Water co-produced with coalbed methane in the Powder River Basin, Wyoming: preliminary compositional data [paper edition]

by Rice, C.A.[1], Ellis, M.S.[1], and Bullock, J.H., Jr.[1]

Open-File Report 00-372

2000

This report is preliminary and has not been reviewed for conformity with the U.S. Geological Survey editorial standards or with the North American Stratigraphic Code. Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

[1]Denver, Colorado

Table of Contents

List of Figures

List of Tables

Water co-produced with coalbed methane in the Powder River Basin, Wyoming: preliminary compositional data

C. A. Rice, M. S. Ellis, and J. H. Bullock, Jr.

INTRODUCTION

Production of water and natural gas from coal beds (coalbed methane, CBM) has increased dramatically over the past ten years and the gas currently accounts for about 6% of the total produced in the United States. The Powder River Basin (PRB) in Wyoming and Montana (Fig. 1) has emerged as one of the most active new areas of CBM production since 1997. Gas and water are being produced from thick coals in the Paleocene age Fort Union Formation primarily in the eastern part of the basin, although development is expanding to the northwest in the basin at the time of this report. The number of producing wells has increased from 270 in March, 1997 to 2,469 as of March, 2000 (Wyoming Oil and Gas Conservation Commission (WOGCC)). CBM production in the same period has increased from 34,529 thousand cubic feet per day (mcf/day) to over 333,000 mcf/day (WOGCC, 2000). Estimates from State and federal officials and industry representatives of the total number of wells expected in the basin over the next 20-30 years vary from 15,000-70,000.

Water is also brought to the surface during production of coalbed methane. The water in coal beds contributes to pressure in the coal beds that keeps methane gas adsorbed to the coal. During production, this water is pumped to the ground surface to lower the pressure in the reservoir and stimulate desorption of methane from the coal. As with gas production, water production in the PRB has also increased in the three-year period between 1997 and 2000 from about 130,000 barrels per day to over 1.28 million barrels per day (WOGCC, 2000), a ten-fold increase. As the number of CBM wells increases, the amount of water produced will also increase. Water production from a CBM well typically declines over the life of the well, and declining water production is anticipated and has been observed in CBM wells that have produced for several years. Decline in water production in developing areas of the basin and the basin as a whole is not expected to occur until most of the CBM wells have been developed and produced for a number of years.

Reliable data on the composition of the water produced from the CBM wells are needed so that State and federal land use managers can make informed decisions on handling, disposal, and possible beneficial use of water produced with CBM. Previous studies of water associated with coal beds in the PRB have focused on small areas near surface coal mines (Drever and others, 1977; Larson, 1988). Composition data on groundwater in the Fort Union Formation presented previously (Larson and Daddow, 1984) and other data acquired by the State of Wyoming Department of Environmental Quality through the discharge permit process are not coal bed specific. The data may represent co-mingled water from multiple coal beds and/or surface water or water from strata in the Fort Union Formation distinctly different from water produced from coal bed methane wells. Compositional data for CBM water can provide information on the heterogeneity of the CBM reservoirs, the potential flow paths in the Fort Union Formation, and the source and compositional evolution of the water.

In an effort to provide a better understanding of CBM resources and associated water, the U.S. Geological Survey, in cooperation with the U. S. Bureau of Land Management and coalbed methane production companies in the PRB is conducting multidisciplinary studies in the Powder River Basin. These studies are investigating regional geology and hydrology, coal composition, gas composition, methane desorption, and water composition. This report provides preliminary compositional data on water from 47 CBM wells sampled between June, 1999 and May, 2000 in the Powder River Basin, Wyoming. Data on major, minor, and trace elements are included. Other analyses on these samples, including deuterium, oxygen, and carbon stable isotopes, and dissolved organic carbon are not yet available. Additional sampling in the basin is planned over the next year to include other areas brought into development.

GEOLOGICAL SETTING

Powder River Basin geology is described by Ellis and others (1998), Flores and Bader (1999), and Flores and others (1999) and summarized below. The Powder River Basin includes over 12,000 square miles (Fig. 1). It is an asymmetrical structural and sedimentary basin with an axis that trends northwest to southeast on the western side. Coalbed methane is currently produced from coal reservoirs in the Paleocene Tongue River and Lebo Shale Members of the Fort Union Formation. The Fort Union Formation crops out along the margin of the Powder River Basin and, in much of the study area, is overlain by the Eocene Wasatch Formation (Fig. 1). Fort Union rocks dip an average of 20 to 25 degrees to the east along the western margin of the basin, and have an average dip of 2 to 5 degrees to the west on the eastern margin of the basin. The formation reaches a maximum of over 6,000 ft in thickness in the deepest part (along the axis) of the basin.

The Fort Union Formation contains conglomerate, sandstone, siltstone, and mudstone, with minor amounts of limestone, coal, and carbonaceous shale. Coal in the formation ranges from a few inches to over 200 ft thick, with an average thickness of 25 ft. The Fort Union was deposited in fluvial environments that consisted of braided, meandering, and anastomosed streams in the center of the basin, and alluvial plains along the basin margins (Flores and others, 1999). Coal developed from peat that accumulated in low-lying swamps and in raised or domed mires, in fluvial floodplains, abandoned fluvial channels, and interchannel environments. The thickest coal beds developed from peat that accumulated in raised mires, which formed above drainage level (Flores and others, 1999). The coal beds either split laterally or pinch out in areas where the peat was incised by fluvial channels, now represented by sandstone; or was inundated with overbank, floodplain, or floodplain-lake deposits, now represented by mudstone (Fig. 2).

