6]Millions of short tons (Wyoming State Inspector of Mines, 1985-1997); [7]Wyoming Department of Revenue, 1985-1997; [8]Millions of pounds of yellowcake (not available [N/A] for 1985 and previous years because it was only reported as taxable value); [9]Millions of short tons.

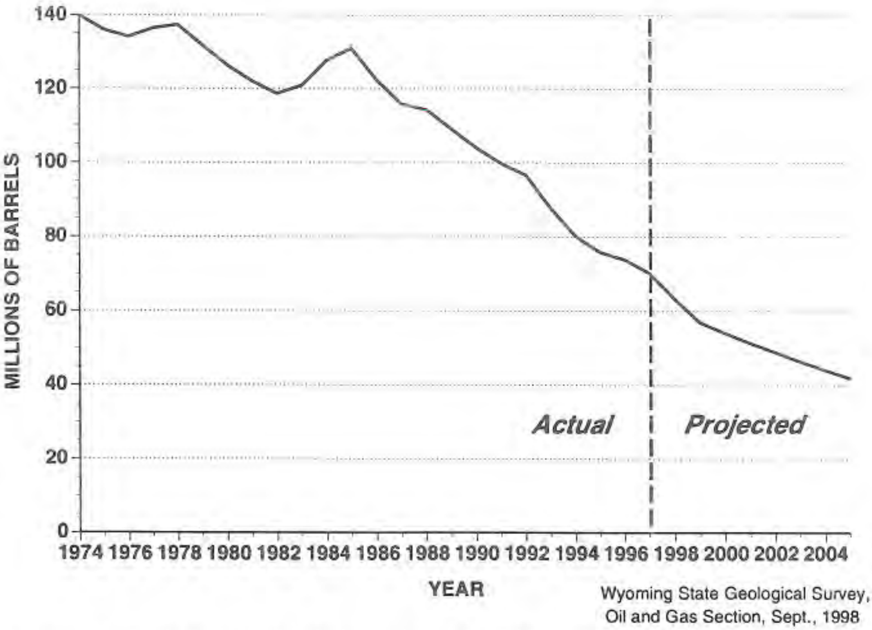

Figure 1. Annual oil production from Wyoming (1974 to 1997) with forecasts to 2005.

growth (**Table 1** and **Figure 2**). The lowered demand is a function of competition both from domestic and Canadian competitors.

The lowered forecast for trona is mostly a reflection of the Asian financial crisis as the growth market for the trona industry's major product, soda ash, is in exports, including Asian markets (**Table 1**). While demand for soda ash in the areas affected by the Asian financial troubles has decreased, it is expected to recover. And there are other markets, such as South America, that may help offset diminished demand from the Asian markets. The forecast shows a plateau in growth for several years, but it also shows growth after that. The trona industry in Wyoming primarily competes with foreign manufacturers of synthetic soda ash, but they also have one competitor in California and a new competitor slated for Colorado.

The forecast for uranium also shows a lowered estimate of anticipated production (**Table 1**). Here again, there is currently an oversupply and at relatively low prices. The oversupply is now exacerbated by the possibility that the U.S. Enrichment Corporation (USEC) may sell uranium to reduce its debt (see p. 37 in this issue).

On a positive note, the forecast for coal production has been increased throughout the forecast period, as record deliveries of Wyoming coal continue (**Table 1** and **Figure 3**). It now looks like coal production will top 301 million short tons in 1998.

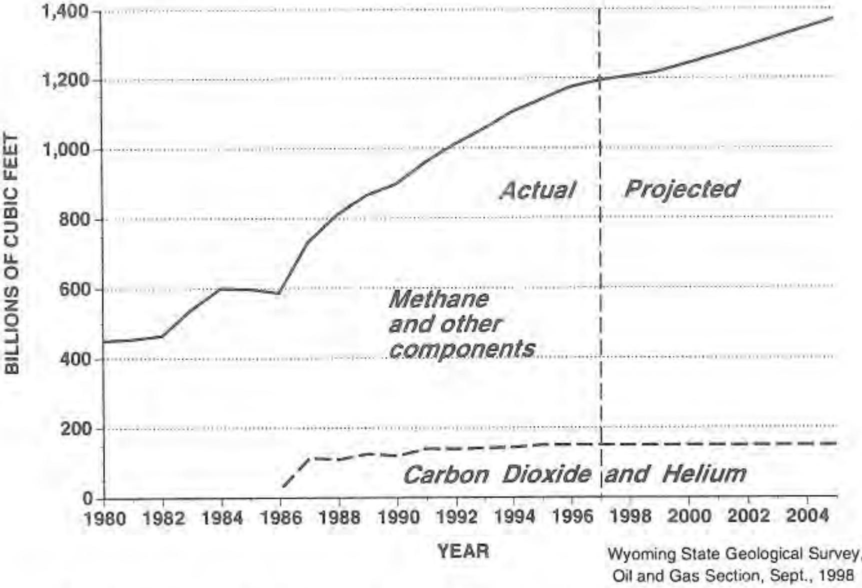

Figure 2. Annual natural gas production from Wyoming (1980 to 1997) with forecasts to 2005.

In regard to prices, the forecasts for oil, coal, and trona were lowered (**Table 2**). Although the price of oil was lowered to $10.50 for 1998 and 1999, it was again forecast at the more traditional $15.00 between 2000 and 2005 (**Table 2** and **Figure 4**).

Coal prices were lowered for the entire forecast period, based on a softening of price (**Table 2** and **Figure 5**). While demand continues to increase, supply has kept up with it, allowing the price to remain low. Within the next few years, however, most of the remaining long-term, higher priced contracts that have offset the lower spot sale prices for some operators will have expired or been bought out. For that reason, the forecast shows a flattening of the present price decline at $5.04 in 2001.

Forecast trona prices also reflect the softened market caused by the crisis in Asian finances (**Table 2**). The forecast shows the price recovering and increasing by 2000.

Unlike oil, coal, and trona, the forecast for methane prices has been revised upwards, reflecting a growing market and a fairly stable price (**Table 2** and **Figure 6**). While the $1.85 forecast for 1998 is nine cents below the $1.95 realized in 1997, the forecast is for an average price of $1.75 for the other years of the estimate. The $1.75 is 25 cents higher than the average price over the last 10 years, which has been about $1.50.

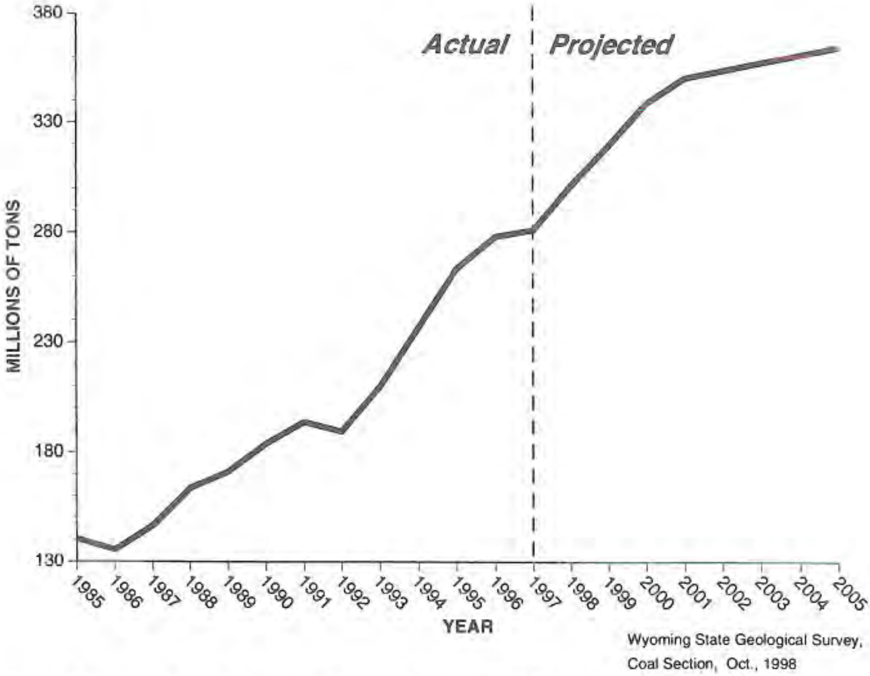

Figure 3. Annual coal production from Wyoming (1985-1997) with forecasts to 2005. Sources: The Wyoming State Inspector of Mines (1985-1997) and the Wyoming Census Revenue Estimating Group (1998-2005).

While the price of uranium is not specifically forecast, there are some that see it declining to as low as $6.00 per pound of yellowcake. At the end of the third quarter, the price was under $10.00 (see p. 38 in this issue).

In regard to other minerals, interest in construction aggregate, diatomite, and dimensional stone are among the items discussed in the **Industrial Minerals and Uranium Update**. The **Metals and Precious Stones Update** features discussions on diamond exploration, platinum group metals, iron and titanium, and disseminated gold. The **Rock Hound's Corner** provides the second part of a two-part article on quartz and chalcedony in Wyoming.

The Red Gulch dinosaur tracksite and new fossil discoveries are among the items featured in the **Geologic Mapping, Paleontology, and Stratigraphy Update**.

This issue also includes the third and last part of an article on Wyoming's study of the sensitivity of its aquifers to contamination (p. 58).

Table 2. Average prices paid for Wyoming oil, methane, coal, and trona (1985-1997) with forecasts to 2005[1].

Calendar Year	Oil[2]	Methane[3]	Coal[4]	Trona[5]
1985	24.67	3.03	11.36	35.18
1986	12.94	2.33	10.85	34.80
1987	16.42	1.78	9.80	36.56
1988	13.43	1.43	9.16	36.88
1989	16.71	1.58	8.63	40.76
1990	21.08	1.59	8.43	41.86
1991	17.33	1.46	8.06	44.18
1992	16.38	1.49	8.13	43.81
1993	14.50	1.81	7.12	40.08
1994	13.67	1.63	6.62	38.96
1995	15.50	1.13	6.38	40.93
1996	19.56	1.46	6.15	45.86
1997	17.41	1.94	5.68	42.29
1998	10.50	1.85	5.42	41.29
1999	10.50	1.75	5.31	39.91
2000	15.00	1.75	5.17	40.26
2001	15.00	1.75	5.04	41.24
2002	15.00	1.75	5.04	42.04
2003	15.00	1.75	5.04	42.53
2004	15.00	1.75	5.04	42.96
2005	15.00	1.75	5.04	43.15

[1] Modified from CREG, Wyoming State Government Revenue Forecast, October, 1998; [2] First purchase price in dollars per barrel (weighted average price for sweet, sour, heavy, stripper, and tertiary oil). Source: Energy Information Administration, 1985-1997; [3] Wellhead price in dollars per thousand cubic feet (MCF). Source: Wyoming Office of State Lands and Investments, 1989-1997 (derived from State royalty payments); Minerals Management Service, 1985-1988 (derived from Federal royalty payments); [4] Dollars per short ton (weighted average price for coal mined by surface and underground methods). Source: Energy Information Administration, 1985-1990 and derived from Department of Revenue, 1991-1997; [5] Dollars per ton of trona, not soda ash. Source: Wyoming Department of Revenue, 1985-1997.

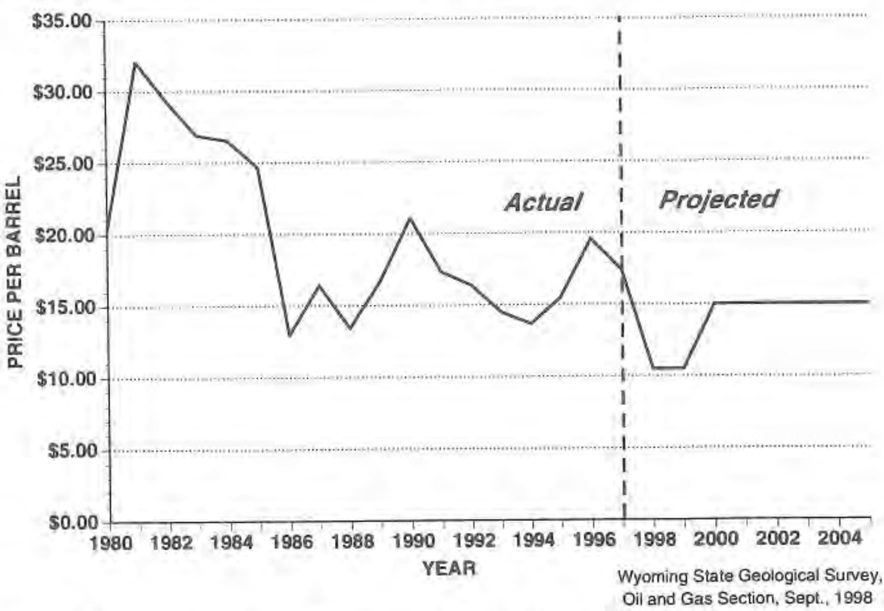

Figure 4. Average prices paid for Wyoming oil (1980 to 1997) with forecasts to 2005.

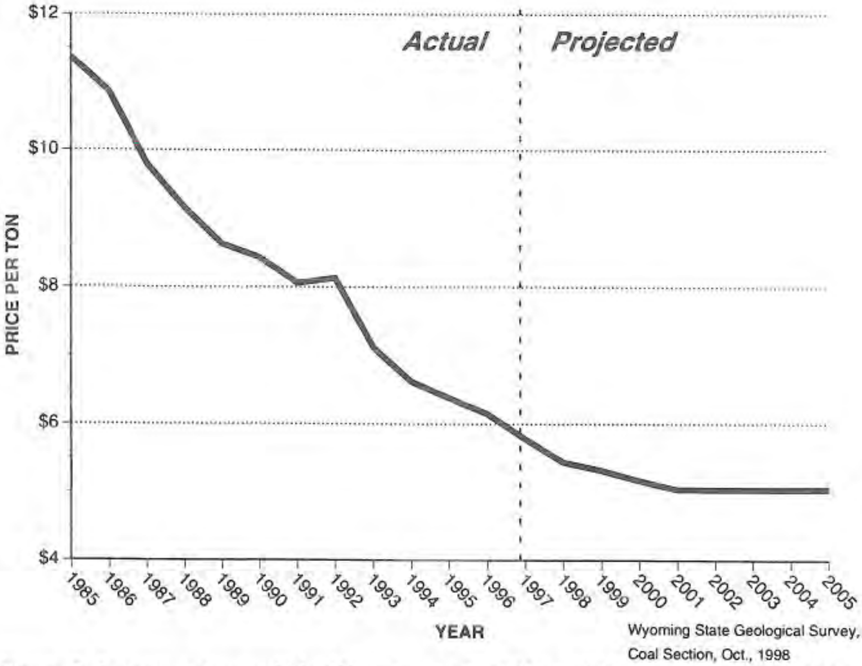

Figure 5. Average prices paid for Wyoming coal (1985 to 1997) with forecasts to 2005. Sources: U.S. Energy Information Administration (1985-1990); Wyoming Department of Revenue (1991-1997); and Wyoming Census Revenue Estimating Group (1998-2005).

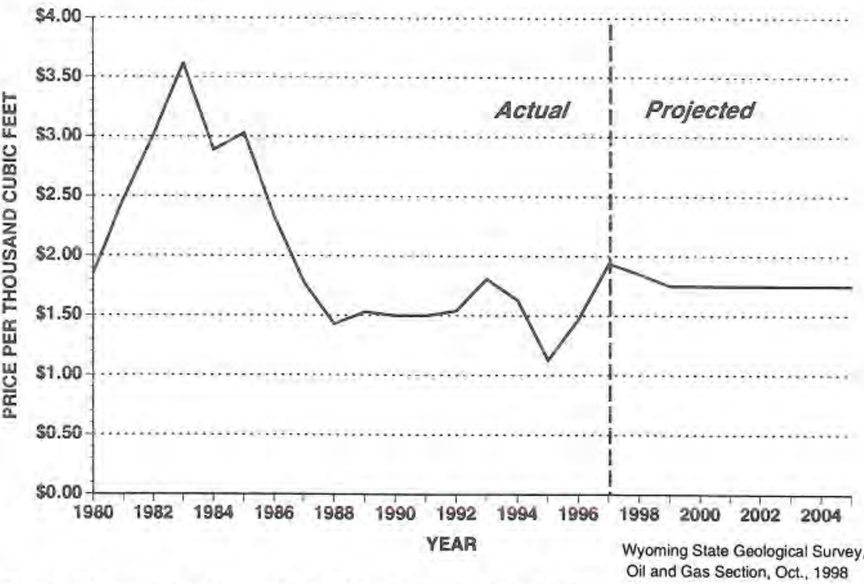

Figure 6. Average prices paid for Wyoming methane (1980 to 1997) with forecasts to 2005.

OIL AND GAS UPDATE

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

During the third quarter of 1998, prices paid to Wyoming oil producers averaged $10.34 per barrel, which is $6.10 lower than for the third quarter of 1997. By the end of the quarter, September's average price had risen to $11.00 per barrel, which was the highest since May (**Table 3**). **Figure 7** shows the posted Sweet and Sour crude prices and first purchase price for Wyoming oil averaged by month.

Oil production in Wyoming for the first half of 1998 was 32.8 million barrels (**Table 4**), according to figures from Petroleum Information/Dwights LLC (PI/D). This production is a drop of about 6.3% from last year's first-half oil production, as reported by PI/D. It is expected that production will decline even faster, if prices remain below $15 per barrel for an extended period.

Spot prices for methane at Opal, Wyoming, averaged $1.65 per thousand cubic feet during the third quarter of 1998. This is 20 cents higher than last year's third-quarter average price of $1.45 per thousand cubic feet. For the first three quarters of 1998, methane averaged $1.79 per thousand cubic feet (**Table 5** and **Figure 8**).

Natural gas production in Wyoming for the first half of 1998 was 590.7 billion cubic feet according to production figures from PI/D (**Table 6**). Production in the first half of 1998 was up only 0.5% from first-half production in 1997, as reported by PI/D.

Table 3. Monthly average price of a barrel of oil produced in Wyoming (1995 to September, 1998).

	1995		1996		1997		1998	
	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative
JAN	$14.77	$14.77	$16.38	$16.38	$22.56	$22.56	$12.79	$12.79
FEB	$15.55	$15.16	$16.28	$16.33	$19.45	$21.01	$12.16	$12.48
MAR	$15.26	$15.19	$18.63	$17.09	$17.99	$20.00	$10.97	$11.97
APR	$16.73	$15.58	$20.29	$17.90	$16.81	$19.20	$11.54	$11.87
MAY	$16.65	$15.79	$18.85	$18.08	$17.74	$18.91	$11.19	$11.73
JUN	$15.52	$15.75	$18.15	$18.10	$15.90	$18.41	$9.63	$11.38
JUL	$14.50	$15.57	$18.98	$18.22	$16.29	$18.11	$10.21	$11.21
AUG	$15.09	$15.51	$19.59	$18.39	$16.61	$17.92	**$9.50**	**$11.00**
SEP	$15.41	$15.50	$21.48	$18.74	$16.42	$17.75	**$11.00**	**$11.00**
OCT	$14.67	$15.42	$22.63	$19.13	$17.89	$17.77		
NOV	$15.32	$15.41	$21.19	$19.31	$16.51	$17.65		
DEC	$16.43	$15.50	$22.42	$19.56	$14.72	$17.41		
Avg. yearly price		**$15.50**		**$19.56**		**$17.41**		

Source: All averages are derived from published monthly reports by the Energy Information Administration, except that averages in bold print in 1998 are estimated from various unpublished bulletins listing posted prices.
Wyoming State Geological Survey, Oil and Gas Section, October, 1998.