The stratigraphic relationship of coal beds in the Fort Union Formation is very complex. The beds merge, split, and pinch out within short distances. Therefore, targeted coalbed methane beds vary across the basin (Figs. 2 and 3). Much of the CBM development is concentrated in the Wyodak-Anderson coal zone, although other beds and zones are locally being targeted as well (Fig. 3). Because of the complex stratigraphy, correlation and nomenclature problems have arisen in the basin. According to operator completion reports filed with the WOGCC, the Tongue River Member coal beds producing coalbed methane in the sampled wells include the Wyodak, Anderson, Canyon, Cook, Big George, Wall, and Pawnee. Two of the reservoirs, identified as the Cache and Moyer, are in the Lebo Shale Member. Also, in the operator completion reports, if the name of the coal bed was not known, the operator designated the producing unit as Fort Union. In an effort to clarify some of the correlation and nomenclature problems, the U.S. Geological Survey is currently working with the U.S. Bureau of Land Management and the WOGCC to standardize coalbed nomenclature (Flores, R.M., personal communication).

METHODS

Wells were selected for water sampling according to the distribution and the age of the wells. Sufficient time (minimum 1-2 weeks) past completion or workover is needed to ensure that formation water uncontaminated by drilling and completion fluids is sampled. Two wells per township were sampled to represent each producing coal seam. From June, 1999 through May, 2000, 47 wells were sampled for water (Fig. 4). Wells sampled, the date of sampling, and other pertinent information is listed in Table 1 and was obtained from the WOGCC well files and drilling completion reports. The producing coal listed in Table 1 for each sample is the well operator's designation (from well completion reports) and identification of coal seams or coal seam names may neither be consistent among operators nor consistent with nomenclature used by others.

Water samples were collected following guidelines of Lico and others (1988). Wells were allowed to flow through the tubing and fittings prior to collection of water samples to ensure flushing of the sample ports and collection of a representative sample. Most wells were pumping nearly continuously so water in the well bore was constantly being replaced. Water was collected directly from the wellhead by attaching tygon tubing to a port on the wellhead tee. The pressure on the port was generally less than 60 psi. Both gas and water were expelled from the well, but the amount of gas expelled was generally small relative to the amount of water. The water was allowed to collect in 5 gallon buckets while flushing the well and into a clean, rinsed polyethylene carboy with spigot or directly to the filter setup during sampling. Clean sample bottles were rinsed with well water at least twice prior to collection of a sample. For those analyses that did not require filtering (total inorganic carbon, alkalinity, and conductivity) samples were taken directly from the tygon tubing.

Water in the carboy was immediately filtered through a 0.1 μm polyethersulfone membrane filter utilizing a peristaltic pump, tygon tubing, and an acrylic filter holder (Fig. 5). Polyethylene bottles for major, minor, and trace cation analyses were prewashed with a mixture of 1.6 N nitric and 3.6 N sulfuric acid followed by a rinse with deionized water. Polyethylene bottles used for anions were prewashed with deionized water. Samples for major, minor, and trace cations, deuterium, oxygen, and carbon stable isotopes, and anions were collected from filtered water. The major, minor, and trace cation samples, except for mercury, were acidified with Ultrex nitric acid to a pH <2. Samples analyzed for mercury were collected in 30 mL glass bottles containing 1.5 mL of a sodium dichromate-ultrapure nitric acid mixture.

Temperature and pH were measured while the well flowed prior to collection of samples. The pH meter and electrode were calibrated using standard buffers before each measurement. Conductivity of the water was measured at the well, but measurements proved to be unreliable because of gas bubbles affecting the conductivity probe. Conductivity reported in this paper is the measured conductivity in the laboratory at 20° C. Total alkalinity for samples was determined by titration with standard sulfuric acid as soon as possible after sample collection, generally within 8 hours of collection. Samples for alkalinity, anions, dissolved organic carbon, ammonia, and $\delta^{13}C$ of bicarbonate were placed on ice in an ice chest in the field and transferred to a refrigerator on return to the laboratory.

Analytical methods used in this study are described in detail in Arbogast, 1996. Major and minor cations were determined by inductively-coupled plasma atomic emission spectroscopy (ICP-AES) with duplicate samples having a mean deviation generally within 6 percent. Trace cations except for mercury and selenium were determined by inductively-coupled plasma mass spectroscopy (ICP-MS). Samples analyzed by ICP-AES and ICP-MS were analyzed using both prepared multi-element standards and standard water samples obtained from the U.S. Geological Survey National Water Quality Laboratory. Mercury was determined by two methods. Sixteen samples were analyzed using cold vapor atomic fluorescence spectroscopy having a detection limit of 0.005 μg/L (Crock, J., USGS, personal communication) and the remainder of the samples were analyzed utilizing cold vapor atomic absorption spectroscopy with a detection limit of 0.1 μg/L. Selenium was determined by hydride generation atomic absorption spectroscopy. Values of detection limits for each element are shown in Tables 2 and 3. Concentrations of anions in the samples were determined by ion chromatography using a Dionex 500 chromatography system equipped with an AS-14 anion exchange column and using a sodium bicarbonate-sodium carbonate eluent. The estimated precision for the anion analyses is +/- 5 percent except for bromide whose concentrations are near the detection limit. Estimated precision for bromide is +/- 11 percent.

RESULTS AND DISCUSSION

Parameters measured at the wellhead such as temperature and pH and the major and minor element composition of the 47 samples are presented in Table 2. The temperature ranges from 13.8 to 28.7° C with a mean of 19.6° C and the pH of the water has a mean of 7.3 and a range of 6.8 to 7. 7. Total dissolved solids (TDS) ranges from 370 to 1,940 mg/L with a mean of 840 mg/L. For comparison, the national drinking water standards recommendation for potable water is 500 mg/L and seawater is about 35,000 mg/L. These samples suggest that TDS in waters in the Wyodak-Anderson coal zone increases from south to north and from east to west (Fig. 6). This trend may be a result of increased water-rock interaction along a flowpath, an increase or change in composition of the ash content of the coal, or other factors not yet recognized. The increase in TDS is generally a result of an increase in the sodium and bicarbonate content of the water. The preliminary data may support other basin-wide trends in constituents.