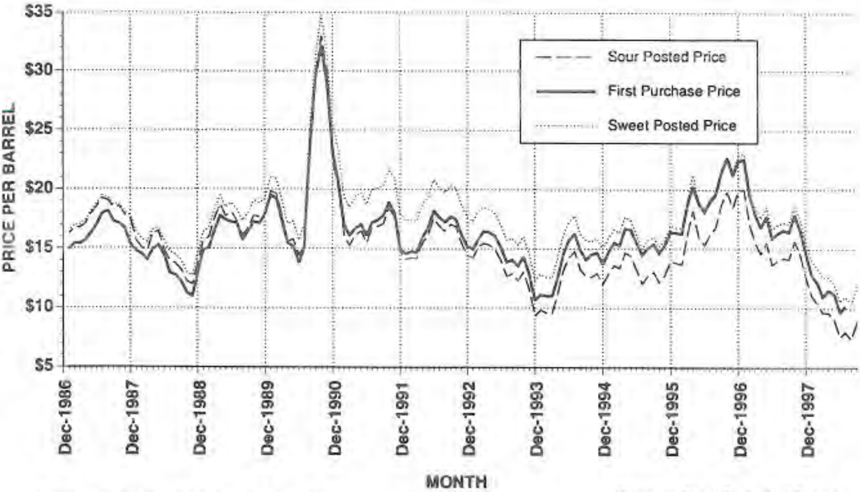

Figure 7. Wyoming posted sweet and sour crude oil prices and first purchase prices, averaged by month (January, 1987 to September, 1998).

In a related item, production figures from the Wyoming Oil and Gas Conservation Commission show that coalbed methane wells in the Powder River Basin produced 2.1 billion cubic feet of gas during the month of May.

Devon Energy acquired both producing and undeveloped coalbed methane properties in the Powder River Basin. Devon reportedly paid $15.4 million to an undisclosed seller for a 35% working interest in 42 producing coalbed methane wells on the north end of Kitty Field and interests in 74 coalbed methane wells that are waiting for pipeline connections.

Devon Energy and KN Energy signed a letter of intent to form Thunder Creek Gas Services, LLC. The new company plans to build and operate a 126-mile gas gathering system and associated facilities in the Powder River Basin. Plans are for a 24-inch pipeline that would extend from Gillette to Glenrock. The new system would cost an estimated $110 million, would have a capacity of 450 million cubic feet of gas per day, and would have access to several interstate pipelines. The pipeline would transport coalbed methane as well as conventional natural gas.

Western Gas Resources and an affiliate of Colorado Interstate Gas also announced plans to build a 20-inch pipeline that would be 90 miles long, would gather 200 million cubic feet of coalbed methane per day in the Powder River Basin, and would also access several interstate pipelines.

Jonah Gas Gathering and Mountain Gas Resources plan to build 54 miles of 16- and 20-inch pipeline between Jonah Field and Mountain Gas Resource's gas processing plant at Granger and 25 miles of pipeline that would tie into the

Table 4. Monthly oil production from Wyoming in barrels (1995 to June, 1998).

	1995		1996		1997		1998	
	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative
JAN	6,700,000	6,700,000	6,153,037	6,153,037	5,964,848	5,964,848	5,837,432	5,837,432
FEB	6,100,000	12,800,000	5,693,084	11,846,121	5,459,518	11,424,366	5,221,262	11,058,694
MAR	6,300,000	19,100,000	6,176,805	18,022,926	6,014,780	17,439,146	5,743,050	16,801,744
APR	6,200,000	25,300,000	5,977,362	24,000,288	5,729,869	23,169,015	5,453,891	22,255,635
MAY	6,300,000	31,600,000	6,035,505	30,035,793	6,050,971	29,219,986	5,242,070	27,497,705
JUN	6,200,000	37,800,000	5,916,019	35,951,812	5,761,549	34,981,535	5,285,352	32,783,057
JUL	6,300,000	44,100,000	6,076,992	42,028,804	5,964,005	40,945,540		
AUG	6,100,000	50,200,000	6,414,850	48,443,654	5,868,789	46,814,329		
SEP	6,100,000	56,300,000	6,180,180	54,623,834	5,710,557	52,524,886		
OCT	6,300,000	62,600,000	6,186,019	60,809,853	5,949,974	58,474,860		
NOV	6,100,000	68,700,000	6,221,912	67,031,765	5,800,811	64,275,671		
DEC	6,300,000	75,000,000	6,330,701	73,362,466	5,900,791	70,176,462		
Total Barrels Reported [1]		**75,000,000**		**73,362,466**		**70,176,462**		
Total Barrels Not Reported [2]		**554,113**		**525,957**		**52,364**		
Total Barrels Produced [3]		**75,554,113**		**73,888,423**		**70,228,826**		

[1] Monthly production reports from Petroleum Information/Dwights LLC, except for 1995, which is estimated by the Wyoming State Geological Survey.

[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, October, 1998.

Table 5. Monthly average spot sale price for a thousand cubic feet (MCF) of natural gas at Opal, Wyoming (1995 to September, 1998).

	1995		1996		1997		1998	
	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative
JAN	$1.40	$1.40	$1.25	$1.25	$3.90	$3.90	$2.05	$2.05
FEB	$1.10	$1.25	$1.20	$1.23	$2.50	$3.20	$1.70	$1.88
MAR	$1.05	$1.18	$1.20	$1.22	$1.40	$2.60	$1.90	$1.88
APR	$1.05	$1.15	$1.05	$1.18	$1.45	$2.31	$1.90	$1.89
MAY	$1.10	$1.14	$0.95	$1.13	$1.60	$2.17	$1.95	$1.90
JUN	$1.15	$1.14	$1.10	$1.13	$1.35	$2.03	$1.65	$1.86
JUL	$1.00	$1.12	$1.20	$1.14	$1.45	$1.95	$1.60	$1.82
AUG	$0.90	$1.09	$1.25	$1.15	$1.40	$1.88	$1.75	$1.81
SEP	$1.05	$1.09	$1.20	$1.16	$1.50	$1.84	$1.60	$1.79
OCT	$1.05	$1.09	$1.30	$1.17	$2.05	$1.86		
NOV	$1.25	$1.10	$2.45	$1.29	$3.00	$1.96		
DEC	$1.30	$1.12	$3.50	$1.47	$1.95	$1.96		
Avg. yearly price		**$1.12**		**$1.47**		**$1.96**		

Source: American Gas Association's monthly reports except for the average yearly price, which comes from Wyoming's Office of State Lands and Investments.
Wyoming State Geological Survey, Oil and Gas Section, October, 1998.

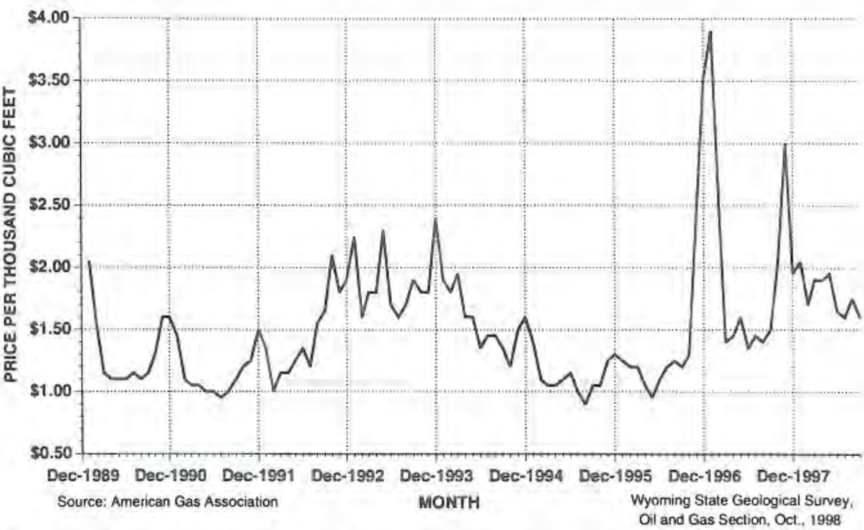

Figure 8. Spot sale prices for methane at Opal, Wyoming, averaged by month (January, 1990, to September, 1998).

new line and take gas to Opal. The new pipeline would move up to 350 million cubic feet of gas per day. The U.S. Bureau of Land Management has issued an Environmental Assessment for the project.

The U.S. Department of Energy (1998) released its new reserve estimates for crude oil, natural gas liquids, and natural gas. **Table 7** shows Wyoming's relative ranking among the top ten states in proved reserves of crude oil and dry natural gas. At the end of 1997, Wyoming ranked third in natural gas reserves and sixth in crude oil reserves. **Table 8** shows that Wyoming's natural

Table 6. Monthly natural gas production from Wyoming in thousands of cubic feet (MCF) (1995 to June, 1998).

	1995		1996		1997		1998	
	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative
JAN	100,224,249	100,224,249	101,359,648	101,359,648	99,579,818	99,579,818	103,374,940	103,374,940
FEB	86,691,577	186,915,826	96,303,300	197,662,948	91,766,159	191,345,977	94,030,315	197,405,255
MAR	94,344,991	281,260,817	103,541,127	301,204,075	104,157,578	295,503,555	102,947,109	300,352,364
APR	93,929,323	375,190,140	99,479,609	400,683,684	99,459,039	394,962,594	97,563,591	397,915,955
MAY	95,791,327	470,981,467	97,900,863	498,584,547	101,070,371	496,032,965	94,920,667	492,836,622
JUN	92,140,614	563,122,081	87,069,612	585,654,159	91,905,308	587,938,273	97,862,992	590,699,614
JUL	92,796,301	655,918,382	100,219,275	685,873,434	100,129,497	688,067,770		
AUG	90,393,416	746,311,798	99,874,019	785,747,453	97,673,622	785,741,392		
SEP	92,589,092	838,900,890	93,510,551	879,258,004	100,028,888	885,770,280		
OCT	98,386,458	937,287,348	95,441,022	974,699,026	102,206,875	987,977,155		
NOV	94,939,660	1,032,227,008	94,015,007	1,068,714,033	100,752,128	1,088,729,283		
DEC	99,314,617	1,131,541,625	99,141,298	1,167,855,331	103,415,430	1,192,144,713		
Total MCF Reported [1]		**1,131,541,625**		**1,167,855,331**		**1,192,144,713**		
Total MCF Not Reported [2]		**6,448,396**		**5,663,874**		**683,432**		
Total MCF Produced [3]		**1,137,990,021**		**1,173,519,205**		**1,192,828,145**		

[1] Monthly production reports from Petroleum Information/Dwights LLC.

[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, October, 1998.

Table 7. Wyoming's 1997 ranking in proved reserves of crude oil (billions of barrels) and dry natural gas (trillions of cubic feet).

State	Crude Oil	State	Dry Natural Gas
Texas	5.687	Texas	37.761
Alaska	5.161	New Mexico	15.514
California	3.750	Wyoming	13.562
New Mexico	0.735	Oklahoma	13.439
Louisiana	0.714	Alaska	10.562
Wyoming	0.627	Louisiana	9.673
Oklahoma	0.605	Kansas	6.989
North Dakota	0.279	Colorado	6.828
Kansas	0.238	Alabama	4.968
Utah	0.234	West Virginia	2.846

Source: U.S. Department of Energy, 1998.

Table 8. Comparison of Wyoming's proved reserves of crude oil (billions of barrels), dry natural gas (trillions of cubic feet), and natural gas liquids (billions of barrels) for the years 1980 through 1997.

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

Source: U.S. Department of Energy, 1998.
[1] Estimated from U.S. Department of Energy figures.

gas reserves increased in 1997 to their highest level ever, despite record production. Reserves of crude oil and natural gas liquids also increased in 1997.

Natural gas was the top valued mineral in the State for the first time. Natural gas valuation totaled $1.43 billion for fiscal year 1998, followed by coal at $1.16 billion, oil at $1.09 billion, and trona at $259 million. The State's total assessed valuation of $7.44 billion was the highest since 1986.

The Federal Energy Regulatory Commission (FERC) approved an order that will allow Alliance Pipeline to construct and operate the U.S. portion of its pipeline system. The Alliance system is designed to carry natural gas from western Canada to the Chicago area. Gas carried by Alliance will compete with gas from the Rocky Mountain region for markets in the Midwest.

Leasing activity at the August U.S. Bureau of Land Management (BLM) sale was again concentrated in the Powder River Basin (**Figure 9**). Total revenue from the first four BLM sales this year is already $38.3 million, which is $6.3 million more than last year's record of nearly $32 million for six sales (**Table 9**). Miller & Tack made the sale's top per-acre bid of $500 for a 320-acre lease that covers the W/2 W/2 section 27 and E/2 E/2 section 28, T49N, R72W (location **A**, **Figure 9**). The parcel is about a half mile north of Minnelusa oil production at Mallard Field and half a mile southwest of Minnelusa oil production at Dry Gulch Field. There are also a number of staked locations for coalbed methane in the area. The sale's second high per-acre bid was $400 by Miller & Tack for a 477.19-acre parcel that covers parts of section 7, T49N, R73W (location **B**, **Figure 9**). The lease is within a mile of Muddy oil and gas production at Lazy B Field and about five miles northwest of several coalbed methane wells. The sale's third high per-acre bid was also by Miller & Tack for a 703.57-acre parcel that covers parts of sections 26, 27, and 35, T48N, R76W (location **C**, **Figure 9**). The parcel is less than a mile from Parkman oil and gas produc-

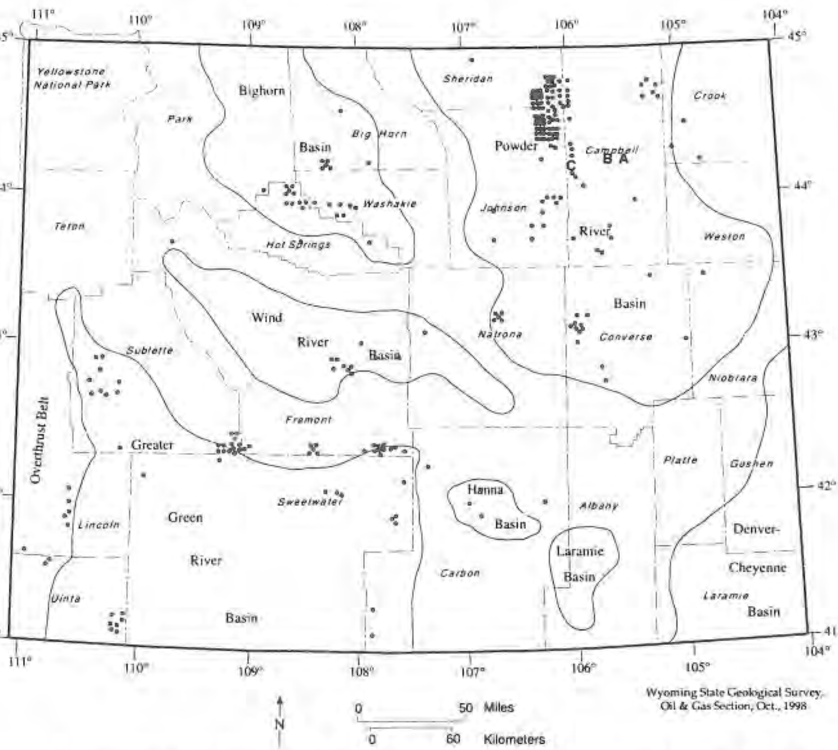

Figure 9. Locations of Federal oil and gas tracts leased by the U.S. Bureau of Land Management at its August, 1998, sale.

Table 9. Federal and State competitive oil and gas lease sales in Wyoming.

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
1995							
TOTAL	$13,047,246	2,649	1,264	2,326,988	1,109,711	$11.76	$1,100.00
1996							
TOTAL	$11,487,567	1,828	1,125	1,403,444	739,505	$15.53	$1,450.00
1997							
February	$2,463,137	267	210	222,486	148,148	$16.63	$250.00
April	$2,612,013	145	137	98,865	90,948	$28.72	$400.00
June	$4,642,113	285	249	313,519	262,682	$17.67	$310.00
August	$4,636,555	426	365	430,213	327,172	$14.17	$600.00
October	$12,133,207	286	227	234,561	169,264	$71.68	$400.00
December	$5,489,578	378	297	279,294	208,428	$26.34	$410.00
TOTAL	$31,976,603	1,787	1,485	1,578,938	1,206,642	$26.50	$600.00
1998							
February	$5,262,908	369	285	366,787	241,654	$21.78	$415.00
April	$10,287,111	247	227	192,561	162,393	$63.35	$395.00
June	$14,737,117	463	367	498,339	368,816	$39.96	$430.00
August	$8,033,029	306	245	349,605	278,095	$28.89	$500.00

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
1995							
TOTAL	$1,656,218	799	492	323,887	202,708	$8.17	$130.00
1996							
TOTAL	$2,325,497	1049	508	418,111	206,814	$11.24	$206.00
1997							
April	$719,005	300	189	119,436	80,548	$8.93	$170.00
June	$1,008,470	300	185	108,470	62,447	$16.16	$162.00
October	$627,935	300	165	102,802	63,003	$ 9.97	$115.00
December	$795,610	298	165	107,588	57,202	$13.91	$340.00
TOTAL	$3,151,020	1198	704	438,296	263,230	$11.97	$340.00
1998							
April	$1,203,792	300	161	115,646	63,848	$18.85	$320.00
June	$1,660,438	300	148	108,654	52,501	$31.63	$600.00

Sources: Wyoming Office of State Lands and Investments, Petroleum Information/Dwights LLC - Rocky Mountain Region Report, and U.S. Bureau of Land Management.

tion at Bogie Draw Field. In all, Miller & Tack accounted for 63% of the bonus bid total at this sale, and all but four of their leases were in the Powder River Basin. There were 44 tracts at this sale that received bids of $50 or more per acre.

There have been 1,720 Applications for Permit to Drill (APDs) in the first three quarters of 1998 (**Table 10**). APDs for the first three quarters are only 188 below the total for last year, and already have exceeded the number of APDs in either 1995 or 1996. Campbell County led with over 62% of the total APDs that were approved, and the majority of those were tests for shallow coalbed methane.

The Wyoming Oil and Gas Conservation Commission permitted 46 seismic projects in the first three quarters of 1998 (**Table 11**). The 1,275 square miles of 3-D seismic are already more than in the last three years, and the 401 conventional miles are more than in either 1995 or 1996.

The average daily rig count for the second quarter of 1998 was 41. This average is six more than in the second quarter of 1998, and is fairly high con-

Table 10. Number of Applications for Permit to Drill (APD) approved by the Wyoming Oil and Gas Conservation Commission (1995 through September, 1998).

County	1995 APDs	1996 APDs	1997 APDs	1998 APDs
Albany	1	1	0	0
Big Horn	16	53	59	11
Campbell	151	554	941	1075
Carbon	50	77	84	55
Converse	29	20	16	5
Crook	15	37	26	23
Fremont	30	26	58	51
Goshen	0	0	0	0
Hot Springs	13	24	42	0
Johnson	6	16	6	16
Laramie	10	2	3	2
Lincoln	64	55	122	80
Natrona	80	74	59	25
Niobrara	4	7	8	6
Park	20	30	25	11
Platte	0	0	0	0
Sheridan	0	0	2	16
Sublette	61	118	179	183
Sweetwater	153	136	210	130
Teton	0	0	0	0
Uinta	11	10	27	18
Washakie	31	30	36	8
Weston	10	10	5	5
Totals	**755**	**1280**	**1908**	***1720**

Source: All data are from the Wyoming Oil and Gas Conservation Commission.

*Number of APDs issued in the first three quarters of 1998.

Wyoming State Geological Survey, Oil and Gas Section, October, 1998.

Table 11. Number of seismic projects and miles permitted by the Wyoming Oil and Gas Conservation Commission (1995 through September, 1998).

	1995			1996			1997			1998		
County	Permits	Conventional Miles	3-D Sq Miles	Permits	Conventional Miles	3-D Sq Miles	Permits	Conventional Miles	3-D Sq Miles	Permits	Conventional Miles	3-D Sq Miles
Albany	0	0	0	1	18	0	0	0	0	0	0	0
Big Horn	1	16	0	2	3	66	2	0	45	0	0	0
Campbell	12	24	43	32	56	220	20	52	79	10	15	100
Carbon	1	0	16	2	5	18	3	7	190	3	0	221
Converse	4	39	20	1	4	0	1	5	0	3	12	230
Crook	1	0	5	5	3	20	7	8	18	2	2	4
Fremont	6	32	56	2	5	15	6	43	126	1	50	0
Goshen	0	0	0	0	0	0	2	227	0	0	0	0
Hot Springs	2	70	9	4	17	29	1	8	0	4	19	0
Johnson	1	4	0	0	0	0	2	7	17	1	4	0
Laramie	0	0	0	0	0	0	0	0	0	0	0	0
Lincoln	2	18	110	0	0	0	3	7	116	1	10	0
Natrona	3	27	3	0	0	0	5	14	101	5	3	214
Niobrara	0	0	0	2	0	23	0	0	0	0	0	0
Park	0	0	0	6	20	82	4	56	58	2	16	127
Platte	0	0	0	0	0	0	0	0	0	0	0	0
Sheridan	0	0	0	1	5	0	0	0	0	1	14	0
Sublette	2	0	162	2	21	52	1	0	61	2	1	115
Sweetwater	9	17	497	8	17	670	4	66	296	5	214	52
Teton	0	0	0	0	0	0	0	0	0	0	0	0
Uinta	0	0	0	1	0	40	0	0	0	2	0	147
Washakie	0	0	0	0	0	0	3	36	0	3	41	30
Weston	1	13	0	1	0	16	1	0	17	1	0	35
Totals	45	260	921	70	174	1251	65	536	1124	*46	*401	*1275

Source: All data are from the Wyoming Oil and Gas Conservation Commission.

*Number of seismic projects and miles permitted during the first three quarters of 1998.

Wyoming State Geological Survey, Oil and Gas Section, October, 1998.

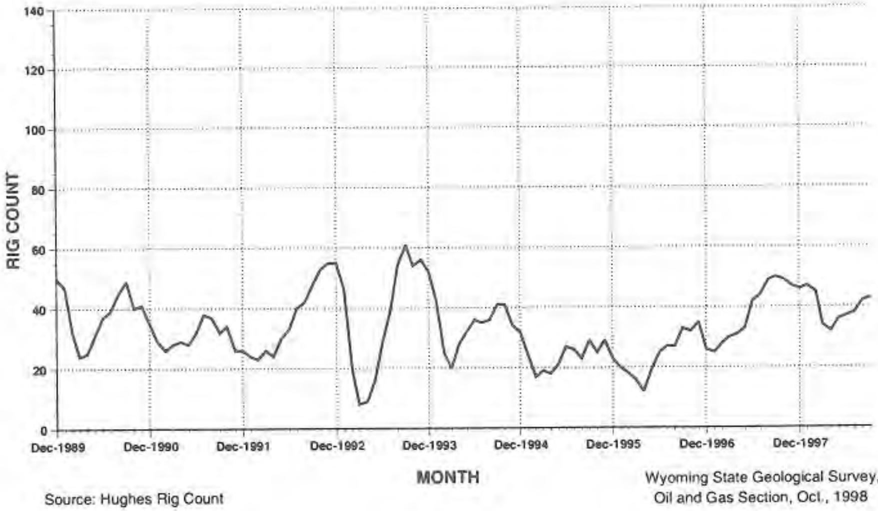

Figure 10. Wyoming daily rig count averaged by month (December, 1989, to September,

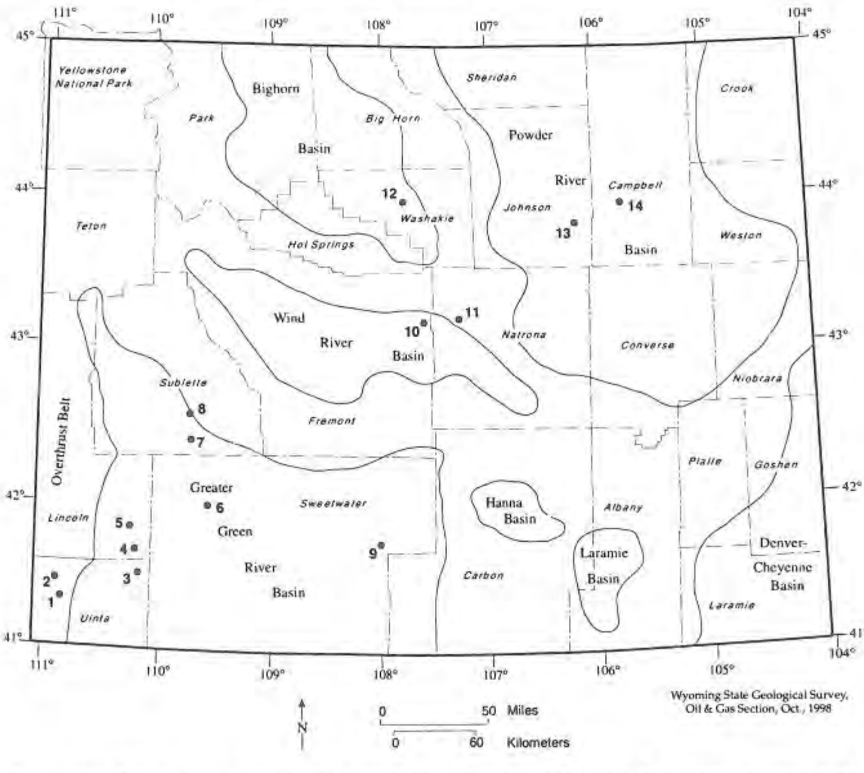

Figure 11. Oil and gas exploration and development activities in Wyoming during the third quarter of 1998 (exclusive of coalbed methane activities).

sidering the low prices for Wyoming crude oil. Most drilling presently is for natural gas. **Figure 10** shows the Wyoming daily rig count averaged by month.

Exploration and Development

Company data, news releases, and information compiled and published by Petroleum Information/Dwights LLC indicate the following significant exploration and development events occurred in Wyoming during the third quarter of 1998. The numbers preceding discussions below refer to locations on **Figure 11**.

1. Chevron USA completed a new horizontally-drilled Nugget Sandstone producer in Painter Reservoir East Field. The 34-32BH PRU well in SW SE section 31, T16N, R119W flowed 250 barrels of oil, 2.5 million cubic feet of gas, and 427 barrels of water per day. True vertical depth of the well was not reported.

2. Amoco Production completed a Madison Limestone producer in Whitney Canyon-Carter Creek Field. The 1A Champlin 457-H well in SE SW section 5, T17N, R119W flowed at the rate of 8.0 million cubic feet of gas and 589 barrels of water per day from between 14,017 and 14,859 feet. Chevron USA also completed a Madison Limestone producer in Whitney Canyon-Carter Creek Field. The 2-36 Ray-State well in NW NE section 36, T18N, R120 flowed 5.9 million cubic feet of gas, 54 barrels of condensate, and three barrels of water per day from an undisclosed interval.

3. Celsius Energy completed a Muddy discovery at its 4 Eakin Ranch Unit well in SE NE section 33, T18N, R113W. The well flowed at a calculated rate of 7.4 million cubic feet of gas per day from between 12,532 and 12,572 feet.

4. Celsius Energy also completed two new discoveries. The 1 Verne Valley Unit well in NE SW section 15, T19N, R113W was completed as a Dakota gas and condensate producer. The 3 Reynard Unit well in SW SE section 11, T20N, R113W was completed as a Frontier gas and condensate producer that is waiting on a pipeline connection.

5. Texaco Exploration & Production discovered gas at its 20-9 Ballerina well in SW NE section 9, T21N, R113W. The well produced commercial amounts of gas during tests of an undisclosed interval in the Dakota and is awaiting a pipeline connection.

6. Yates Petroleum discovered gas in the Almond at its 1 Prairie Schooner-Federal well in C SE section 17, T23N, R107W. The well produced an average of 165,000 cubic feet of gas, 126 barrels of condensate, and 23 barrels of water per day during its first month on line. The new well is a mile east of an abandoned Almond well in Stagecoach Draw Field.

7. Activity remains high in Jonah Field. McMurry Oil completed a new Lance well and is testing a second well in the Lance. The 5-7 Jonah Federal

well in SW NW section 7, T28N, R108W flowed 7.2 million cubic feet of gas, 97 barrels of condensate, and five barrels of water per day from an undisclosed Lance interval above 10,366 feet. McMurry also completed the 5-12 Yellow Point well in SW NW section 12, T28N, R109W. The well flowed 3.3 million cubic feet of gas, 40 barrels of condensate, and 30 barrels of water per day from an undisclosed interval in the Lance above 10,433 feet.

8. The Pinedale anticline area is also active. Ultra Petroleum completed its 9-23 Warbonnet well in NE SE section 23, T30N, R108W in two Lance intervals. The well flowed 1.0 million cubic feet of gas per day on tests of the Lance between 11,926 and 12,027 feet. The interval was closed off with a bridge plug prior to tests of the shallower interval between 11,596 and 11,618 feet, which flowed 1.0 million cubic feet of gas and 10 barrels of condensate per day. Ultra brought its 15-8 Mesa Draw well in SW SE section 8, T32N, R109W into production in August. The well was completed in eight Lance sands between 12,450 and 12,832 feet and is flowing 16.1 million cubic feet of gas and 200 barrels of condensate per day. Ultra Resources, McMurry Oil, and other companies notified the U.S. Bureau of Land Management (BLM) that they plan to develop approximately 197,000 acres in Townships 29N to 33N and Ranges 107W to 110W. The companies propose to proceed with development activities in the summer of 1999. The companies are currently drilling up to 14 exploratory wells, as allowed by a decision of the BLM in May, 1998. The BLM has also begun preparation of an Environmental Impact Statement regarding the proposed oil and gas development in this area.

9. Amoco Production completed two new producers in Wamsutter Field. The 14 C.G. Road Unit well in SE SE section 3, T20N, R94W flowed 2.3 million cubic feet of gas per day from the Lewis between 8,890 and 8,990 feet and from the Mesaverde between 10,156 and 10,497 feet. Amoco also completed the 21 C.G. Road Unit well in SW NE section 36, T21N, R94W. The well was directionally-drilled and flowed 1.8 million cubic feet of gas and 1,810 barrels of water per day from the Lewis and the Mesaverde. True vertical depths of the producing intervals were not disclosed.

10. KCS Mountain Resources completed a new discovery at its 33-36 Squaw Butte well in NW SE section 36, T37N, R90W. The new well is producing 750,000 cubic feet of gas and 50 barrels of fluids (condensate and water) per day from an undisclosed interval in the Lance.

11. Prima Oil & Gas completed the westernmost producer in Waltman Field. The 25-43 NW Cave Gulch well in NW SE section 25, T37N, R87W flowed 1.6 million cubic feet of gas, 27 barrels of condensate, and 60 barrels of water per day from the Lance above 8,560 feet.

12. Continental Resources acquired the properties of Bass Enterprises in the Cottonwood Creek Field area. This field currently produces about 4,300 barrels of oil per day. Continental recompleted the 2-1 Cottonwood Creek-Federal well in SW NE section 2, T46N, R91W in the Frontier between 6,910 and 6,918 feet. The well flowed at a calculated daily rate of 2.1 million cubic

feet of gas per day. The well was originally completed in 1980 as a Phosphoria oil producer.

13. The BLM approved the Jepson Draw Unit Infill Development Plan submitted by Ensign Operating. The plan allows the company to drill up to 35 additional infill development wells over the next five years within Jepson Draw, Holler Draw, and Nipple fields. Ensign completed its 3A21JDU well in NE NE section 21, T44N, R77W in Holler Draw Field, pumping 201 barrels of oil per day from the Shannon Sandstone between 10,004 and 10,022 feet.

14. UMC Petroleum discovered oil and gas at its 12-16 State well in SW NW section 16, T45N, R74W. The well produced an average of 18 barrels of oil, 15,000 cubic feet of gas, and 36 barrels of water per day from an undisclosed interval in the Sussex Sandstone during its first month on line. UMC also completed a new producer in House Creek Field. The 13-28 Rassbach well in NW SW section 28, T46N, R74W, pumped an average of 91 barrels of oil, 16,000 cubic feet of gas, and eight barrels of water per day from an undisclosed interval in the Sussex.

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COAL UPDATE

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Coal deliveries, as derived from the Federal Energy Regulatory Commission's (FERC's) Form 423, indicate that deliveries from Wyoming producers were at a record level through the second quarter of 1998. Through the end of June, deliveries of coal from Wyoming totaled 148,092,625 short tons. This represented an increase of 11% over the 133,401,126 tons delivered through the same period in 1997. The coal went to power plants in at least 26 different states.

Table 12 shows the monthly coal deliveries, as reported on FERC Form 423, for the period 1995 to 1998. **Figure 12** shows monthly coal deliveries over the past three years. **Figure 13** breaks these monthly deliveries into spot sales and contract sales.

Table 13 depicts historic and projected coal production by county. It also provides an estimate of the coal tonnage from the Powder River Basin that sells for more than $5.00/ton. The tonnage sold at these higher prices is the remaining, older, long-term contracts that had escalation clauses built into them.

Table 12. Monthly coal deliveries from Wyoming's mines in short tons (1995-June,1998)

	1995		1996		1997		1998	
	monthly	cumulative	monthly	cumulative	monthly	cumulative	monthly	cumulative
JAN	21,586,303	21,586,303	21,793,387	21,793,387	25,165,405	25,165,405	26,536,217	26,536,217
FEB	20,839,926	42,426,229	20,374,055	42,167,442	20,743,224	45,908,629	23,196,152	49,732,369
MAR	21,707,422	64,133,651	22,507,800	64,675,242	22,566,012	68,474,641	23,861,472	73,593,841
APR	20,066,616	84,200,267	22,579,959	87,255,201	20,961,008	89,435,649	24,768,989	98,362,830
MAY	21,509,916	105,710,183	22,216,016	109,471,217	23,102,867	112,538,516	25,278,960	123,641,790
JUN	18,602,505	124,312,688	20,698,814	130,170,031	20,862,610	133,401,126	24,450,835	148,092,625
JUL	21,334,608	145,647,296	24,842,971	155,013,002	24,074,929	157,476,055		
AUG	21,356,870	167,004,166	24,421,537	179,434,539	23,002,254	180,478,309		
SEP	21,355,730	188,359,896	23,339,792	202,774,331	22,452,566	202,930,875		
OCT	21,178,610	209,538,506	22,615,721	225,390,052	21,623,057	224,553,932		
NOV	21,042,260	230,580,766	21,421,085	246,811,137	21,695,072	246,249,004		
DEC	22,032,910	252,613,676	22,105,530	268,916,667	24,695,740	270,944,744		
Total Tonnage Reported[1]		**252,613,676**		**268,916,667**		**270,944,744**		
Total Tonnage Not Reported[2]		**11,324,347**		**9,508,289**		**10,536,772**		
Total Tonnage Produced[3]		**263,938,023**		**278,424,956**		**281,481,516**		

Source: [1]COALDAT Marketing Reports by Resource Data International. Inc. (1995); and from Federal Energy Regulatory Commission (FERC) Form 423 1996-1998.
[2]Includes estimates of residential, industrial, and exported coal, plus tonnage not reported on FERC's Form 423.
[3]Wyoming State Mine Inspector's Annual Reports.
Wyoming State Geological Survey, Coal Section, October, 1998.

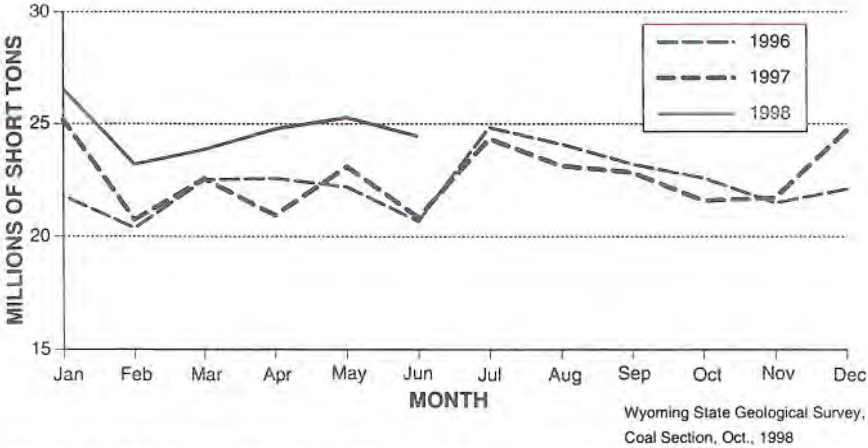


Figure 12. Reported monthly deliveries from Wyoming coal mines (1996 through June, 1998). From the Federal Energy Regulatory Commission's bulletin board.

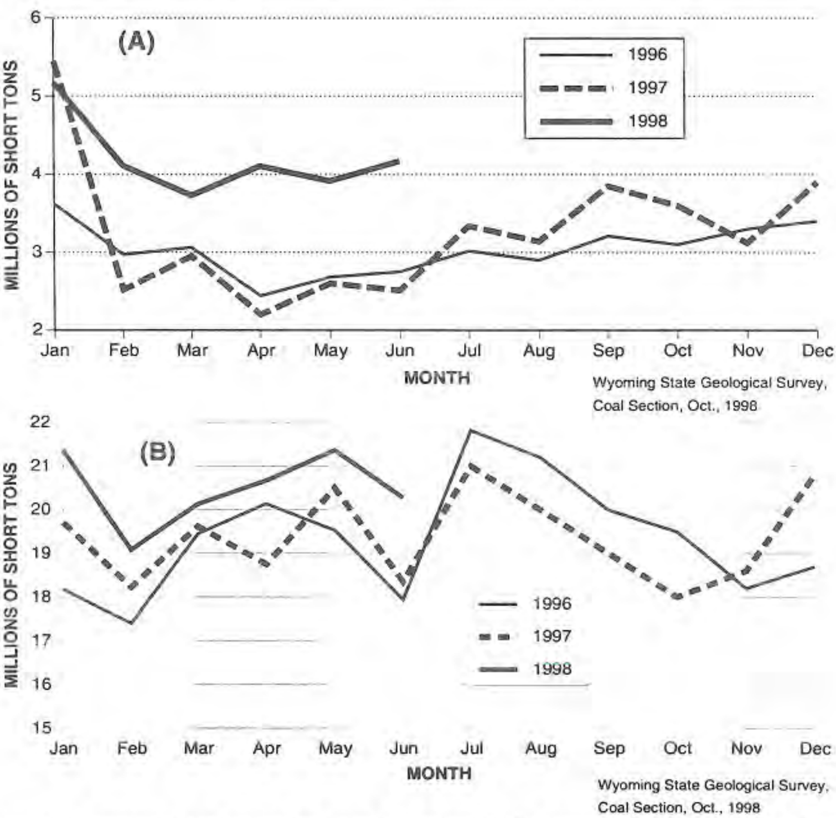


Figure 13. Monthly coal deliveries from Wyoming (1996 through June, 1998). (A) Coal sold on the spot market and (B) coal sold on contract. From the Federal Energy Regulatory Commission's bulletin board.