Powder River Basin CBM water has sodium as the dominant cation and bicarbonate as the major anion with the remaining cations and anions contributing less than 16 percent of the TDS (Table 2, Fig. 6). The major element composition of water in this study is in close agreement with water sampled from Tongue River Member coals in June, 1999 by the Water Resources Division of the USGS (Bartos, T., USGS, personal communication; Swanson and others, 1999). The data differ significantly from values reported in Larson and Daddow, 1984 for waters from the Fort Union Formation in Campbell County. In particular, many of the water analyses in Larson and Daddow have sulfate concentrations in the hundreds to thousands of mg/L, whereas sulfate concentrations in waters from Tongue River Member coals collected in this study range from <0.01 to 12 mg/L with a mean of 2.4 mg/L. As mentioned earlier, data from Larson and Daddow may not represent water from specific coal beds or zones in the Fort Union Formation.

Low values of sulfate in the CBM waters analyzed in this report are consistent with water in contact with a coal reservoir that has undergone or is undergoing methanogenesis. Sulfate concentrations in the CBM water have a direct influence on the amount of barium found in the water because barite (barium sulfate) generally controls the solubility of barium in most natural waters (Hem, 1992). Barium concentrations in the water analyzed in this study are relatively high compared to most groundwater because of the low sulfate concentrations. During coalification and methanogenesis, water in contact with the coals is anoxic and reducing. Elements such as iron and manganese, which are soluble as reduced species (Fe^{2+} and Mn^{2+}), have concentrations that are relatively high compared to surface water values as a result of the reducing environment. On contact with oxygen in the atmosphere at the surface, the dissolved concentrations of these elements may be expected to decrease significantly.

Trace element concentrations in water from the 47 CBM wells sampled in this study are given in Table 3. Concentrations for most of the elements are at or below detection limits. All of the concentrations for elements in Table 3 are below the maximum contaminant level (MCL) given by the Environmental Protection Agency (EPA) in the Drinking Water Standards (EPA, 1996). No noticeable trends in trace element concentrations are apparent.

ACKNOWLEDGMENTS

This study would not be possible without the cooperation of many of the companies and operators in the Powder River Basin who kindly gave permission to sample their coalbed methane wells and provided support in locating well sites and sometimes replumbing wellhead configurations. Thanks to Ocean Energy, Barrett Resources, Pennaco Energy, CMS Energy, Hi-Pro Production, Western Gas Resources, and Big Basin Petroleum. Jim Crock of the U. S. Geological Survey Mineral Resources Team kindly provided analyses of mercury in water samples by fluorescence spectroscopy.

REFERENCES

Arbogast, B. F., ed.,1996, Analytical methods manual for the Mineral Resources Surveys Program, U. S. Geological Survey Open-File Report 96-525, 248 p.

Drever, J. I., Murphy, J. W., and Surdam, R. C., 1977, The distribution of As, Be, Cd, Cu, Hg, Mo, Pb, and U associated with the Wyodak coal seam, Powder River Basin, Wyoming: Contributions to Geology, University of Wyoming, Vol. 15, pp. 93-101.

Ellis, M.S., Stricker, G.D., Flores, R.M., and Bader, L.R., 1998, Sulfur and ash in Paleocene Wyodak-Anderson coal in the Powder River Basin, Wyoming and Montana: A non-sequitur to externalities beyond 2000: Proceedings of the 23rd International Technical Conference on Coal Utilization, Clearwater, FL, March 9-13, 1998.

Flores, R.M. and Bader, L.R., 1999, Fort Union coal in the Powder River Basin, Wyoming and Montana: A synthesis: U.S. Geological Survey Professional Paper 1625-A, Chapter PS, 49 p., on CD-ROM.

Flores, R.M., Ochs, A.M., Bader, L.R., Johnson, R.C., and Vogler, Daniel, 1999, Framework geology of the Fort Union coal in the Powder River Basin: U.S. Geological Survey Professional Paper 1625-A, Chapter PF, 17 p., on CD-ROM.

Hem, J. D., 1992, Study and interpretation of the chemical characteristics of natural water: U. S. Geological Survey Water Supply Paper 2254, 263 p.

Larson, L. R., 1988, Coal-spoil and ground-water chemical data from two coal mines; Hanna Basin and Powder River Basin, Wyoming: U.S. Geological Survey Open-file report 88-481, 18 p.

Larson, L. R. and Daddow, R. L., 1984, Ground-water-quality data from the Powder River structural basin and adjacent areas, northeastern Wyoming: U.S. Geological Survey Open-file report 83-939, 56 p.

Lico, M. S., Kharaka, Y. K., Carothers, W. W., and Wright, V. A., 1988, Methods for collection and analysis of geopressured geothermal and oil field waters: Geological Survey Water Supply Paper 2194, 21 p.

Swanson, R. B., Mason, J. P., and Miller, D. T., eds., 1999, Water Resources Data, Wyoming, Water Year 1999, Volume 2, Groundwater: U. S. Geological Survey Water-Data Report WY-99-2, 125 p.

Wyoming Oil and Gas Conservation Commission (WOGCC), 2000, On-line database accessible at http://wogcc.state.wy.us.