Table 13. Wyoming coal production by county (in millions of tons), from 1995 to 1997 with forecasts to 2005.

	1995[1]	1996[1]	1997[1]	1998[2]	1999[2]	2000[2]	2001[2]	2002[2]	2003[2]	2004[2]	2005[2]
Campbell County	232.4	245.3	246.3	269.5	287.8	307.9	320.2	323.7	327.2	330.8	334.4
Converse County	14.1	15.8	17.8	15.0	15.3	15.3	15.3	15.3	15.3	15.3	15.3
Sheridan County	M	M	M	M	M	M	M	M	M	M	M
Carbon County	3.8	4.7	5.0	4.2	3.7	2.8	2.0	2.0	2.0	2.0	2.0
Sweetwater County	9.1	8.2	7.8	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Lincoln County	4.5	4.4	4.6	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Total Wyoming	**263.9**	**278.4**	**281.5**	**301.7**	**319.8**	**339.0**	**350.5**	**354.0**	**357.5**	**361.1**	**364.7**
Annual Change	11.4%	5.5%	1.1%	7.2%	6.0%	6.0%	3.4%	1.0%	1.0%	1.0%	1.0%
Higher-priced coal[3]	**26%**	**24%**	**22%**	**17%**	**13%**	**9%**	**6%**	**4%**	**4%**	**4%**	**4%**

[1]Tonnage from the Wyoming State Inspector of Mines. 1995-1997.
[2]County estimates by the Wyoming State Geological Survey, October, 1998.
[3]Estimated percentage of Powder River Basin coal production that is sold at prices above $5.00/ton (older long-term contracts that have not yet expired).
[M means minor tonnage (less than a million tons)].

Table 14 shows a breakdown of the average prices for coal produced in northeastern Wyoming and southern Wyoming over the past ten years, with projections to 2005.

Statistics published by the Energy Information Administration (EIA), showed that utilities in 29 states, as well as Canada and Spain, consumed Wyoming coal in 1997 (EIA, 1998) (**Figure 14**). In 1997, new markets were tested in Arizona, North Dakota, and North Carolina.

When combined with coal exports, electric utility companies used 273.3 million short tons of Wyoming coal in 1997. This is 97% of the production (**Figure 15**). In addition, industrial customers used 3.9 million tons, and residential and commercial markets consumed just under 0.4 million tons of Wyoming coal. At year-end, another 3.6 million tons of coal were reportedly stockpiled at mines across the State. There was an additional 1.3 million tons of coal produced in Wyoming that was not accounted for by the EIA. This tonnage is the difference between the year-end production total published by EIA (1998) and the total published by the Wyoming State Inspector of Mines (Stauffenberg, 1998). This unassigned tonnage is probably an aggregate of smaller purchases, perhaps from all of the consumer categories listed above.

Table 14. Breakdown of average prices paid for coal from northeastern Wyoming, southern Wyoming, and Wyoming as a whole (1988-1997) with forecasts to 2005.

Year	Northeastern	Southern	Statewide
1988	$7.35	$21.45	$9.16
1989	$6.94	$19.76	$8.63
1990	$6.86	$19.36	$8.43
1991	$6.58	$18.81	$8.06
1992	$6.61	$18.84	$8.13
1993	$6.02	$17.72	$7.12
1994	$5.62	$17.42	$6.62
1995	$5.60	$17.35	$6.38
1996	$5.40	$17.30	$6.15
1997	$5.03	$17.19	$5.78
1998	$4.73	$16.83	$5.42
1999	$4.66	$17.11	$5.31
2000	$4.61	$16.63	$5.17
2001	$4.51	$16.89	$5.04
2002	$4.52	$16.79	$5.04
2003	$4.52	$16.91	$5.04
2004	$4.53	$16.81	$5.04
2005	$4.54	$16.70	$5.04

Statewide data for 1988-1990 are from reports by the U.S. Department of Energy's Energy Information Administration; data for 1991-1997 are derived from Wyoming Department of Revenue information; estimates for 1998-2005 and for all regional breakdowns are by the Wyoming State Geological Survey (October, 1998).

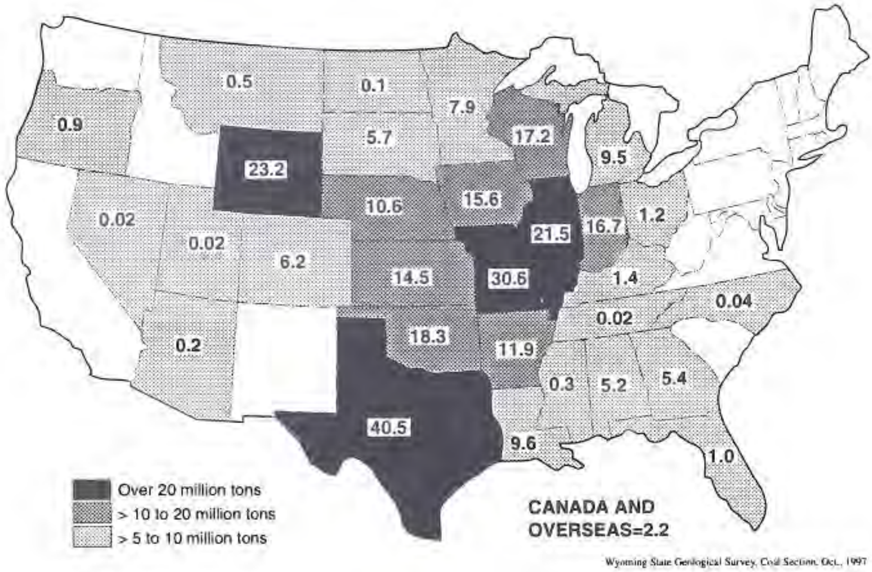
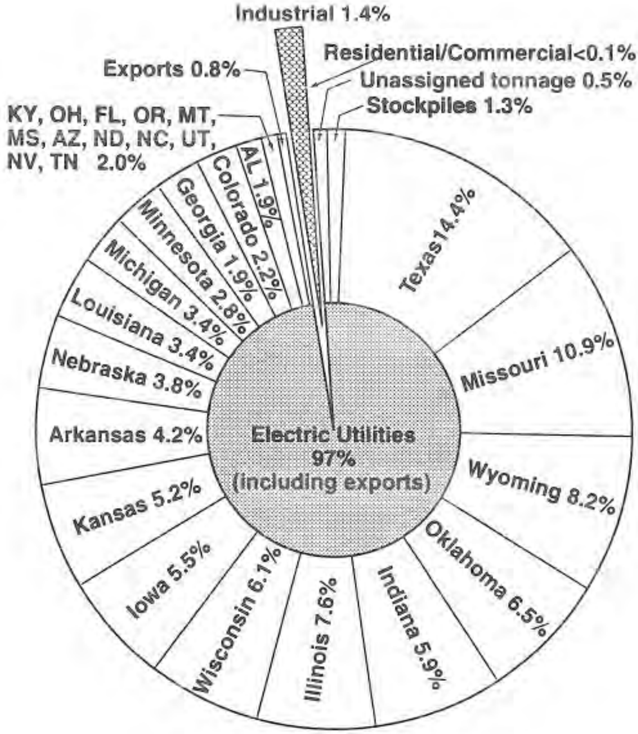


Figure 14. Wyoming coal deliveries to electric generating plants in 1997 in millions of tons (adapted from EIA, 1998).

Developments in the Powder River Basin (PRB)

At the end of September, the U.S. Bureau of Land Management (BLM) held their competitive auction for the Thundercloud coal lease tract. For the first time since their Lease by Application (LBA) program started in 1989, the successful bidder was not the original nominating company or its successor. In 1995, the Kerr-McGee Coal Company applied for the Thundercloud LBA to supplement coal operations at their Jacobs Ranch mine. In June of this year, Kennecott Energy purchased the mine for $400 million (*Wyoming Geo-notes No. 59*, p. 25). At the time of their new purchase, Kennecott Energy indicated that they would pursue the purchase of the Thundercloud coal lease to add an estimated eleven years of reserves to the Jacobs Ranch operation.

But on October 1st, Arch Coal Company announced that they had the winning bid for the 3,545-acre coal lease. Their bid of $158,000,008.50 for the Thundercloud LBA's reported 412 million tons of coal reserves equates to 38.3 cents/ton. Kennecott's bid was $124,113,546 (30.1 cents/ton). The results of the auction, while disappointing to Jacobs Ranch, means that the State of Wyoming will receive about $79 million dollars over the next five years as its share of the bonus bid. Arch Coal said they would use the new lease to expand operations at their Black Thunder mine. **Table 15** is a summary of LBA activity in the PRB.



TONNAGES (MILLIONS OF TONS)		
Electric utilities	=	95.9%
Industrial	=	1.4%
Residential / Commercial	=	0.1%
Exports	=	0.8%
Unassigned Tonnage	=	0.5%
Stockpiles	=	1.3%
Total Annual production		100.0%
Electrical utilities including exports	=	97%

Wyoming State Geological Survey, Coal Section, Oct., 1998

Figure 15. Utilization of Wyoming coal in 1997 in percent (adapted from EIA, 1998).

Prior to the lease sale, Arch Coal announced their decision to add a fourth dragline at their Black Thunder mine (*Coal Outlook*, 9/14/98). The company bought a Marion 8750 dragline that has been sitting idle at the closed Sunspot mine in Fulton County, Illinois, for the last 15 years. Originally a 110-cubic yard dragline, Arch believes they can convert it into a 130- to 140-yard machine. According to the article in *Coal Outlook*, the dragline has just 35,000 hours on it, and Arch believed it was the best deal on the market.

It will take 15 to 18 months to break the machine down, move it, and set it up again at Arch's mine. And it will require 200 truckloads to move the machine's components to Wyoming. Arch expects the new machine to boost production

Table 15. Summary of Leases by Application (LBA) in the Powder River Coal Field of Wyoming.

LBA Name/ Company Applicant	Application Date	Applied for Acreage	Applied for Tons	Offered for Bid Acreage	Offered for Bid Tons	Status	Total of Bid	Bid in Cents/ton
Jacobs Ranch/Kerr-McGee	10/10/89	1,465	123 MM	1,709	147.4 MM	Accepted 9/26/91	$20,114,930	13.6
West Black Thunder/ Thunder Basin Coal Co.	12/22/89	3,225	400 MM	3,492	429 MM	Accepted 8/12/92	$71,909,282	16.8
North Antelope & Rochelle/ Powder River Coal Co.	3/3/90 (2 Applications)	954 1,196	120 MM 150 MM	3,064 (Offered as 1 Tract)	403.5 MM	Accepted 9/28/92	$86,987,765	21.6
West Rocky Butte/ Northwestern Resources Co.	12/4/90	390	50 MM	463	56.7 MM	Rejected 12/3/92 Accepted 1/7/93	$14,200,000 $16,500,000	25.8 29.1
Eagle Butte/AMAX Land Co.	7/21/91	915	150 MM	1,059	166.4 MM	Accepted 4/5/95	$18,470,400	11.1
North Rochelle/Zeigler Coal Co.	7/22/92	1,440	144 MM	1,482	157.6 MM	Rejected 7/29/97 Accepted 9/26/97	$26,800,000 $30,600,000	17 19.4
Antelope/Antelope Coal Co.	12/29/92	617	60 MM	617	60.4 MM	Rejected 9/28/96 Accepted 12/4/96	$6,645,045 $9,064,600	11 15
Powder River/ Powder River Coal Co.	3/23/95	4,200	555 MM	4,224	532 MM	Accepted 7/3/98	$109,600,000	20.6
Thundercloud/Kerr-McGee* *Arch Coal successful bidder	4/14/95	3,396	427 MM	3,545	412 MM	Accepted 10/1/98	$158,000,009	38.3
New Keeline/ Evergreen Enterprises	5/13/96	7,841	675 MM	na	na	PRRCT reviewed 4/23/97 and recommended this LBA not be considered; decision appealed		
Horse Creek/Antelope Coal Co. (Amended)	2/14/97 5/1/98	1,471 2,838	177.5 MM 356.5 MM	na na	na na	PRRCT reviewed & approved to proceed 4/23/97 Reopened scoping period 6/18/98		
Belle Ayr/AMAX Land Co.	3/20/97	1,032	200 MM	na	na	PRRCT reviewed & approved to proceed 4/23/97		

Adapted from the 1997 Draft EIS, Powder River & Thundercloud Leases, prepared by the U.S. Bureau of Land Management, and revised by the Coal Section of the Wyoming State Geological Survey in October, 1998.
MM = Millions; PRRCT = Powder River Regional Coal Team.

at Black Thunder by 15 million tons per year, increasing the mine's annual production to about 55 million tons per year.

Arch Coal announced, during the first week in October, that its Black Thunder mine shipped its 500 millionth ton of coal. The company believes this is a first for a single mine in the U.S. Arch projects the mine will produce close to 45 million tons in 1998 (*Coal Daily*, 10/12/98).

Kennecott said it was disappointed in the outcome of the Thundercloud sale, but that other coal adjacent to Jacob's Ranch is available. The New Keeline LBA is an adjacent tract that was applied for by Evergreen Enterprises in May of 1996. Although the BLM rejected that LBA in 1997, its decision is under appeal. The BLM said it would consider a lease application by Kennecott on any or all of the New Keeline tract, but that it could not offer a lease until the Evergreen appeal is resolved (*Coal Outlook*, 10/5/98).

In unrelated news, Kennecott Energy has reshuffled general managers at their PRB mines. Jerry Tystad moved from the Antelope mine to the Cordero-Rojo complex. Dean DeVorak was reassigned to Jacobs Ranch from Cordero-Rojo. Lyle Randon moves from the Spring Creek mine (Montana) to the Antelope mine. Curt Weittenhiller, formerly with Kerr-McKee, was appointed general manager of the Spring Creek operation.

The Federal Trade Commission, in late August, granted AEI Resources Inc. (AEI) and Zeigler Coal Holding Company (Zeigler) an early termination of the pre-acquisition waiting period under the Hart-Scott-Rodino Act. This allowed completion of AEI's purchase of Zeigler (*Wyoming Geo-notes No. 59*, p.28).

Before the ink was dry on AEI's acquisition of Zeigler, AEI announced plans to sell the Triton Coal Company portion of Zeigler, including the North Rochelle and Buckskin mines. AEI has opened a data room at Triton headquarters in Gillette, Wyoming (*Coal Outlook*, 9/14/98). Several companies have signed confidentiality agreements so they can investigate the Triton offering. AEI hopes for a sale by the end of the year.

Also as successor to Zeigler, AEI owns 50% of ENCOAL Corporation's liquids-from-coal (LFC) technology and their demonstration plant. They also have the right to market LFC worldwide after April 12, 2000. SGI International had been negotiating to buy Zeigler's LFC interests. SGI now hopes to continue talks with AEI, saying that they still plan to form a joint venture with Mitsubishi Corporation to develop LFC in the PRB (*Wyoming Geo-notes No. 59*, p.31).

An on-again off-again rumor was ended when Cyprus Amax Minerals announced that it intended to sell its coal division. Solomon Smith Barney has been hired to facilitate the sale of Cyprus-Amax Coal Co. Cyprus-Amax has mines in Pennsylvania, Utah, Colorado, Illinois, Australia, and Wyoming. In Wyoming, it operates the Belle Ayr and Eagle Butte mines in the PRB as well as the Cyprus-Shoshone underground mine in the Hanna Basin. In 1998, Cyprus-Amax expects to produce 72 million tons of coal. All but about 10 million tons of that production will come from its holdings in the U.S. Collectively, the Wyoming mines accounted for 43.6 million tons in 1997.

The Dave Johnston power plant and Glenrock Coal Company celebrated their 40th Anniversary the first weekend in August. A story in the *Casper Star-Tribune* (8/2/98), pointed out that although Dave Johnston is one of Pacific Power's oldest power plants, it is one of its most cost-efficient producers of electricity. Built in 1958, it can supply the electricity needs of 330,000 homes.

Developments in Southern Wyoming

As mentioned above, Cyprus Amax Minerals has opted to sell its coal division, which includes the Cyprus-Shoshone underground mine near Hanna. At this time, there is no indication when a sale might be concluded.

Chevron Oil, in an August 18th press release, announced its intention to exit the coal business, and sell its wholly-owned subsidiary, the Pittsburg & Midway Coal Mining Co. (P&M). Interested purchasers have been invited to view a data room set up at P&M's headquarters in Englewood, Colorado. Bids are expected sometime near year's end, with closing targeted for the first or second quarter of 1999. P&M owns and operates five coal mines in four different states, including the Kemmerer open-pit mine in Lincoln County, Wyoming.

The Tennessee Valley Authority has renegotiated a coal supply contract with Arch Coal. The contract was originally signed in 1996 for 10,000 tons/week from the Seminoe II mine in Carbon County, Wyoming. While the original contract was for six years (1997 to 2002), shipments ceased last year by mutual agreement. Now the contract has been reinstated with Arch's newly acquired Black Thunder mine as the source through 2002. The coal goes to the Allen plant near Memphis, Tennessee, on a rail-barge move (*Coal Outlook*, 9/21/98).

Transportation Developments

A new, $10 million, railroad car repair and maintenance facility outside Evanston, Wyoming, has been opened. The Union Tank Car Company's (UTCC's) three-building, 92,000 square feet facility covers 56 acres and employs 50 workers. UTCC expects to hire an additional 100 employees in the next few years (*Casper Star-Tribune*, 9/18/98).

Shortly after the Wyoming Mining Association acknowledged that the Union Pacific/Southern Pacific Railroad (UP/SP) had made substantial improvements in its deliverability, the railroad reported that it hauled record tonnage from the Powder River Basin (PRB) in August. Eight hundred twenty-four unit-trains carried 10,611,000 tons of PRB coal. UP/SP's previous record, set in January of this year, was 10,577,000 tons in 827 trains (*Coal Daily*, (9/7/98). Currently averaging 26 loaded coal trains per day, the railroad estimates it will move roughly 120 million tons of coal out of the PRB this year. UP/SP projects that it will double that figure by the year 2008.

During the final week of September, UP/SP announced that it had loaded its 75,000th unit-train in the southern PRB. UP/SP also said it is set to increase the number of loaded coal trains it handles on the PRB joint line by five trains/day. That increase will bring their total daily number of trains to roughly 30/day.

The Dakota, Minnesota, & Eastern Railroad's (DM&E's) proposed new rail line into the PRB is still before the Surface Transportation Board.

Coalbed Methane Developments

Coalbed methane currently accounts for about two percent of all gas produced in Wyoming or about 60 million cubic feet of the total 325 million cubic feet produced daily. And daily production of coalbed methane is increasing.

The Powder River Basin (PRB) is currently the hottest play for this resource. As an example of the interest, on September 17th, a symposium on Wyoming coalbed methane was held in Casper. Jointly sponsored by the Society of Petroleum Engineers (SPE) and the Wyoming Geological Association (WGA), the meeting unexpectedly drew nearly three hundred attendees.

Devon Energy Corp. (Devon) announced (7/14/98) that they had made a $15.4 million dollar acquisition of natural gas properties in Wyoming. Devon acquired both developed coalbed methane reserves as well as an estimated 150,000 net acres of undeveloped properties in Campbell County, Wyoming. The acquired properties are adjacent to their existing Kitty Field.