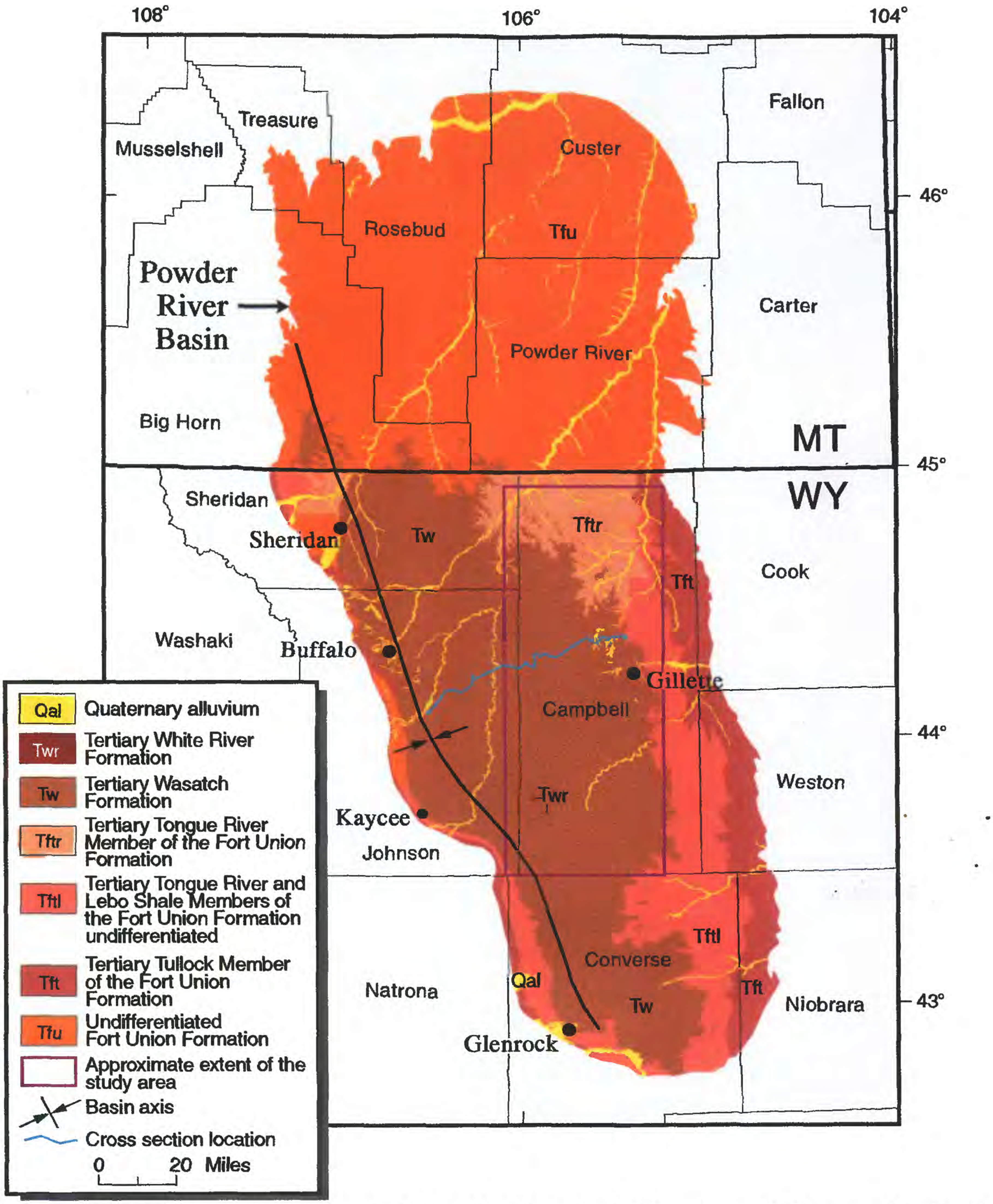

Figure 1. Generalized geologic map of the Powder River Basin,Wyoming and Montana showing the basin axis, counties, major cities, location of cross section (fig. 2), and approximate extent of the study area (modified from Flores and Bader, 1999).

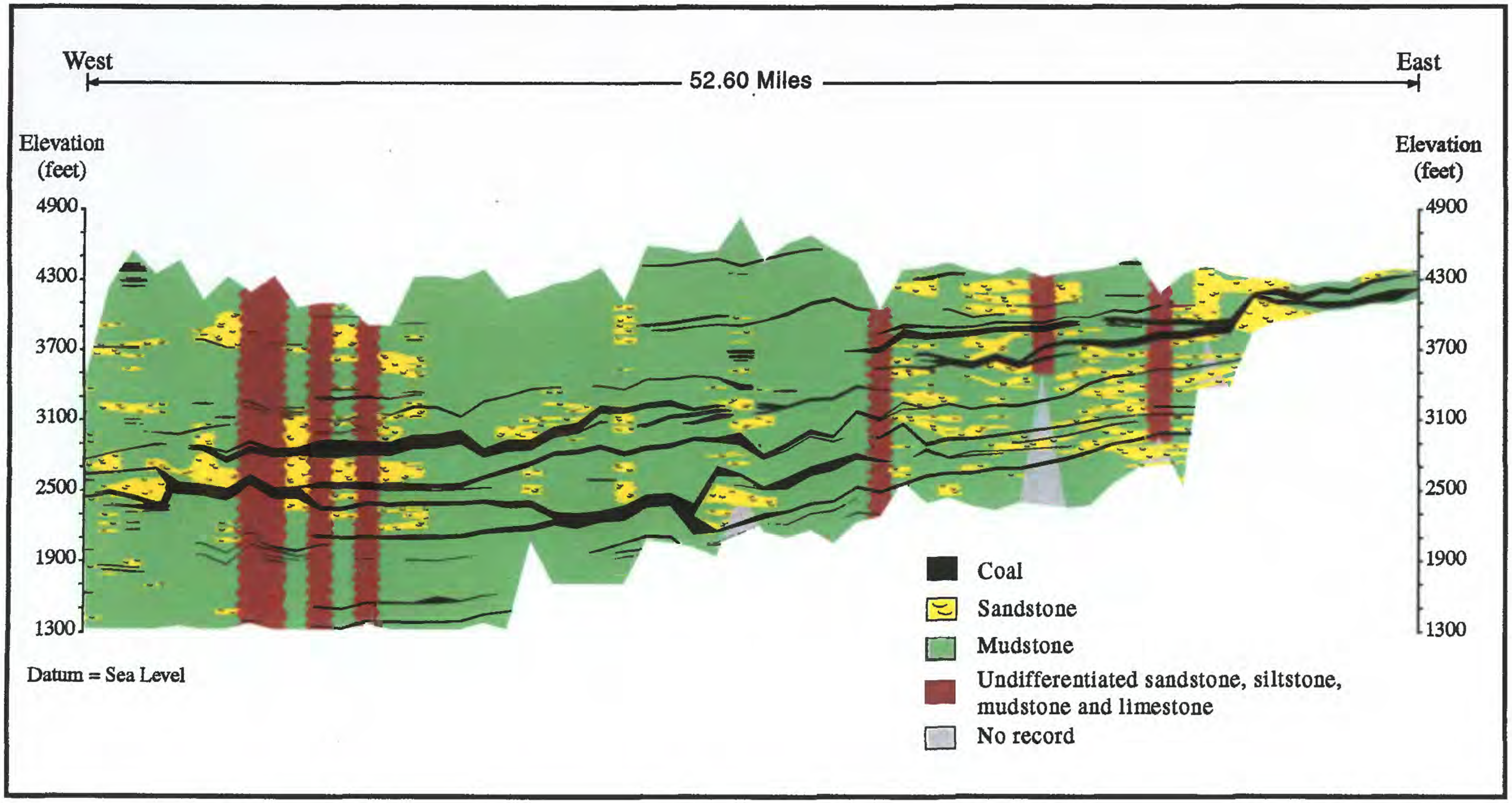

Figure 2. Cross section showing an example of the complex stratigraphic relationship of coal beds in part of the Tongue River Member of the Fort Union Formation. This cross section is in the central part of the Powder River Basin,Wyoming near the city of Gillette. (Modified from Flores and others, 1999).

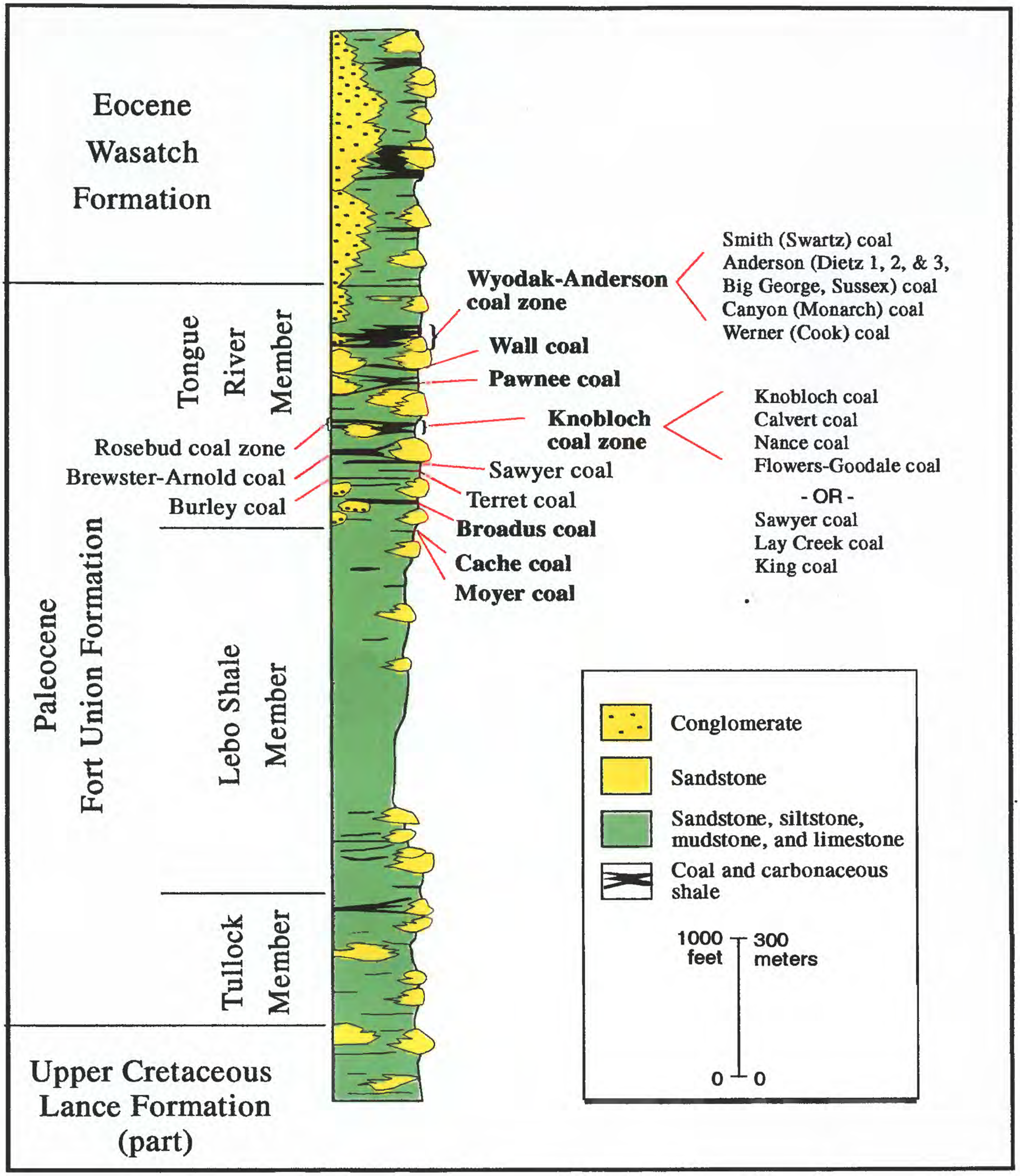

Figure 3. Composite stratigraphic column showing the Upper Cretaceous Lance Formation (part), and Tertiary Fort Union and Wasatch Formations in the Powder River Basin, Wyoming and Montana. Major coal beds and zones in the Fort Union Formation are identified. Coal zones or beds targeted for coalbed methane are bold. (Modified from Flores and Bader, 1999)