Devon estimates the proven reserves on these properties at 5.3 billion cubic feet. The properties include a 35% working interest in 42 producing wells. These wells currently produce 8.5 million cubic feet per day. Also included, is a similar interest in 74 completed wells waiting connection to pipelines.

Devon has also teamed up with Kansas Nebraska Energy (KNE) and will soon start construction of a gas pipeline in the PRB. This pipeline will be owned by a separate, jointly-owned company called Thunder Creek Services LLC (TCS). In the first phase of this project, TCS will lay the Sage Creek line between North Buck Draw Field in southern Campbell County and the Sage Creek gas gathering plant at Douglas, Wyoming. This is a 12-inch line. In the second phase, however, TCS will lay a 24-inch, 450 million cubic feet a day (mmcf/d) line northward into the coalbed methane play (Thunder Creek Project). This latter project includes the construction of a gathering system and an amine plant to remove CO_2. Completion of the Thunder Creek Project is expected in the fall of 1999.

According to a news release by the U.S. Forest Service, the Thunder Basin National Grasslands has approved Barrett Resources' plans to the drill 76 new coalbed methane wells. The wells are located west of the Black Thunder coal mine and south of Wyoming Highway 450.

Western Gas Resources, Inc. and Colorado Interstate Gas Company (a subsidiary of Coastal Corp.) have announced plans to build a non-jurisdictional, large-diameter gathering and treating system to handle the growing volume of coalbed methane in the PRB. Both companies anticipate participation from other parties. Current plans are for a 20-inch system running 90 miles through the heart of the coalbed methane development in Campbell County, Wyoming. Initially, the system's capacity would be 200 mmcf/d. At the southern end of the system, interconnections with the Colorado Interstate, KN Interstate, and Pony Express pipelines are planned. The system will also connect with Wyoming Interstate Company's proposed new expansion of its interstate pipeline to Cheyenne. The gas will require treatment prior to entering the pipelines, and plans call for a CO_2 treatment plant at the southern end of the gathering system.

While coalbed methane operators are still concerned by the recent ruling by a Federal appeals court, which concluded that coalbed methane belongs to the coal estate rather than the oil and gas estate, some relief came with new Federal legislation. Sponsored by Wyoming's congressional delegation, a new law was passed in November that protects current coalbed methane leases by grandfathering them as oil and gas leases. President Clinton signed the bill on November 10th. Meanwhile Amoco is asking the U.S. Supreme Court to overturn the U.S. 10th Circuit Court of Appeals earlier ruling. It is still uncertain if the Supreme Court will agree to hear the matter.

Regulatory Developments

The Mine Safety and Heath Administration (MSHA) announced a final rule that calls for a 10% increase in civil penalty fines for all mine safety and heath violations. All increases went into effect in June. MSHA's maximum civil penalty increased from $50,000 to $55,000 per violation. The fine limits were increased to comply with the 1996 Debt Collection Improvement Act, which requires that government agencies make inflation adjustments on civil penalties every four years (*Coal Daily*, 7/18/98).

The U.S. Office of Surface Mining has awarded Wyoming $259,950 to assist in funding their Abandoned Mine Lands Reclamation Program.

Lawmakers have directed the U.S. Environmental Protection Agency (EPA) to withhold its decision on whether it would regulate mercury emissions until the completion of an 18-month study on the pollutant by the National Academy of Sciences (*Coal Daily*, 10/6/98). The EPA initially was under a court order to make the decision by November 15, 1998. The EPA has issued a request calling for stack testing at a range of plants based on the type of coal they burn and the type of sulfur dioxide control they use. The EPA wants utilities to submit quarterly reports of coal analyses conducted on every shipment of coal that arrives for burning at a given boiler. The analyses should include the mercury content of the coal as well as the quantity and source of the coal (*Coal Daily*, 9/24/98).

In a somewhat related item, it looks like the removal of mercury could be an expensive item for utilities. For example, to remove 80% of the mercury emissions from a power plant, Environmental Element Corporation's (EEC's) patented corona discharge reactor would cost approximately $500,000 a year for a 100-megawatt plant. Going to a 90% removal rate would double the cost (*Coal Daily*, 7/17/98). The device, a corona discharge reactor, uses electric power to oxidize mercury, making the resultant compound easier to capture upstream in a precipitator. The other method now available is carbon injection. While it works on a similar principle, apparently the carbon can end up in the spent coal's fly ash rendering it unmarketable.

Market Developments and Opportunities

Increasing reliance on capital-intensive mining technologies and pricing advantages stemming from dominant market position are likely to continue the regional consolidation trend experienced by the Wyoming coal industry (*Coal Age*, v. 103, no. 8, p. 95-96). Expiration of above-market contracts in the past and coming years will impact market price and mining operations. As the higher price contracts expire or are renegotiated to current market level, coal companies will be unable to subsidize the low current prices.

Analysis of the Federal Energy Regulatory Commission's (FERC's) Form 423 data indicates that coal delivered on the spot market reached its lowest price level in 1995. And prices have risen only slightly since then. The average delivered price of coal shipped on a contract basis has fallen every year since 1990. The spread between spot and contract prices has narrowed dramatically.

Coal Daily (9/18/98) said that after a quiet few weeks, the over-the-counter market for Powder River Basin (PRB) coal is picking up, but prices in this new movement are apparently soft. For 8,800 Btu/lb. coal, a year-2000 sale occurred at $4.59/ton. Roughly one month ago, the bid/offer range for that specification stood at $4.70/ton. *Coal Daily* further pointed out that a recent year-2000 sale for an 8,400-Btu/lb. coal was reported at $3.49/ton. Just a month ago, the bid/offer range for that coal stood at $3.60 to $3.80/ton.

Black Hills Capital Group, a subsidiary of Black Hills Corp., acquired the assets of Coal Network, Inc. and Coal Niche, Inc. of Mason, Ohio. The new company, Black Hills Coal Network, Inc., will stay based in Mason (*Coal Week*, 9/23/98). In the announcement, a company spokesperson said, " We have 200 million tons of uncommitted coal at our Wyodak mine that Coal Network can market through their extensive coal market experience and industrial contacts east of the Mississippi River. Our past acquisition of the Clovis Point property provides us with train loading facilities, and our recent acquisition of the Earthco coal upgrading facilities at the Wyodak mine will provide Coal Network an opportunity to market Earthco's enhanced coal products."

Black Hills Power and Light uses most of the current production from the captive Wyodak mine. However, a company spokesperson noted that the Wyodak and Clovis Point operations will be combined, and future production will be available for marketing elsewhere. Clovis Point is currently idle, but remains fully permitted. Company officials believe that at full production the Clovis Point mine is capable of producing three million tons per year.

Kennecott Energy has established a new sales office in the Denver area. The shift involves moving six employees from their coal office in Gillette, Wyoming. The rest of their sales staff will remain in Gillette. The main issue prompting the move was accessibility to air transportation. Company officials concluded that to meet the needs of their customers a move was required.

Texas Municipal Power Agency (TMPA) had to suspend coal deliveries to its Gibbon's Creek plant under the *force majeure* provision of its contract with Kennecott Energy. The utility turned away roughly 350,000 tons of coal from the Antelope and Cordero-Rojo mines. The problem occurred when a plant operator failed to notice that the unit's heater controls were in manual position. That caused excess water to back up into the turbine, damaging the blades. TMPA expected the repairs and scheduled maintenance to keep the unit down until early in November (*Coal Daily*, 9/30/98)

Table 16 is a tabulation of some of the contracts, spot sales, tests, and solicitations for Wyoming coal announced during the third quarter of 1998.

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INDUSTRIAL MINERALS AND URANIUM UPDATE

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Construction Aggregate

UMETCO is awaiting approval of its mining permit application to quarry 500,000 cubic yards of rock from the western end of the Rattlesnake Hills in westernmost Natrona County (*Wyoming Geo-notes No. 59*, p. 40). The rock would be quarried in large-sized pieces and used for covering uranium tailings at UMETCO's former uranium operations in the East Gas Hills (**Figure 16**). UMETCO believes this site is the closest source of suitable rock for use at the tailings site. Although UMETCO favors covering the site with vegetated soil above already installed clay and sand, the cover of rock is required by the Nuclear Regulatory Commission. The proposed quarry has been protested by nearby residents.

Diatomite

Diatomite is a soft, very fine grained, sedimentary rock composed of the siliceous external skeletons of diatoms, which are one-celled plants that lived in concentrations in ocean or fresh water. Diatomite is used as a filter aid, a mineral filler in paint and plastics, an absorbent for industrial spills, as an abrasive, and as an insulating material. It is currently mined in Arizona, Idaho, Oregon, and Washington. These states together produced about 773,000 short tons in 1997. The price of diatomite increased to $269.00 per short ton in 1997. It was $266.00 per short ton in 1996. About 20% of the diatomite mined in the U.S is exported (Antonides, 1998).

Diatomite is found at several localities in Wyoming, particularly in Tertiary rocks in western Wyoming and at one reported locality in Goshen County in eastern Wyoming (Harris and King, 1986). There has been continuous interest in Wyoming's diatomite, because these deposits are closer to existing markets than current U.S. production. To date, however, no diatomite has been mined in Wyoming.

Dimensional Stone

Raven Quarries continues its quarrying of a black granite (Wyoming Raven) and a pink swirled granite (Fantastico) at its redesigned quarry in Albany County west of Wheatland (**Figure 16**). Quarried blocks (roughly 10' x 5' x 5') are shipped to Western Granite in Tijuana, Mexico, for processing into polished slabs (4' x 8' x 3/4") and tile (1' x 1' x 3/8").

V.A. Resources is looking for a quarry operator at its dimensional limestone site at Plumbago Creek, 30 miles northwest of Laramie (**Figure 16**). The Plumbago Creek site is described in a report by the Wyoming State Geological Survey (Harris, 1988).

Dimensional Stone Exploration (DSE), a Wyoming company owned by ICM, has applied for permits to quarry limestone and granite at three localities near Laramie and Cheyenne (**Figure 16**). This is in addition to two quarries it has recently permitted and opened in Montana. ICM is an Italian-based manufacturer and distributor of dimensional stone equipment. The proposed quarries in Wyoming will be limited to five acres. Because the rock will be extracted by wire line saws, there will not be any blasting. These quarries have been protested by nearby residents.

Table 16. Marketing activities for Wyoming coal producers during the third quarter of 1998.[1]

	Utility	Power Plant	Coal Mine/Region	Activity	Tonnage	Comments
1.	Carolina Power & Light Co.	Mayo & Roxboro	PRB	T	100,000 t	10 trainloads for test burn
2.	Central Louisiana Electric Co.	Rodemacher	PRB	So	0.5-1 million t	For 1999 and beyond
3.	First Energy Corp.	Bayshore & Avon Lake	PRB	So	275,000 t/month	September - November
4.	Grand River Dam Authority	System	Northern or southern PRB	So	l million t	For delivery on either railroad
5.	Hastings Utilities	System	Coal Creek mine/PRB	C	0.30-0.35 million t/y	3-year-term starting in 1999
6.	Lower Colorado River Authority	Fayette No.1 & 2 units	Cordero-Rojo Complex/PRB	Sp	1 million t	Spot order for 1999
7.	Lower Colorado River Authority	Fayette	Coal Creek mine/PRB	Sp	120,000 t	40,000/month, 4th Quarter 1998
8.	Mid American Energy	Neal Station	Hanna Basin	So	0.1-0.2 million t	For delivery in 1999
9.	Omaha Public Power District	System	Coal Creek mine/PRB	C	2.4-4.8 million t/y	For 5 years starting in 1999
10.	Salt River Project	Craig	PRB	So	290,000 t	For supplementary coal needs in 1999
11.	Tampa Electric	Gannon	PRB	So	1.3 million t	In equal monthly amounts; also considering Ill and eastern KY coals
12.	Texas Utilities Electric	Monticello	PRB	So	1.0-2.5 million t/y	3-year-term starting in 1999
13.	Western Farmers Electric Coop.	System	PRB	So	1.2 million t	Delivery in 1999
14.	Western Fuels Association	Laramie River	PRB	So	2.2 million t/y	Delivery starts in 1999; through 2005
15.	Wisconsin Electric Power Co.	Oak Creek	North Antelope/Rochelle/PRB	T	Unspecified	For test burn

[1]Data obtained from: *Coal Week*, *Coal Outlook*, *Coal Daily*, FERC databases, and personal contacts.
Note: C = contract coal; Sp = spot coal; So = solicitation; T = test burn; t =short ton; t/y = short tons per year; and PRB = Powder River Basin.
Wyoming State Geological Survey, October, 1998.

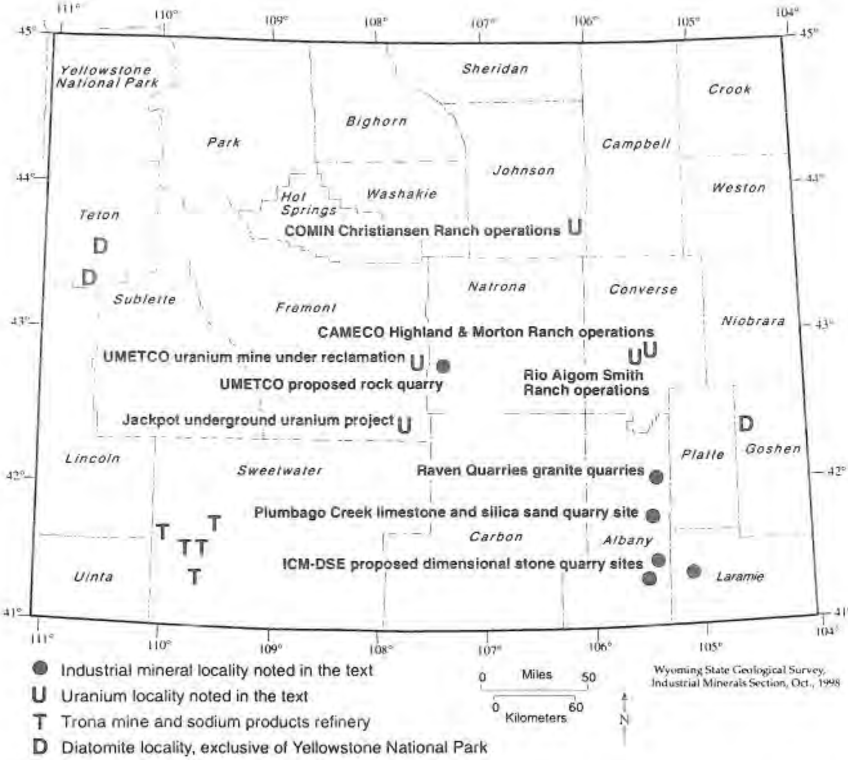

Figure 16. Map of Wyoming's industrial mineral and uranium localities of interest in the third quarter of 1998.

Trona

Trona is mined at five locations in the Green River Basin west of Green River. Extraction is from underground mines supplemented by solution mining techniques and the recovery of trona from mine water (**Figure 16**). Trona is refined at on-site plants into soda ash and other sodium-based products. Trona production set a record in 1997 at 19.4 million short tons.

According to soda ash producers, the 1998 production of soda ash is running 2.5% less than in 1997. This is primarily the result of the global financial crisis, which has lowered the amount of soda ash purchased by foreign buyers.

FMC, Wyoming's largest soda ash producer in 1997, announced that it will lay off 100 employees out of a workforce of 1,060, which is a cut of just under 10%. This is another effect of the global financial crisis. Additionally, OCi's earlier announced expansion of its workforce has been placed on hold, and it is "mothballing" 0.9 million tons of its capacity (*Casper Star-Tribune*, 11/18/98).

Solvay announced earlier this year that it was planning to delay its proposed production increase (*Wyoming Geo-notes No. 58*, p. 44).

Uranium

Uranium is the power source for nuclear power plants. Uranium^{235}, which is about 0.03% of natural uranium, is concentrated to 3% for use as a fuel in nuclear power plants. Heat generated by the natural radioactive decay of uranium powers turbines, which in turn run electrical generators.

The use of nuclear power varies widely geographically. Lithuania has the greatest percentage of nuclear-generated electricity, at 87%. France gets 78% of its electricity from nuclear plants, Japan 31%, and the United States 21% (Finch, 1997). For the past four years, 109 nuclear power plants have been operating in the U.S. The nation's share of world nuclear power, however, is decreasing due to the construction of nuclear power plants in other countries.

Uranium is mined in Australia, Canada, Namibia, Niger, South Africa, Kazakhstan, Uzbekistan, and the U.S. (Finch, 1997). In addition, stockpiles of mined uranium in formerly communist Eastern Europe and the decommissioning of uranium weapons have become present and future sources for fuel-grade uranium. Because large amounts of uranium from these latter sources are available, these sources contribute to the current, low price of uranium.

According to the Uranium Exchange, the price for uranium decreased in the third quarter of 1998, from $10.95 per pound of yellowcake to $9.85 per pound of yellowcake (**Figure 17**). The Uranium Exchange figures are available on the internet at: <http://www.uxc.com/top_review.html>.

In July, U.S. Enrichment Corp. (USEC), a government-operated company, was sold to the public through a stock offering. The privatization will include the transfer of Federally-owned uranium to the company, which announced plans to sell this uranium to reduce an estimated $500 million debt. Some analysts feel this sale could flood an already unsteady uranium market and lower the price of yellowcake to between $6.00 and $8.00 a pound. Uranium mining companies have joined together to sue the Federal government over the transfer of uranium to USEC.

U.S. Energy (USE), which has been developing the Jackpot uranium mine on Green Mountain south of Jeffrey City in Fremont County, suspended its activities at the end of July (*Wyoming Geo-notes No. 59*, p. 44). USE has already spent a reported $21 million to develop this underground mine (**Figure 16**). John L. Larsen, CEO of USE, said that the sale of USEC's uranium holdings would keep the price of uranium too low for USE's mine to be competitive. He also said the mine needed yellowcake prices around $20.00 a pound. The mine had employed 45 workers.

Uranium is produced in Wyoming by solution mining methods at three localities in the Powder River Basin. These are CAMECO's Highland-Morton

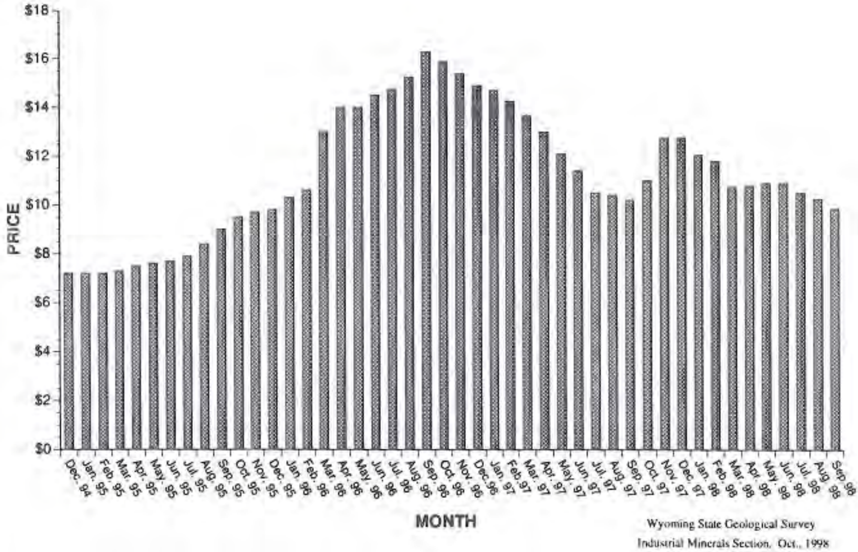

Figure 17. Domestic yellowcake prices, December, 1994, through September, 1998 (from Uranium Exchange).