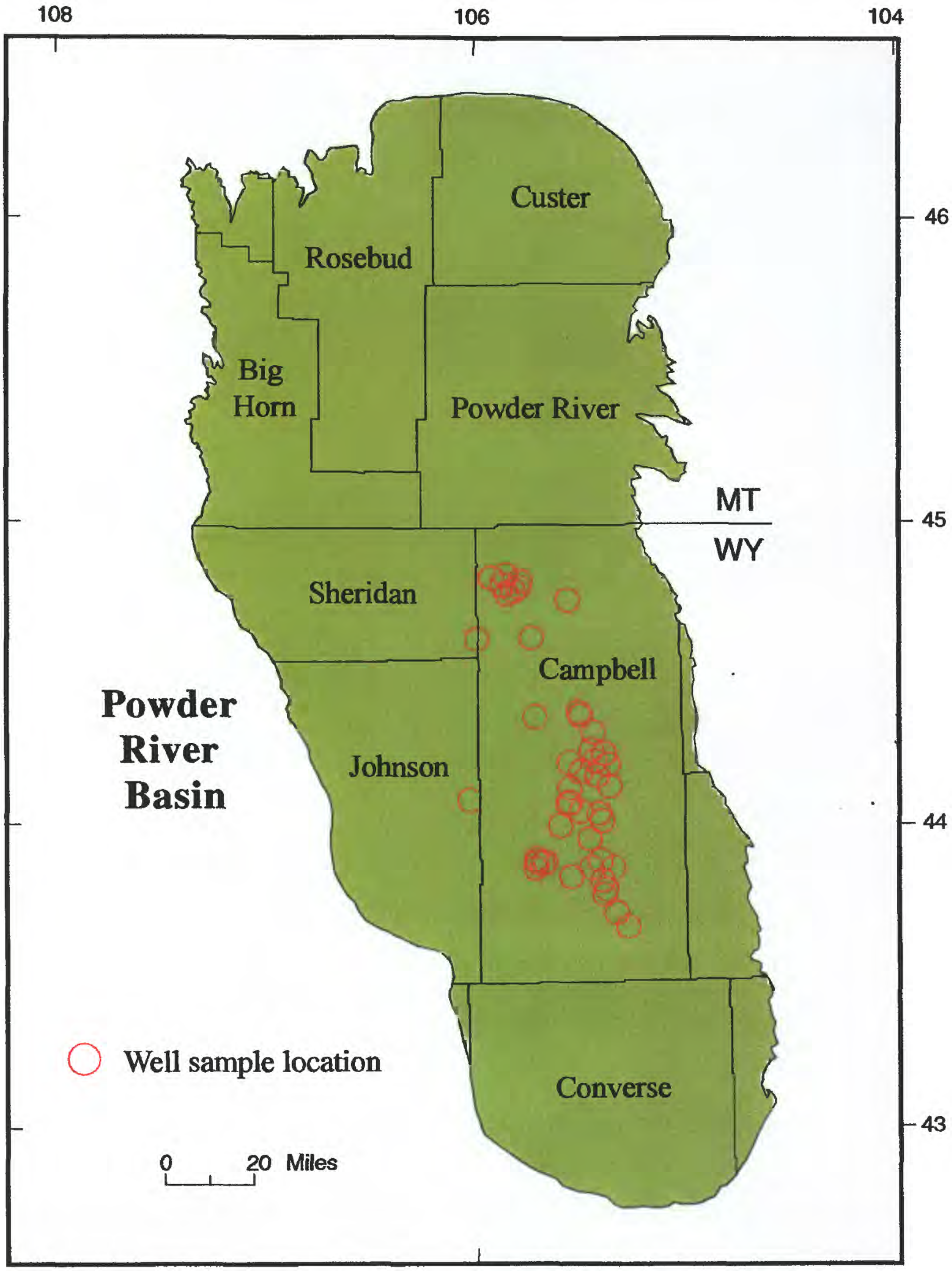

Figure 4. Map showing the Powder River Basin, counties, and location of well sites sampled for this study.

Figure 5. Collecting filtered samples for analysis.

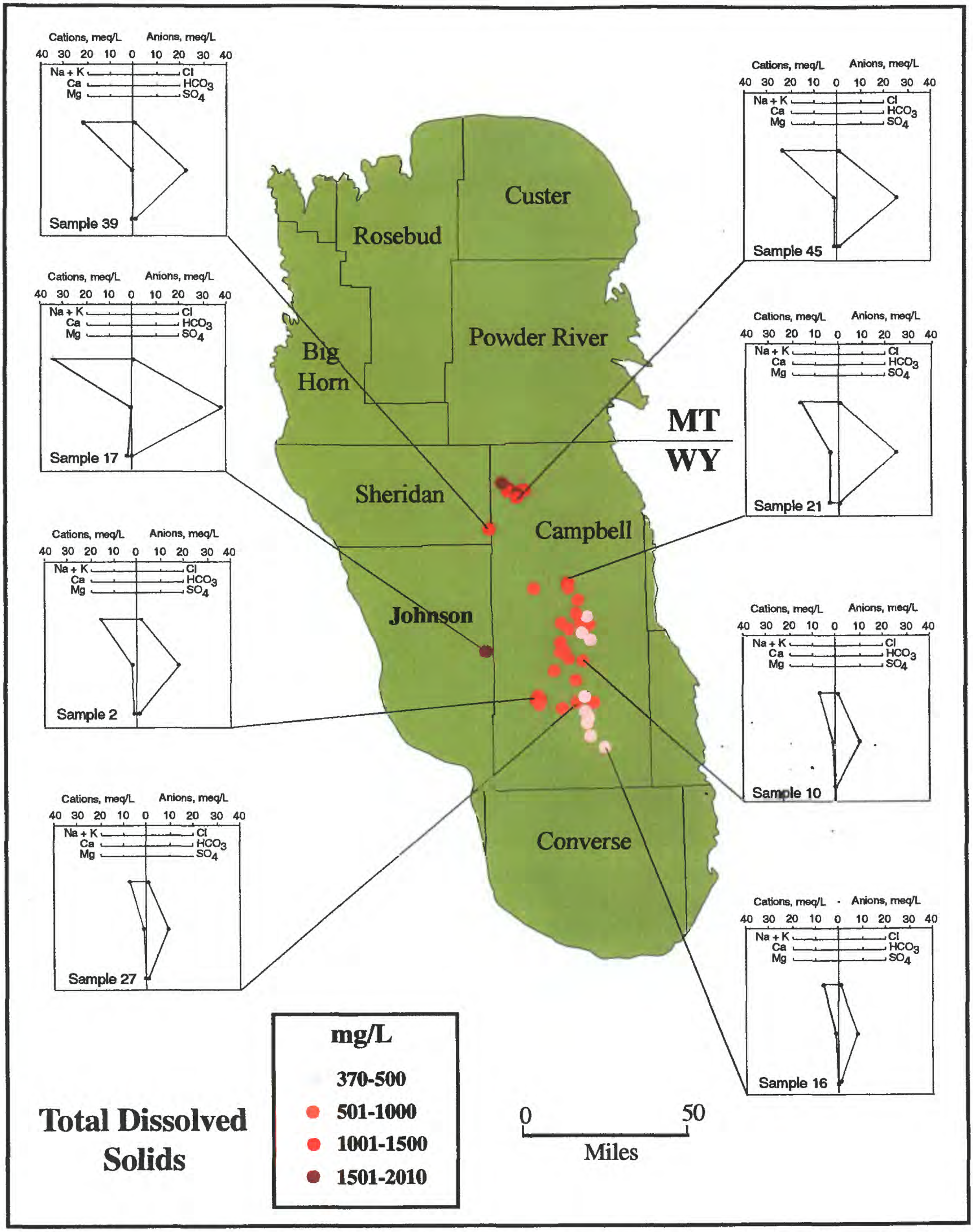

Figure 6. Distribution of total dissolved solids in water co-produced with coalbed methane from the Wyodak-Anderson coal zone. Composition of selected samples indicated by Stiff diagrams.

Table 1. Information on wells sampled. Information is from Wyoming Oil and Gas Conservation Commission well files and completion reports.

Sample #	Sampling Date	API #	Well Name	Township	Range	Section	Latitude	Longitude	Total Depth (feet)	Producing Interval (feet)	Operator Defined Producing Coal	Completion Date
1	6/24/1999	4900534171	Schlautmann 16-10-45-74C	45	74	10	43.88351	105.73106	1432	1386-1432	Canyon	6/18/1999
2	6/25/1999	4900534172	Schlautman 16-10-45-74A	45	74	10	43.88351	105.73129	1175	1112-1175	Anderson	6/18/1999
3	6/25/1999	4900534175	Schlautmann 15-10-45-74C	45	74	10	43.88350	105.73602	1417	1377-1417	Canyon	6/19/1999
4	6/25/1999	4900534176	Schlautmann 15-10-45-74A	45	74	10	43.88350	105.73625	1146	1082-1146	Anderson	6/19/1999
5	8/21/1999	4900534174	Schlautmann 9-10-45-74A	45	74	10	43.88731	105.73128	1225	1160-1225	Anderson	7/13/1999
6	8/17/1999	4900532910	Lange 14-14	48	73	14	44.13226	105.60496	901	828-894	Fort Union	7/21/1998
7	8/18/1999	4900533975	Moser 14-35	48	73	35	44.08870	105.60644	1014	917-1008	Wyodak	2/8/1999
8	8/18/1999	4900534118	Persson-12-33	47	73	33	44.00868	105.64655	1315	1213-1281	Wyodak	7/7/1999
9	8/18/1999	4900534083	Heiland 42-3-4773	47	73	3	44.08138	105.61156	992	918-992	Wyodak	5/18/1999
10	8/19/1999	4900530949	Mankin 14-23	47	72	14	44.04820	105.47708	612	512-612	Wyodak	4/9/1996
11	8/19/1999	4900531919	State 616-22	46	72	22	43.96485	105.51628	915	818-906	Fort Union	5/12/1998
12	8/20/1999	4900532860	W. Fork Flocchini 43-12	44	72	12	43.80146	105.44485	879	798-860	Wyodak	9/29/1998
13	8/20/1999	4900531561	Durham Ranch 1-21-24	44	72	24	43.77962	105.45448	832	711-829	Wyodak	7/8/1997
14	8/20/1999	4900532517	Arch 22-26	43	71	26	43.67377	105.35406	465	386-444	Wyodak	12/2/1998
15	8/21/1999	4900531900	MM 24-7	47	72	7	44.05850	105.55986	853	758-846	Fort Union	4/22/1998
16*	8/21/1999	4900533187	Thunder Edwards 21-7	43	71	7	43.72163	105.43550	606	537-583	Wyodak	9/29/1998
17	9/22/1999	4900533446	Iberlin 31-36	48	77	36	44.09563	106.05625	1335	1208-1342	Big George	10/13/1998
18	9/22/1999	4900535416	Floyd 10-28-51-74	51	74	28	44.36711	105.75997	812	715-762	Anderson	8/16/1999
19	9/24/1999	4900533031	Swanson 13-14-49-72	49	72	14	44.21950	105.48659	531	437-514	Anderson	4/28/1999
20	9/25/1999	4900533964	Hemala 9-19-49-71	49	71	19	44.20856	105.43045	450	369-434	Anderson	5/14/1999
21	9/24/1999	4900530031	Echo 15-19	51	72	19	44.37943	105.55658	562	446-514	Wyodak	3/1/1991
22	9/24/1999	4900529839	Walls Fee 74-7	51	72	30	44.36825	105.55089	480	375-480	Wyodak	5/28/1990
23	9/23/1999	4900534205	Parks Longhorn 6-14-55-73W	55	73	14	44.74927	105.59760	545	493-532	Pawnee	2/16/1999
24	9/23/1999	4900535136	Sorenson 15-28-54-74	54	74	28	44.62670	105.76550	1245	1200-1243	Wall	8/6/1999
25	5/4/2000	4900531234	Durham Ranch 3-31-20-4571	45	71	20	43.86696	105.41218	4837	411-450	Wyodak	1/25/1997
26	5/4/2000	4900533115	Durham Ranch 13-36	45	72	36	43.83005	105.46381	4795.4	662-746	Wyodak	11/4/1998
27	5/4/2000	4900531760	Durham State 34-16	45	72	16	43.86996	105.51315	4807.6	643-715	Anderson	5/28/1999
28	5/4/2000	4900531494	Durham Ranch 8-42-11	45	72	11	43.89283	105.46752	4813	514-561	Anderson	8/28/1997
29	5/4/2000	4900539435	Durham Ranch 23-26-4573	45	73	26	43.84389	105.60111	4870.1	938-1040	Wyodak	4/11/2000
30	5/6/2000	4900532105	Haight 22-25	47	72	25	44.02273	105.45669	4687	1272-1411	Pawnee/Cache	9/20/1999
31	5/6/2000	4900534735	Rourke 8-18-48-71	48	71	18	44.13940	105.42654	4671	414-482	Anderson	7/26/1999
32	5/6/2000	4900535392	McCreery 3-2-48-72	48	72	2	44.17195	105.47718	4645	551-624	Anderson	7/16/1999
33	5/3/2000	4900535985	Steinhoefel 5-7-49-71	49	71	7	44.24217	105.44584	4571	264-310	Anderson	8/25/1999
34	5/3/2000	4900538024	Steinhoefel 5-7-49-71D	49	71	7	44.24185	105.44585	4572	1016-1044	(Moyer) Canyon	2/24/2000