Ranch operation; Rio Algom's Smith Ranch project; and COMIN's Christiansen Ranch operation (**Figure 16**).

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METALS AND PRECIOUS STONES UPDATE

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During the 1998 field season, the Wyoming State Geological Survey (WSGS) continued field investigations in the Iron Mountain district of the Laramie Mountains and Barlow Gap in the Granite Mountains. The WSGS also responded to numerous inquiries for information on the State's mineral resources.

The WSGS is involved in several diamond research projects. These are considered important because of the potential for diamonds to develop into a major new industry in Wyoming. For example, the discovery of diamonds in the State Line district in 1975, has led to the recovery of more than 130,000 diamonds from the Colorado-Wyoming State Line district during the past 20 years, and to the later development of the first diamond mine in the western U.S. The Kelsey Lake mine in northernmost Colorado produced about 9,000 carats in 1997 (Cappa, 1998), most of which were recovered from the Colorado side of the border. The diamonds have included gemstones as large as 28.3 carats. One diamond from the mine was cut into a 16.8-carat gemstone - the largest cut diamond from the U.S.

Recent discoveries in a similar geologic setting in the Northwest Territories of Canada are currently being developed into a multi-billion-dollar industry, where no diamond industry existed before. Canada's first diamond mine is scheduled for production prior to the close of 1998. Revenue from this industry is expected to exceed several billion dollars.

Global Japan is currently producing a special on the *"Mysteries of Diamond"* which is scheduled for viewing later this year to an audience of more than two million people on Japanese Public TV. Global Japan has contacted the WSGS and is considering filming portions of the program in Wyoming.

The WSGS is also conducting research related to several other commodities. One of the more notable is large-tonnage, low-grade, disseminated gold deposits. In addition to gold, some of the commodities sought by industry during the past quarter included platinum-palladium, titanium, iron, and gemstones. Gemstones with some economic potential include diamond, ruby, sapphire, aquamarine, garnet, pyroxene, cordierite, fluorapatite, jade, jasper, and agate.

The WSGS has begun mapping the geology of the 1:24,000-scale, Barlow Gap Quadrangle in the Granite Mountains of central Wyoming. The Barlow Gap area is underlain by structurally complex Archean supracrustal rocks and gneiss intruded by Precambrian granite and locally by Tertiary alkalic volcanics. The Precambrian terrain is unconformably overlain by Tertiary sedimentary rocks. The WSGS will continue this project over the next several years in order to complete a 1:100,000-scale map of the Rattlesnake Hills Quadrangle, which includes Barlow Gap, the Rattlesnake Hills gold district, and the Gas Hills uranium district.

In addition to field projects, the WSGS continued laboratory work related to the Iron Mountain kimberlites and the Leucite Hills lamproites. Laboratory work included petrographic and geochemical studies.

Kimberlite, Lamproite, and Diamond

The WSGS' research on kimberlites and lamproites is designed to identify favorable regions for these unique rock types, and to search for possible gemstones associated with those rocks. Since the beginning of the 1998 field season, two publications on the Survey's research have been released, and a third is in press: Hausel and others, 1998; Hausel, 1998a; and Hausel and others, in press.

A field report on a discovery of gemstones related to lamproites in the Green River Basin was also released in 1998 (Hausel, 1998b). The report describes gem-quality olivine found by the WSGS.

Much research related to kimberlites and lamproites surrounds rare, mantle-derived, kimberlitic indicator minerals (pyrope garnet, pyrope-almandine garnet, chrome diopside, chrome enstatite, magnesian ilmenite, and chromite). The presence of these minerals indicates a nearby, deep-seated, intrusive(s), which carried these minerals from great depths to the surface. The actual location of the intrusive(s) can be difficult to ascertain as they tend to be small and weather rapidly compared to surrounding country rock. Additionally, the intrusives are susceptible to burial by debris from the surrounding country rock.

During erosion, the mineral trains tend to migrate downstream from the host intrusive, and are often found within relatively short distances from the intrusive(s). Once the minerals are identified, they are tested by solid geochemical methods to predict depth of formation. Since the kimberlitic indicator minerals are many times more common than diamond, their chemistry is used to assess the potential for the discovery of diamond.

Bighorn Basin

In August, the WSGS initiated reconnaissance in the Bighorn Basin in northwestern Wyoming in search of kimberlite, lamproite, diamonds, and other gemstones. Initial reconnaissance resulted in the identification of several anthills containing rounded garnets in two different areas. The garnets are pink, red (with slight purple coloration), and yellow-orange.

Some garnets from the anthills were tested for index of refraction. One yielded an index of refraction <1.760, which is characteristic of pyrope. In addition, some small, emerald green prismatic minerals were recovered that are similar in appearance to chromian enstatite. These minerals will be examined using an electron microprobe. The resulting geochemistry will help assess the diamond potential of this region.

The Bighorn Basin as well as the surrounding Bighorn and Owl Creek Mountains, are considered favorable terrains to search for kimberlites. These lie within the Archon of the Wyoming craton. Archons typically have thick, cool, lithospheric root zones, and are favorable terrains for generation of magmas from great depths.

Iron Mountain District

Sampling and mapping continued in the Iron Mountain district in the Laramie Mountains 35 miles northwest of Cheyenne. Several previously unknown kimberlites were mapped by the WSGS during the 1997 and 1998 field seasons. Many of these are extensions of kimberlites previously mapped by Smith (1977). Based on mapping by the WSGS, four major kimberlite dike/blow complexes occur in the district - the largest has a strike length of 2.5 miles, and contains scattered blows ranging from tens of feet to 1,000 feet across (**Figure 18**).

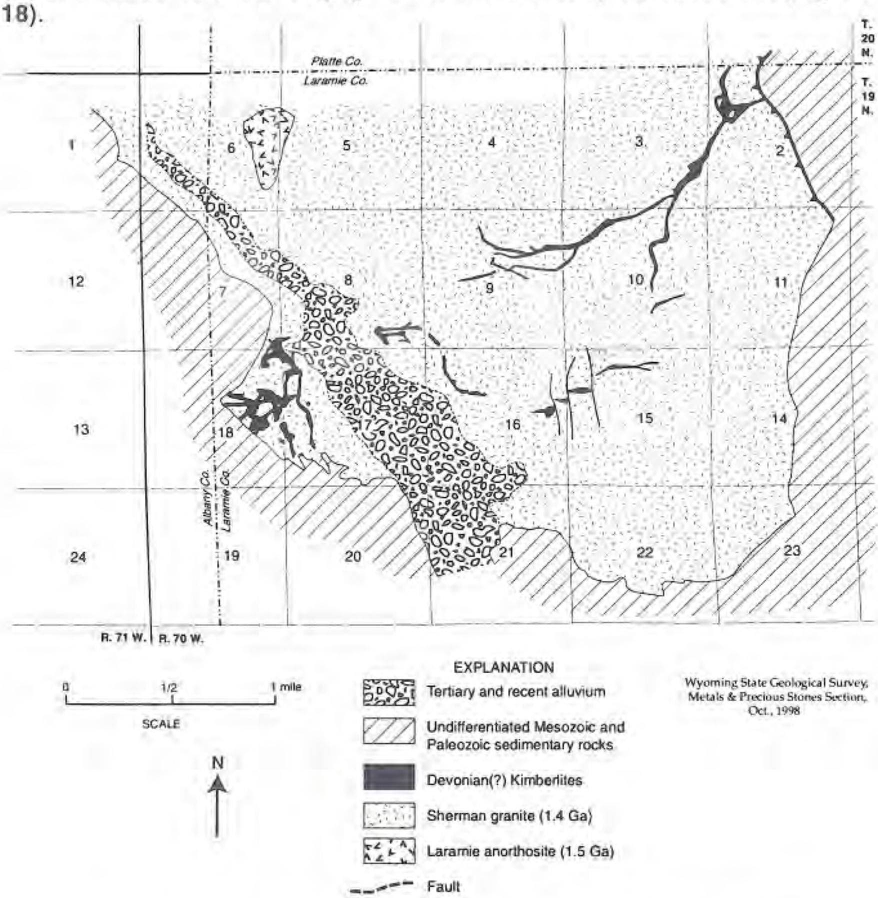

Figure 18. Revised preliminary map of the Iron Mountain kimberlite district.

The most recent discovery in the district was a kimberlite sill found in August. Most of the other mapped kimberlites, have either been dikes or blows (root zones of pipes), and sills have been uncommon. The kimberlites have been mapped based on the presence of outcrops, grassy vegetation anomalies, and/or blue ground. However, the newly discovered sill exhibits some blue ground, but is covered with sagebrush, unlike most other kimberlites in the area.

Evidence suggests the possible presence of other kimberlites in the district. Stream-sediment samples collected by the WSGS more than a decade ago (Hausel and others, 1988) indicated possible kimberlite to the north and west of the known intrusives. Additionally, the presence of several parks and boggy areas along some of the known kimberlite trends also suggest hidden dikes and blows.

Kimberlites may also underlie Tertiary conglomerate along the western flank of the district. In this region, Devonian (?) kimberlites were traced to the edge of the conglomerate. Locally, the conglomerate contains ilmenite megacrysts scattered within limestone boulders and cobbles. Future geophysical surveys (EM and magnetics) may isolate hidden kimberlites in the conglomerate.

Electron microprobe analyses of kimberlitic indicator minerals extracted from the Iron Mountain kimberlites suggest that portions of the intrusives may have originated within the diamond stability field. The analyses of recovered garnets have yielded both calcic (G9) and subcalcic (G10) chrome-pyropes. The subcalcic G10 garnets have similar chemistry to diamond-inclusion garnets and are interpreted to have originated within the diamond-stability field. A small sampling of pyrope-almandine garnets of probable eclogitic paragenesis show TiO_2 and Na_2O contents that also suggest probable genesis within the diamond stability field. Some chromite compositions exhibit compositions similar to diamond-inclusion chromite.

Future geochemical work will concentrate on apparent diamond grades and oxidizing/reducing conditions to aid in the prediction of the probability of diamond mineralization and preservation. As the final stage, small samples from the favorable intrusives will be tested for diamond.

Platinum-group Metals (PGM)

Late in the 1998 field season, staking of platinum-group metals (PGM) was reported in at least two different areas. This activity was centered on mafic-ultramafic complexes in southeastern Wyoming.

In the Medicine Bow Mountains, there are two large layered mafic intrusives of Proterozoic age. The Mullen Creek complex lies along the boundary between the Archean and Proterozoic terrains. This complex is sheared and intensely deformed. At the turn of the century, some PGMs were mined from sheared, hydrothermally altered, mafic schist. Reports indicate as much as

18,000 ounces of PGM's with some Au, Ag, and significant Cu were recovered from the New Rambler mine in this complex.

The Lake Owen complex to the southeast of the Mullen Creek complex is virtually undeformed and unmetamorphosed. Cumulus sulfide mineralization has been identified in at least 12 stratigraphic horizons in the complex with a few horizons containing PGM+Au mineralization in grades >1 part per million (ppm) (Louchs, 1991). This complex represents one of the better PGM exploration targets in the U.S.

West of the Medicine Bow Mountains in the Sierra Madre, several relatively unexplored mafic to ultramafic fragments and complexes occur. These include the Puzzler Hill complex along the northeastern flank of the Sierra Madre. PGM and Ni were identified in this complex by the WSGS in 1995. Select samples from prospects within the complex showed 0.01%-4.43% Cu, 66 ppm-3.72% Ni, 14 parts per billion (ppb)-0.29 ounce per ton (opt) Au, <5 ppb-828 ppb Pt, 5 ppb-0.12 opt Pd, <0.1 ppm-0.19 opt Ag, 21 ppm-831 ppm Co, 64 ppm-294 ppm Cr, and trace Pb and Zn (Hausel, 1997).

Other complexes in southeastern Wyoming include the Tony Ridge peridotite and the 350-square-mile Laramie anorthosite-gabbro complex in the Laramie Mountains, and the Woods Mountain and Elkhorn Mountain complexes in the Sierra Madre.

Iron and Titanium

There has been considerable interest in Wyoming's iron and titanium resources, as the State contains several, large deposits. These have been described by Harrer (1966), Houston and Murphy (1962), and Hausel (1990).

Particularly sizable iron resources occur in banded iron formation (BIF) in the South Pass and Seminoe Mountains greenstone belts, the Copper Mountain area, and as massive hematite in the Hartville uplift. Large resources are also found complexed with titanium in titaniferous magnetite in the Laramie anorthosite. Other iron and titanium resources are found in several titaniferous black sandstone deposits. Iron is also found in the Rawlins uplift, Barlow Gap, Rattlesnake Hills, Elmers Rock, and Sellers Mountain areas.

BIF occurs in Wyoming as finely laminated quartz-rich layers that alternate with magnetite-rich layers that typically assay greater than 25% Fe. BIF mined at the Atlantic City mine in South Pass from 1962 to 1983 totaled more than 90 million tons. During the height of mining, Bayley (1968) reported indicated reserves at 300 million tons (30 % Fe). More recent mapping and sampling by Hausel (1991) indicated sizable, in-place resources at the mine, as well as along strike to the northeast. Smaller resources were also mapped to the southwest. The BIF is steeply dipping, less than 100 feet thick, with an average grade of 33.5% Fe and 50% SiO_2. Locally, the BIF had been structurally thickened (fourfold) along the northern margin of the South Pass greenstone belt.

BIF was also mapped along the eastern limb of the South Pass greenstone belt in the vicinity of Lewiston Lakes. This deposit has similar mineralogy and chemistry as the Atlantic City iron deposits, but is smaller and relatively unexplored.

Large BIF deposits also occur in the Seminoe Mountains greenstone belt in central Wyoming. These are locally jasperized and contain zones of massive hematite. Harrer (1966) outlined a 100-million-ton deposit of BIF, and a 0.2- to 1.0-million-ton deposit of massive hematite. Samples of hematite yielded 31.4%-68.7% Fe and the BIF yielded from 28.0%-44.1% Fe. Typically, the BIF is less than 100 feet thick, although beds up to 800 feet thick and with nearly 3,500 feet of strike have been mapped (Hausel, 1994).

The Copper Mountain belt in the Owl Creek Mountains in northwestern Wyoming contains widespread BIF found in relatively narrow beds (<100 feet thick) with strike lengths of as much as 11 miles. Iron values range from 20%-36.9%. The BIF is locally cupriferous (Hausel, Graff, and Albert, 1985). Similar deposits have also been mapped in the Rattlesnake Hills and Barlow Gap areas in central Wyoming.

In the Hartville uplift in eastern Wyoming, massive hematite was found in pods at the Sunrise, Michigan, Good Fortune, Chicago, and Central deposits. With the exception of the Michigan deposit, all of these have been extensively mined. A minimum of 45 million tons of hematite with some copper was recovered in this region through 1980. The hematite was localized in a steeply plunging synform within the Silver Springs Schist near its contact with the overlying Wildcat Hills Dolomite. The ore continued to a depth of 1,000 feet, and covered a surface area 2,100 feet long by 50 to 600 feet wide (Snyder and others, 1989). In 1974, the mine reportedly contained about 25 million tons of iron reserves.

At Muskrat Canyon to the north, a 300- to 350-foot-thick hematitic iron formation is structurally overlain by sericitic metachert at the Michigan mine. The iron formation progressively becomes more sheared, cupriferous, and silicified to the west in the direction of the metachert. Two samples of the cupriferous iron formation were assayed and yielded 0.76% and 1.08% Cu, 14.0% and 21.0% Fe, with no detectable Au or Ag (Hausel, 1997). The iron formation occurs in two ore bodies. The northern body contained an estimated 75.5 million tons of ore averaging 25.3% Fe, and the southern body an estimated 41 million tons of ore averaging 24% Fe.

Several titanium deposits of potential economic interest have also been recognized (Hausel, 1990). They are of two types: (1) magmatic titaniferous magnetite in the Laramie anorthosite complex, and (2) titaniferous black sandstone paleoplacers scattered throughout several of Wyoming's basins.

The anorthosite complex hosts at least 30 massive deposits and one large disseminated deposit (Hagner, 1968), and the possibility of hidden deposits is very high. While there are large estimated resources of iron, titanium, chrome, and vanadium estimated for this complex, there is also the potential for the discovery of PGMs and Ni. Along the western flank of the complex, a large disseminated titaniferous magnetite deposit, known as the Strong Creek deposit, was drilled by U.S. Chrome several years ago. This deposit has an estimated resource of 300 million tons of titanium-iron ore.

Numerous titaniferous black sandstone deposits have been recognized in Mesozoic sedimentary rocks in Wyoming. In the Bighorn Basin, the Grass Creek occurrence is separated into two deposits. Drilling and outcrop sampling of the northern deposit identified a three-million-ton resource of 21% TiO_2 and 4.8% $ZrSiO_4$.

Disseminated Gold

During field reconnaissance in 1982, the WSGS discovered significant gold mineralization in the Rattlesnake Hills district in central Wyoming. This district lies near the northern flank of the Granite Mountains, 50 miles west of Casper. The core of the district is formed from a fragment of a partially exposed synformal Archean greenstone belt intruded by Tertiary alkalic plugs and dikes.

Three types of deposits are recognized in the district: (1) Tertiary-age disseminated gold in Tertiary alkalic volcanics and associated disrupted zones, (2) Precambrian-age stratabound exhalative gold mineralization, and (3) later cross-cutting auriferous structures in the Precambrian terrain.

The Rattlesnake Hills and Barlow Gap areas have been intruded by approximately 50 (Tertiary) felsic and alkalic stocks, laccoliths, domes, dikes, and plugs. Precambrian rocks adjacent to some quartz latites are iron-stained, brecciated, hydrothermally altered and provide potential targets for large-tonnage, low-grade, gold deposits. Similar volcanic rocks continue south of the Rattlesnake Hills and west of Barlow Gap.

Since the WSGS' discovery in 1982, drilling programs by exploration companies resulted in the discovery of other significant gold anomalies. American Copper and Nickel Co. drilled 32 holes between 1983 and 1987. Newmont Exploration drilled 14 holes between 1993 and 1995. More recently, Stratmore Resources has obtained a land position on the Sandy Mountain gold prospect (Dave Miller, personal communication, 1997). As a result, a large-tonnage, low-grade, gold deposit has been delineated. The deposit is more than a few hundred feet thick with a reported grade of 0.042 opt (Dick Fruchey, personal communication). Estimated in-place gold resources total at least 250,000 ounces, and the gold mineralization is open at depth and laterally.

Significant stratabound gold mineralization with an average grade of more than 0.3 opt over a 10-foot thickness was also intersected during drilling. Because of the numerous targets in this district, the Rattlesnake Hills is a significant gold prospect in the western U.S.

In addition to the Sandy Mountain prospect in the Rattlesnake Hills, some other large-tonnage, gold deposits have been recognized in recent years. These include Smith Ridge in the Bear Lodge Mountains. Exploration drilling in this region a few years ago by FMC, International Curator, and Coca Mines reportedly resulted in the discovery of an estimated 8.2-million-ton resource averaging 0.02 opt Au (Hausel, 1997). The alkalic volcanics and associated breccias in the Bear Lodge Mountains are extensive, and should provide numerous other targets for disseminated gold mineralization (as well as rare earths). Another very promising target is the Copper King deposit in the Silver Crown district in the Laramie Mountains west of Cheyenne. This copper-gold porphyry has been explored and drilled in recent years. Drilling and exploration by Mountain Lake Resources has reportedly identified a resource of 425,000 contained ounces of gold and 63,000,000 pounds of copper, with excellent potential for expansion (Brian Burmeister, personal communication, 1998).

Other areas with favorable geology for disseminated gold include the Mineral Hill district in the Black Hills, Quaking Asp Mountain in the Green River Basin, and several areas in the Absaroka Mountains.

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MINERAL RESOURCE AND RESERVE BASE ESTIMATES FOR WYOMING

PETROLEUM

Remaining Technically Recoverable Resources (January 1, 1998)	
Discovered (Includes oil, gas liquids, and condensate)	3.47 billion barrels[1]
Undiscovered	6.18 billion barrels[1]
Total	9.65 billion barrels
Remaining Reserve Base (January 1, 1998)	
Measured reserves (Proved reserves) (Includes: 0.627 billion barrels of oil and 0.600 billion barrels of gas liquids and condensate)	1.23 billion barrels[2]
Indicated and inferred reserves (Reserve growth in conventional fields)	2.41 billion barrels[1]
Total	3.64 billion barrels

NATURAL GAS

Remaining Technically Recoverable Resources (January 1, 1998)	
Discovered (Includes 35.6 trillion cubic feet (TCF) of methane[1] and 121.5 TCF of CO_2[3])	157.1 trillion cubic feet
Undiscovered (Includes 14.72 TCF of conventional methane[1]; 5.43 TCF of coalbed methane; 119.3 TCF of methane in tight gas sands in the Green River Basin; and 31.2 TCF of CO_2[3])	170.6 trillion cubic feet
Total	327.7 trillion cubic feet
Remaining Reserve Base (January 1, 1998)	
Measured reserves (Proved reserves) (Includes 13.6 TCF of methane[2] and 59.8 TCF of CO_2[3])	73.4 trillion cubic feet
Indicated and inferred reserves (Reserve growth in conventional fields)	22.8 trillion cubic feet
Total	96.2 trillion cubic feet

COAL

Remaining Resources (January 1, 1998)	
Identified and Hypothetical (Discovered)	1,426.6 billion tons[4]
Speculative (Undiscovered)	31.5 billion tons[4]
Total	1,458.1 billion tons
Remaining Reserve Base (January 1, 1998)	
Demonstrated strippable (Measured and indicated reserve base)	25.0 billion tons[5]
Demonstrated underground-minable (Measured and indicated reserve base)	42.5 billion tons[5]
Total	67.5 billion tons

TRONA

Original Resources	
Trona	76.0 billion tons[6]
Mixed trona and halite	51.0 billion tons[6]
Total	127.0 billion tons

URANIUM

Remaining Resource (December 31, 1989)	1.99 billion pounds U_3O_8[9]
Remaining Reserve Base (December 31, 1989)	
Uranium oxide recoverable at $30.00 per pound	66 million pounds[7]

OIL SHALE

Original Resources (January 1, 1981)	
Identified (Discovered)	320 billion barrels of shale oil[8]

[1] Modified from U.S. Geological Survey National Oil and Gas Resource Team, 1995, 1995 National Assessment of United States oil and gas resources: U.S. Geological Survey Circular 1118, 20 p.
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[4] Modified from Wood, G.H., Jr. and Bour W.V., III, 1988, Coal map of North America: U.S. Geological Survey Special Geologic Map, 1:5,000,000-scale (color) and 44 p. pamphlet.
[5] Modified from Jones, R.W., and Glass, G.B., 1992, Demonstrated reserve base of coal in Wyoming as of January 1, 1991: Geological Survey of Wyoming, Open File Report 92-4, 26 p.
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GEOLOGIC MAPPING, PALEONTOLOGY, AND STRATIGRAPHY UPDATE

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GEOLOGIC MAP COMPLETED FOR THE LARAMIE AREA

The Wyoming State Geological Survey (WSGS) recently revised its geologic map covering the city of Laramie (**Figure 19**). The new map is the WSGS' first map completed and published using mapping software. This color, geologic map is part of a series of maps prepared at either a 1:100,000- or 1:24,000-scale. The 1:24,000-scale Laramie Quadrangle was originally released in 1995 as Preliminary Geologic Map PGM 95-1. The map shows the bedrock and surficial rock deposits in the Laramie area.

The new map also shows the locations of sand and gravel, limestone, and gypsum resources. Information is supplied on potential landslides, unstable windblown deposits, areas of gypsum-rich soils, areas prone to debris flows, all of which are important considerations for future development of the area. In addition, new structural information is included on the map, which in conjunction with the bedrock information, is useful in locating sites for water wells.

Revisions and additions to the map include extending the Laramie fault to the north and adding in the outlines of sand and gravel, limestone, and gypsum quarries in the Laramie area. Both active and inactive or abandoned quarries are included. The name of the operator is included for the active quarries.

The map is titled: *Geologic map of the Laramie Quadrangle, Albany County, Wyoming*, and is available in hard copy from the WSGS in Laramie, as Map Series 50. Included with the map is a short narrative, which discusses the mineral resources, groundwater resources, geologic hazards, general geology, and structural geology within the map area.

The WSGS is now revising and digitizing the Red Buttes Quadrangle (**Figure 19**), located immediately to the south of the Laramie Quadrangle and the city of Laramie. The Buttes and Summit Estates housing developments occur within this quadrangle.

In a related note, the WSGS is currently compiling the geology for the Laramie 1:100,000-scale geologic map (**Figure 19**). During the 1998 field season, the WSGS mapped and field checked areas on the crest of the Laramie Mountains and along the southern portion of the basin. This mapping project is funded through a cooperative Federal/State program, called the STATEMAP program.

RED GULCH DINOSAUR TRACKSITE NEAR SHELL

In the spring of this year, the Worland District Office of the U.S. Bureau of Land Management (BLM) announced the discovery of rare fossil footprints on public lands near Shell, Wyoming (*Wyoming Geo-notes No. 58*, p. 63-64) (**Figure 19**). Referred to as the Red Gulch dinosaur tracksite, this significant discovery could lead to reinterpretations of traditional views of the paleoenvironment of Wyoming during the Middle Jurassic Period (160 to 180 million years ago). Geologists traditionally interpreted the green glauconitic shales, sandstones, and limestones of the Middle Jurassic Sundance Formation as deposited in a marine environment. Fossil oyster shells, *Gryphaea* (fossil bivalve mollusks), and belemnites (fossil squid-like creatures) are commonly found in outcrops of these rocks.

Eric Kvale, a research geologist from the Indiana Geological Survey, discovered the theropod (meat-eating) dinosaur tracks in ripple-marked shoreline limestones in a Sundance Formation outcrop on the Red Gulch road south of

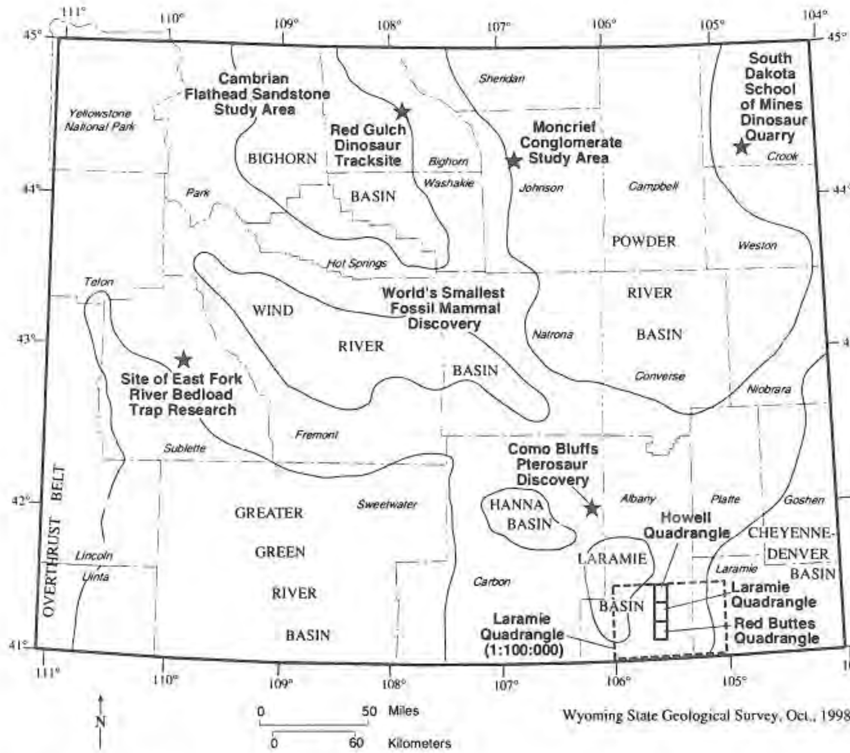

Figure 19. Index to recent paleontologic activities, geologic mapping, and geologic reports in Wyoming.

Shell. The Red Gulch dinosaur tracksite is the largest tracksite discovered in Wyoming. Because very little is known about dinosaurs of the Middle Jurassic, this site is providing an excellent opportunity to study them.

This summer, Brent Breithaupt, director of the University of Wyoming's Geological Museum, led researchers from the Smithsonian, Indiana Geological Survey, University of Colorado, South Dakota School of Mines, Kansas State University, Rocky Mountain College, Dartmouth College, and University of Wyoming in the investigation of the tracks at the site. The 40-acre site provided an opportunity for paleontology and geology students and researchers to study a little known part of the paleontologic record. Researchers measured and photographed the tracks and one researcher used GPS technology and computer mapping techniques to produce a three-dimensional rendition of the site. Various-sized theropods are indicated by tracks at the site. However, at this point the researchers do not know exactly which dinosaurs produced these tracks. Invertebrate fossils are also being studied at the site. Researchers have begun work characterizing the environments of deposition of these sediments and determining the extent of the deposits. The sediments at the tracksite indicate a tidal flat environment that may extend for miles. While work at the site has ended for this field season, researchers will need several years to complete an analysis of the site.

Concern with protecting and managing the Red Gulch tracksite and the desire of the scientific community to study the site has prompted the BLM to begin a planning review of the discovery area. The review will consider management options for public education, interpretation, scientific research, and recreation in the area and will allow for public participation in the planning process. The BLM plans to conduct public meetings and will accept written comments on the approach to management of the area as part of the preparation of an environmental analysis. Comments can be sent to the following address:

Bureau of Land Management
Worland District Office
P.O. Box 119
Worland, WY 82401-0119

In September, unauthorized plaster casting of the tracks was discovered at the site, emphasizing the need for protection and management of these resources. The individuals responsible for this vandalism apparently used chisels to remove the casts and have damaged some of the best footprints.

For those wishing to know more about the Red Gulch tracksite, the BLM has created a web page, which describes the tracksite and the ongoing research, as well as profiling the researchers working on the project. Their address is: <http://www.wy.blm.gov/whatwedo/tracsite/trac.html>.

DINOSAUR RECOVERY CONTINUES WEST OF SUNDANCE

The South Dakota School of Mines and Technology (SDSMT) continues to excavate dinosaur bones in a quarry exposed in a road cut west of Sundance (**Figure 19**). Six years ago Dr. James Martin, Curator of Paleontology at the SDSMT, and some of his students opened the quarry. Numerous specimens, including articulated camarasaur and allosaur skeletons and various Jurassic mammals, have been recovered from the quarry since its discovery. Work this summer focused on the removal of a 40-foot-long adult allosaur and a rare juvenile allosaur. Juvenile dinosaurs are seldom preserved due to the fragile nature of the small bones and their susceptibility to scattering by stream flow. These fossils were preserved in an abandoned stream channel formed in the Jurassic Morrison Formation nearly 150 million years ago. After preparation, assembled skeletons from the dig will be displayed at the Crook County Museum in Sundance.

PTEROSAUR BONES FOUND NEAR COMO BLUFFS

Tate Museum diggings near Como Bluffs yielded some interesting new discoveries this field season (**Figure 19**). Ed Pulver of Kokomo, Indiana, and Tate Museum staff member, Jordan Hand, uncovered a phalanx (finger bone) and a femur of a pterosaur (the first pterosaur upper leg bone recovered from Jurassic deposits in Wyoming). This discovery adds to the fossil record of pterosaurs in Wyoming during Upper Jurassic time. The femur is relatively large for a Jurassic pterosaur, indicating a possible wingspan of more than three feet. Two species of pterosaur have previously been found in the Como Bluff area, *Comodactylus*, which has a relatively long tail, and *Dermodactylus*, characterized by a much shorter tail. Researchers have yet to determine the species of this new find.

WORLD'S SMALLEST FOSSIL MAMMAL FOUND IN NORTHCENTRAL WYOMING

Researchers at a University of Michigan lab recently recovered the bones of *Batodonoides*, a very tiny shrew-like creature. The specimen was found in a fossilized, tropical, tree trunk, which was imbedded in Paleocene limestone sediments dating to 65 million years before the present. The specimen was recovered from the Fort Union Formation in the Wind River Basin of northcentral Wyoming (**Figure 19**). The little creature probably weighed as little as 1.3 grams. Researchers used acid to dissolve the limestone from around the tiny bones. Other members of this shrew-like group persisted for more than 45 million years after the extinction of dinosaurs at about 65 million years before the present. This fossil tree trunk also yielded a fossilized egg and egg shells.

NEW PUBLICATIONS ON WYOMING GEOLOGY

Beebee and Cox (1998) discuss the stratigraphy and depositional history of the quartz-rich sheet sandstone that makes up the Flathead Sandstone in northwestern Wyoming and Montana (**Figure 19**). This unit immediately overlies the Archean igneous and metamorphic basement rocks in the area and represents the first cycle of deposition as the Middle Cambrian sea transgressed over the craton. Various stratigraphic techniques were used to study the environments of deposition and provenance of this unit.

A recently released report by Hoy and Ridgway (1998) summarizes their work on the Eocene Moncrief Conglomerate in the footwall of the Clear Creek thrust fault on the east flank of the Bighorn Mountains (**Figure 19**). Analysis of various features noted within this unit indicates numerous types of deformation. Footwall deformation was accommodated by bedding-parallel faults, backthrust faults, progressive rotation of bedding, and deformation of conglomerate clasts. The authors also note that the deformation of the Moncrief Conglomerate in the footwall represented the final stage in the movement of the Clear Creek thrust, which was responsible for the formation of a large fault-related fold along the eastern flanks of the Bighorn Mountains.

During the 1970s scientists from the U.S. Geological Survey operated a bedload trap on the East Fork River, a tributary flowing westerly out of the Wind River Range and joining the New Fork River near the town of Boulder (**Figure 19**). This research is believed to be the only successful bedload trap research in the world. Leopold and Emmett (1997) summarized the results of this work in their recent report, which discusses the construction and design of the trap and the significance of the research findings.

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ROCK HOUND'S CORNER

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PART II: QUARTZ (CHALCEDONY) IN WYOMING

This is the second part of a two-part discussion of quartz and chalcedony in Wyoming. The first part of this article was published in the previous issue of *Wyoming Geo-notes* (Hausel, 1998).

In the Black Hills in northeastern Wyoming, minor amounts of chalcedony and uncommon amethyst have been found in the past. Agates and jasperoids are reported in stream gravels in the Mineral Hill district and the Black Buttes area east of Sundance. These are apparently related to Tertiary alkalic volcanic rocks in the area. Some amethyst was found along the western flank of Mineral Hill a few years ago by the author.

In the Powder River Basin to the west and south of the Black Hills, there are several varieties of chalcedony, including petrified wood as well as chert and jasper associated with Paleozoic limestones along the eastern flank of the Bighorn Mountains. The majority of the petrified wood occurs in the Wasatch Formation (Eocene). Occasionally, some spectacular, large-diameter, stumps and logs are found, such as the wood east of Buffalo at the U.S. Bureau of Land Management's Dry Creek petrified tree site. Although sometimes impressive, this wood is poorly silicified, quite brittle, and easily crumbles into small pieces that are not suitable for tumble polishing.

Another type of petrified wood, the Crazy Woman Creek wood, is more durable and well suited to lapidary purposes. This wood is well silicified, banded in shades of brown and white, and is found in terrace gravels about 60 to 120 feet above Crazy Woman Creek in an area extending from the flank of the Bighorn Mountains to where Dry Creek joins Crazy Woman Creek. Large pieces of the Crazy Woman petrified wood, up to 18 inches in diameter and 16 inches long, were collected from the vicinity of Crazy Woman Creek in the past and can be found in landscaping and in local collections in Buffalo. Similar material has been found in terrace gravels along the Powder River near Kaycee (Sutherland, 1990). East of Buffalo, Zeitner (1966) reported some amethyst-lined cavities were found in specimens of petrified wood.

The Granite Mountains in central Wyoming consist of extensive, low-lying, deeply eroded, rounded, bare hills of Archean granite with some localized metamorphic rocks. These ancient rocks are submerged in a sea of flat-lying Tertiary tuffaceous sedimentary rock, and in past years have been known for the extensive jade deposits found in the region. In addition, the range contains several types of agate, jasper, and petrified wood. One of the better known varieties of agate is the Sweetwater moss agate, which usually occurs as small pebbles in lag gravel and in the basal conglomeratic sandstone of the Split

Rock Formation (Tertiary). These agates will fluoresce a brilliant yellow due to the presence of hydrous uranium arsenate. They often contain a brown, opaque surface that can be removed by tumbling. Tumbling results in a highly polished, light gray to blue agate with black manganese dendrites (Love, 1970).

Another unit, known as the Ice Point Conglomerate (Tertiary), contains rounded fragments of black petrified wood. The Bridger Formation (Eocene) in the same area contains fossil tree stumps, water-worn fragments of petrified wood, and dark gray and brown agates (Love, 1970). Some clear chalcedony spheres coated with opal and white ash have also been found in the region. These have been loosely termed 'moonstones' (Cheyenne Mineral and Gem Society, 1965).

Another popular agate, the 'Angel' agate, is found in a 6-inch zone in the upper porous sandstone of the Split Rock Formation. Attractive pale-greenish-gray agates occur as nodules that are about 1 to 3 inches in diameter with a chalky-white surface coating. The agates fluoresce a brilliant greenish-yellow under ultraviolet light, and are slightly radioactive (Love, 1970).

In the Tin Cup area in the western Granite Mountains, beautiful jasperized breccias with angular fragments of blood-red, chocolate-brown, and butterscotch yellow-brown jasper are found along three prominent faults. Some attractive chalcedony found in this area is gray, banded, isoclinally folded agate.

The Greater Green River Basin of southwestern Wyoming includes the Great Divide, Washakie, and Green River Basins. In the Eden Valley area in the northern part of this basin, petrified wood is found over a wide area centered around Farson. This wood resembles ordinary weathered wood. It has an opaque, cream colored, outer coating of silica, which covers a silicified core that varies from black to brown and gray, with gray streaks in darker specimens. Most of the material is smaller than a few inches in diameter and less than a foot in length (Sutherland, 1990). The Laney Shale Member in the upper part of the Green River Formation and the overlying Bridger Formation appear to be the source of this material. The Laney Shale Member was deposited in a large inland lake during Eocene time.

The overlying Bridger Formation is primarily fluviatile with some thin lacustrine layers. Locally the formation contains silicified limestones and marlstones. Petrified wood is also commonly found in the formation, particularly in the vicinity of Oregon Buttes (Bradley, 1964). Much of the wood is encrusted with algae and silicified by processes similar to those petrified materials in the underlying Laney Shale. According to the Cheyenne Mineral and Gem Society (1965), this wood, known as the Bridger-type, consists of partially silicified black wood, and includes limbs, trunks, stumps and roots. Where the wood is completely replaced by silica, it is brown, tan, and green. In addition to the wood, some clear chalcedony and vein moss agates are found in this region.

Some of the prettiest wood found in Wyoming is the Blue Forest agate several miles west of Farson. The wood has a black to brown central core surrounded by clear blue chalcedony, which produces a unique and very attractive, silicified wood (Eloxite Corporation, 1971).

Reefs and beds of silicified *goniobasis* gastropods (snails), which were deposited only at certain depths within prehistoric Lake Gosiute, are found throughout the area. Some of the better collecting localities are along Delany Rim south of Interstate 80 near Red Desert, Wyoming. Not all occurrences of *goniobasis* were equally silicified. Some *goniobasis* agates that are light brown in color with a weathered appearance do not take a good polish. However, agates in shades of dark brown to black typically will polish.

Banded jasperoids on Quaking Asp Mountain south of Rock Springs consist of dark- to light-gray banded agate with cross-cutting veins of quartz, and banded red, yellow-orange, and gray jasperoid and onyx. These produce beautiful lapidary stones when polished.

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PART III: STUDY OF THE SENSITIVITY OF AQUIFERS TO CONTAMINATION

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This is the third and final part of a discussion on Wyoming's study of the sensitivity of aquifers to contamination. Part I addressed the project background and an overview of the State's aquifer sensitivity analysis (Case, 1998). Part II addressed the factors or maps used to conduct the analysis as well as a portion of the contributions of the Wyoming State Geological Survey (Case and Arneson, 1998). This final part discusses the geohydrologic setting sensitivity analysis and the vadose zone analysis.

GEOHYDROLOGIC SETTING SENSITIVITY ANALYSIS

As used in Wyoming's analysis, the geohydrologic setting sensitivity factor represents the capability of a geologic formation to transmit water and to attenuate the transmission of a contaminant. As mentioned in Part I of this discussion, the Environmental Protection Agency's (EPA's) DRASTIC model uses aquifer media and hydraulic conductivity, instead of this single factor, which was developed for use in Wyoming. DRASTIC's aquifer media factor is based upon the type of rock or unconsolidated material that comprises the aquifer. The primary assumption with the sensitivity analysis for the aquifer media factor is that the larger the grain size and the more fractures or openings within the aquifer, the higher the permeability and the lower the attenuation capacity of the aquifer media. The hydraulic conductivity factor in DRASTIC is based solely on the hydraulic conductivity of an aquifer.

For Wyoming, the two DRASTIC factors were combined into the geohydrologic setting sensitivity, because hydraulic conductivity data are limited. Since lithology, rock type, and type of unconsolidated material are used in DRASTIC to determine aquifer media sensitivity, and those same elements would have to be used in Wyoming to generate DRASTIC's hydraulic conductivity sensitivity, it made sense to combine the two factors into one.

In the Wyoming study, the geohydrologic setting sensitivity factor is composed of sensitivity ratings for all exposed geologic formations rather than for specific aquifers. This was done because very few maps of aquifers are available. It is realized that many geologic formations in Wyoming can be composed of multiple aquifers; that some formations, which are generally not considered an aquifer, can have a specific bed that does serve as an aquifer; and that some aquifers are composed of multiple formations. A map that represents all of these options has not been created, and would be very difficult to generate.

The fact that Wyoming researchers used one final factor instead of two does not mean that the process of deriving the individual sensitivity ratings for the geologic formations or Quaternary-age features is greatly simplified. In fact, in some aspects the process is more complex. In order to generate a final geohydrologic setting sensitivity rating for a geologic formation or unit, it is necessary to generate an initial rating based upon a rating chart developed by Dr. Peter Huntoon at the University of Wyoming (**Figure 20**). The rating chart combines elements from the rating charts for the two DRASTIC factors. The initial rating for each geologic formation or unit is then modified based upon the known water-production and generalized aquifer characteristics of the geologic formation or unit, and on estimates of the capability of the geologic formation or unit to absorb or disperse a contaminant.

Through the course of the study, it became apparent that it was important to modify the initial geohydrologic sensitivity ratings (**Figure 20**) by considering known water production and generalized aquifer characteristics of a geo-

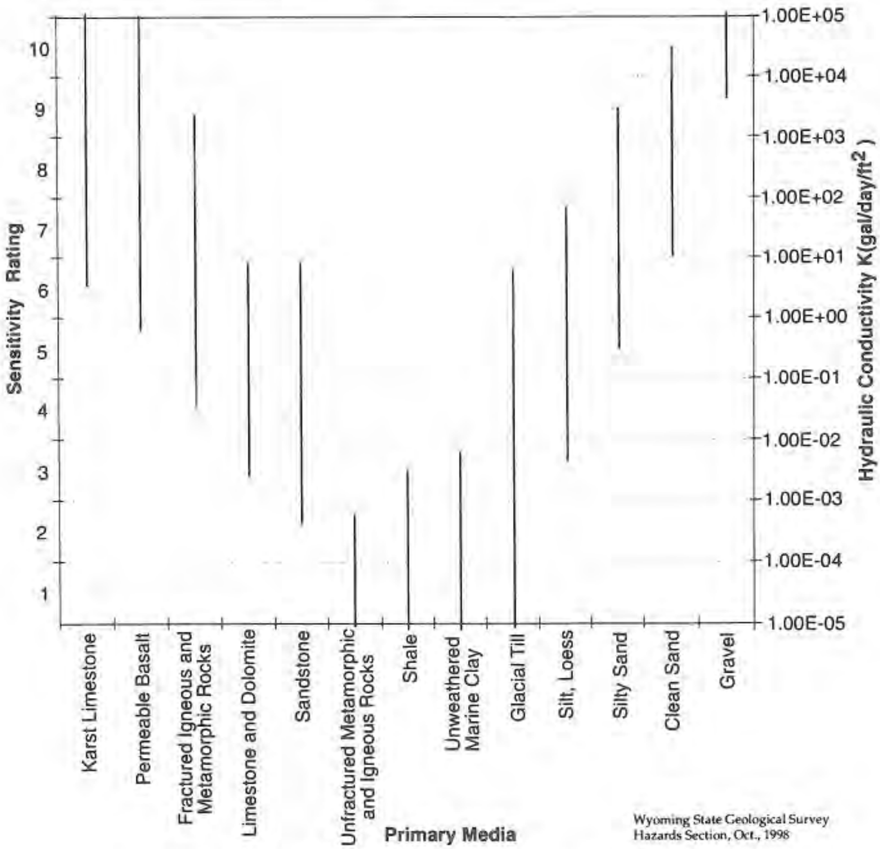

Figure 20. Ranges and ratings for geohydrologic setting sensitivities.

logic formation or unit. For example, the Tertiary-age Brule Formation is predominantly composed of tuffaceous claystone. Based upon material type alone, it would have a rather low hydraulic conductivity and sensitivity rating, and would not be considered a good aquifer. In reality, portions of the formation are significantly fractured, and it can serve as a significant aquifer. In order to account for these discrepancies, the Wyoming State Geological Survey (WSGS) developed a classification scheme to rank all geologic formations in Wyoming by their generalized aquifer and yield characteristics. The aquifer and yield characteristics were derived from numerous published reports, with most data derived from basin-wide ground-water reports generated by the Wyoming Water Resources Center and the U.S. Geological Survey's Water-Resources Investigation Reports, Hydrologic Atlases, and Water Supply Papers. The ranking scheme is as follows:

Rank	Generalized Aquifer Characteristic
8	Aquifer – high yield
7	Aquifer – high to moderate yield
6	Aquifer with aquitard interbeds, secondary permeability – moderate to high yield
5	Aquifer with aquitard interbeds – moderate yield
4	Aquifer and aquitard mixed – moderate to low yield
3	Aquitard with aquifer interbeds, secondary permeability – low to moderate yield
2	Aquitard with aquifer interbeds – low yield
1	Aquiclude/aquitard – low to no yield

For the purposes of this study the following definitions of yield were used:

High yield: May provide a water supply for irrigation or water supplies for large communities in Wyoming. In general, such formations may provide over 100 gallons per minute, and may even provide thousands of gallons per minute.

Moderate yield: May provide water supplies for small communities or for light industrial needs. In general, such formations may provide approximately 30 gallons per minute.

Low yield: May provide a limited water supply for stock or domestic use. In general, such formations may provide up to five gallons per minute.

The values for yield are approximate, and in localized areas any geologic formation may produce significantly more or less water than indicated by the classification. The classification represents average characteristics for a formation over an entire basin.

Using the *Stratigraphic chart showing Phanerozoic nomenclature for the State of Wyoming* (Love, Christiansen, and Ver Ploeg, 1993), geologic formations were classified by the geographic region of Wyoming in which they occur. Generalized aquifer characteristics applied to the formations range from a high yield aquifer to an aquiclude/aquitard with low to no yield. If a geologic formation was assigned an initial aquifer ranking from 1 to 3, it was checked against actual water production data from the formation. For example, the Hilliard Shale was initially ranked as an aquitard/aquiclude (Rank 1), based upon existing descriptions in the literature. The exposed portions of the Hilliard Shale were checked against water well records for shallow wells to determine if there actually was any production from the formation. Since limited production was found, the formation was reassigned to Rank 2.

The generalized aquifer characteristic rankings were compared to the geohydrologic setting sensitivity rankings for all geologic formations in Wyoming. The geohydrologic setting sensitivity rankings were then adjusted based upon the observed relative relationships. Some initial sensitivity ratings for a geologic formation were changed by three steps after a consideration of the generalized aquifer characteristics of that formation.

The 1:500,000-scale, *Geologic map of Wyoming* (Love and Christiansen, 1985) was used as the basis for the final geohydrologic setting sensitivity analysis. In many areas of the State, however, the areal extent of some geologic formations were too small to be shown at a scale of 1:500,000, and were lumped together on the *Geologic map of Wyoming*. As a result, many of the formations that were individually ranked in regard to their geohydrologic setting sensitivity were combined with other formations. The combined formations were reclassified based upon the percentage of each formation present in the map unit. In addition, a composite ranking was developed for single formations that had rankings that slightly differed from one area to another.

VADOSE ZONE ANALYSIS

The vadose zone is the unsaturated zone above the water table and below the soil. The type of vadose zone media determines the attenuation characteristics of the material. The media also controls the path length and routing of a contaminant. The EPA manual on DRASTIC (Aller and others, 1987) defined sensitivity ranking for vadose zone media, with the ranking ranging from 1-10. Rank 1 represents a confining layer with no potential for contaminants to migrate to the saturated zone. Rank 2 represents unfractured massive shale and silt/clay deposits or lightly fractured crystalline rock with a low potential for contaminants to migrate to the saturated zone. Rank 10 represents highly fractured and jointed basalt or karst limestone with a high potential for contaminants to migrate to the saturated zone.

The sensitivity ranking for vadose zone media was modified by the WSGS to reflect media present in Wyoming. Media added are eolian silt (rank 5-7), coal sequences (rank 3-8), eolian sand (rank 7-9), volcaniclastics (rank 3-9), and clinker (rank 8-10). The modified ranking scheme is shown in **Figure 21**.

The vadose zone in Wyoming can be composed of bedrock, surficial materials, or a combination of bedrock and surficial materials. As a result, the WSGS first assigned a vadose zone rank to the average composition of each geologic

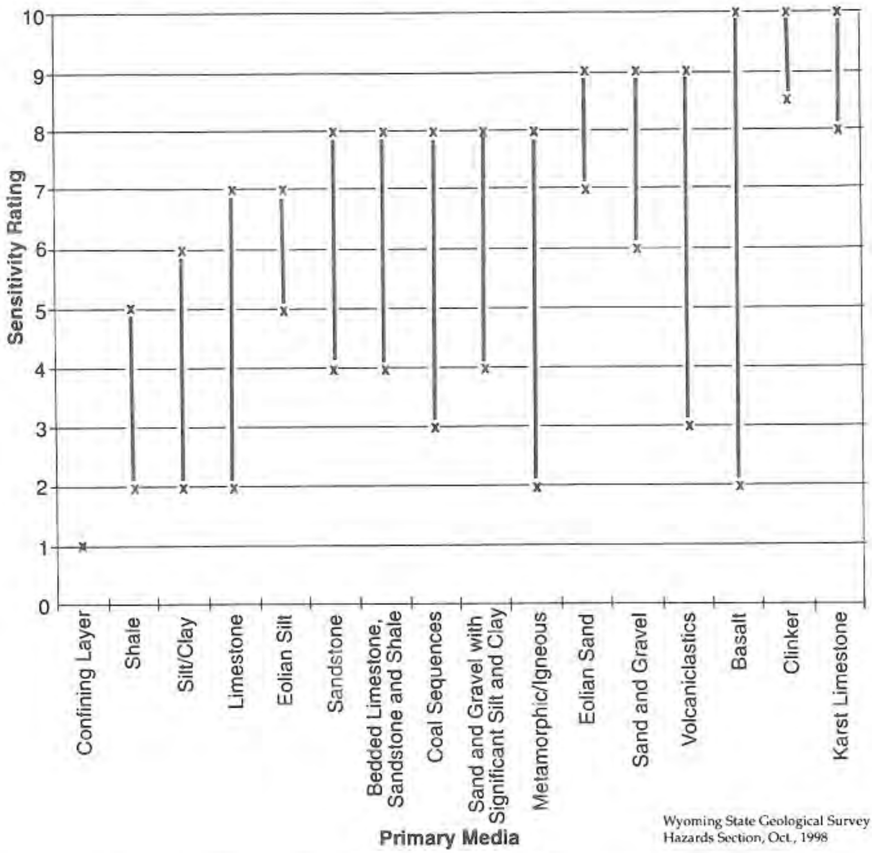

Figure 21. Ranges and ratings for impact of the vadose zone media.

formation or combinations of geologic formations present on the *Geologic map of Wyoming* (Love and Christiansen, 1985). The surficial units (25-element classification) present on each geologic formation were then defined and assigned a vadose zone rank that reflected the possible influence of the underlying bedrock on the composition and properties of the surficial unit. In many cases, the vadose zone includes bedrock and the overlying surficial materials, requiring a composite rank that reflects both the bedrock rank and the rank of the surficial materials. A series of formulas were developed to allow for the timely generation of the composite rankings. The formulas used for generating a total vadose ranking are presented in **Table 17**, with TV=Total Vadose (composite) Rank, BV=Bedrock Vadose Rank, and SV=Surficial Materials Vadose Rank. The generalized aquifer characteristic rank and the 25-element surficial geology classification are both used to determine which formula to use.

Formula Used	Aquifer Rank	Surficial Units
TV = SV	1-3	Ai, aR, ti, tre, fi, ei, gi, li, pea, ki
TV = SV	All	ai, oai, Mi, Ki, xi, Ti
TV = 10	All	glacier, lake
TV = BV	All	Ri
TV = 50% BV + 50% SV	4-8	Ai, aR, ti, tre, li, ki
TV = 50% BV + 50% SV	All	bi, mi
TV = 75% BV + 25% SV	4-8	fi, pea
TV = 75% BV + 25% SV	All	bdi, tdi, fdi, sci, ri, ui
TV = 25% BV + 75% SV	4-8	ei, gi

Table 17. Formulas for ranking vadose zone media

BENEFITS OF THE PROJECT

The maps generated through the project as well as the final aquifer sensitivity analyses are useful to many diverse groups and entities in Wyoming. The generated products are valuable tools for county, city, and statewide planning. The products can also assist in the siting of new facilities. Perhaps most importantly, the sensitivity analyses can help protect sensitive parts of aquifers in Wyoming.

ADDITIONAL INFORMATION

Additional information on the project is available through the Spatial Data and Visualization Center (SDVC) at the University of Wyoming or through the SDVC data clearinghouse at <http://www.sdvc.uwyo.edu>. A Ground-water Vulnerability Assessment Handbook is also in preparation and will be available from the SDVC.

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NEW PUBLICATIONS BY THE WYOMING STATE GEOLOGICAL SURVEY

Diamonds and mantle source rocks in the Wyoming craton with a discussion of other U.S. occurrences, by W.D. Hausel, 1998: Report of Investigations 53 - $10.00. ISBN 1-884589-13-8.

Preliminary 1:500,000-scale digital surficial geology map of Wyoming, by J.C. Case, C.S. Arneson, and L.L. Hallberg, 1998: Geologic Hazards Section Digital Map HSDM 98-1 - $10.00, available only on CD-ROM, for use on PC-based computers using Windows 95/98 or Windows NT.

Preliminary geologic map of the Guernsey Reservoir Quadrangle, Platte County, Wyoming, by R.E. Harris, 1998: Preliminary Geologic Map PGM 98-3 - $4.00.

*Publications available from the Wyoming State Geological Survey, September, 1998 - free.

*Sixty-fifth annual report of the Wyoming State Geological Survey for Fiscal Year 1998 (July 1, 1997, to June 30, 1998), by G.B. Glass and S.G. Bruhnke, 1998: Annual Report for FY98 - free.

*Geologic map of the Laramie Quadrangle, Albany County, Wyoming, by A.J. Ver Ploeg, 1998: Map Series 50 - $7.50.

*Proceedings of the First International Soda Ash Conference - Volume II, edited by J.R. Dyni and R.W. Jones, 1998: Public Information Circular 40 - $25.00. ISBN 1-884589-14-6.

*A review of Wyoming's coal mines and markets, 1998, by R.M. Lyman and L.L. Hallberg, 1998: Coal Report CR 98-1 - $15.00.

*Digital geologic map of the Cheyenne 30' x 60' Quadrangle, southeastern Wyoming, western Nebraska, and northern Colorado, by A.J. Ver Ploeg, J.C. Case, and C.A. Jessen, 1998: Geologic Hazards Section Digital Map HSDM 98-2 - $10.00, available only on CD-ROM for PC-based computers using Windows 95/98 or Windows NT.

*Preliminary digital surficial geologic map of the Casper 30' x 60' Quadrangle, Natrona and Converse Counties, Wyoming, by J.C. Case, L.L. Hallberg, and C.A. Jessen, 1998: Geologic Hazards Section Digital Map HSDM 98-3 - $10.00, available only on CD-ROM for PC-based computers using Windows 95/98 or Windows NT.

*Preliminary digital surficial geologic map of the Cheyenne 30' x 60' Quadrangle, southeastern Wyoming, western Nebraska, and northern Colorado, by J.C. Case, L.L. Hallberg, and C.A. Jessen, 1998: Geologic Hazards Section Digital Map HSDM 98-4 - $10.00, available only on CD-ROM for PC-based computers using Windows 95/98 or Windows NT.

*Preliminary digital surficial geologic map of the Laramie 30' x 60' Quadrangle, Albany and Laramie Counties, Wyoming, by J.C. Case, L.L. Hallberg, and C.A. Jessen, 1998: Geologic Hazards Section Digital Map HSDM 98-5 - $10.00, available only on CD-ROM for PC-based computers using Windows 95/98 or Windows NT.

*Preliminary digital surficial geologic map of the Rawlins 30' x 60' Quadrangle, Carbon and Sweetwater Counties, Wyoming, by J.C. Case, L.L. Hallberg, and C.A. Jessen, 1998: Geologic Hazards Section Digital Map HSDM 98-6 - $10.00, available only on CD-ROM for PC-based computers using Windows 95/98 or Windows NT.

*Subsurface correlation of selected Late Cretaceous and older formations along the eastern Powder River Basin, Wyoming (Cross section B-B'), by R.H. De Bruin, 1998: Geophysical Log Cross Section GLCS 98-1 - $5.00, available only as rolled blueline copy.

*Coalbed methane activity in the eastern Powder River Basin, Campbell and Converse Counties, Wyoming, by R.H. De Bruin, R.M. Lyman, and L.L. Hallberg, 1998, Coalbed Methane Map CMM 98-1 - $25.00, available only as a plotted color copy.

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