Table 1. Continued.

Sample #	Sampling Date	API #	Well Name	Township	Range	Section	Latitude	Longitude	Total Depth (feet)	Producing Interval (feet)	Operator Defined Producing Coal	Completion Date
35	5/5/2000	4900537482	Milne 15-30-49-72	49	72	30	44.18918	105.55771	4888	849-902	Anderson	1/7/2000
36	5/6/2000	4900536125	Meserve 5-3-49-72	49	72	3	44.25615	105.50685	4553	446-490	Anderson	9/9/1999
37	5/5/2000	4900536827	Swansong 15-14-49-73	49	73	14	44.21788	105.5994	4816	841-900	Anderson	11/6/1999
38	5/2/2000	4900531229	Miller 5-32-15	50	72	15	44.31513	105.49627	4443	192-253	Anderson	11/16/1996
39	5/10/2000	4903320335	Floyd 9-29A	54	76	29	44.62621	106.02277	3811.2	612-656	Anderson	8/16/1999
40	5/10/2000	4900534475	West 12-28CA	56	75	28	44.80021	105.90096	4077	665-688	Canyon	6/27/1999
41	5/9/2000	4900534466	West 6-28CO	56	75	28	44.80393	105.89547	4035.9	837-896	Cook	11/18/1999
42	5/0900	4900536006	West 6-28WP	56	75	28	44.80351	105.89423	4038		Wall/Pawnee	
43	5/9/2000	4900535352	West 16-13CO	56	76	13	44.82480	105.94563	4156.6	976-1020	Cook	10/29/1999
44	5/8/2000	4900534690	LX-State-1-36C	56	75	36	44.79349	105.82354	3961	645-687	Canyon	5/2/1999
45	5/8/2000	4900535333	LX-State-1-36A	56	75	36	44.79362	105.82395	3956	365-390	Anderson	7/17/1999
46	5/8/2000	4900534425	LX Fee 14-35A	56	75	35	44.78226	105.85366	4030	764-805	Anderson	4/1/1999
47	5/8/2000	4900534424	LX Fee 6-2C	55	75	2	44.77510	105.85416	4044	531-??	Canyon	5/28/1999

* The API number for sample 16 indicates that the well is in Campbell County. However, the Latitude and Longitude place the sample in Johnson County as shown in Figures 4 and 6.

Table 2. Measured parameters and major and minor element concentrations in waters produced with coalbed methane from wells in the Powder River Basin, WY. Alkalinity is reported as mg/L $HCO3^-$. Total dissolved solids (TDS) is calculated assuming approximately half of the bicarbonate is lost on evaporation (Hem, 1992). Conductivity measured in lab at 20.0 °C. Temp=temperature; Cond=Conductivity; ND=not determined; SAR=Sodium Adsorption Ratio; µS/cm=microsiemens per centimeter; mg/L=milligram per liter; <=detection limit.

Sample #	pH	Temp °C	Cond µS/cm	TDS mg/L	F mg/L	Cl mg/L	SO_4 mg/L	Br mg/L	Alkalinity mg/L	NH_4^+ mg/L	Ca mg/L	K mg/L	Mg mg/L	Na mg/L	Ba mg/L	Fe mg/L	Si mg/L	Sr mg/L	SAR
1	7.3	25.3	1280	900	0.77	9.2	12	0.14	1000	1.5	52	6.9	16	300	0.59	0.75	5.3	1.0	9.3
2	7.3	22.1	1640	1050	0.55	64	8.4	0.80	1100	2.0	49	5.9	18	350	0.79	0.52	4.4	1.6	11
3	7.3	25.7	1130	730	0.63	7.8	3.4	0.07	840	1.5	39	4.7	9.0	240	0.42	1.0	5.1	0.82	9.0
4	7.3	23.0	1640	1120	0.50	60	1.5	0.85	1170	1.9	56	5.9	18	390	0.80	1.1	4.6	1.8	12
5	7.4	21.7	1480	970	0.61	48	5.1	0.68	1020	2.0	38	6.1	18	340	0.80	1.2	4.7	1.2	11
6	7.0	21.2	1280	840	0.80	9.5	<0.01	0.08	950	3.1	42	14	25	270	1.3	0.79	4.6	0.95	8.1
7	7.0	21.9	1040	660	0.68	8.6	<0.01	0.09	760	3.2	34	12	18	210	0.67	4.9	4.8	0.71	7.3
8	7.1	24.8	1080	700	1.0	9.4	0.89	0.08	800	2.3	41	9.2	15	230	0.62	3.8	5.2	0.85	7.8
9	7.2	23.6	1090	710	1.3	14	1.9	0.08	800	2.9	37	12	24	220	0.83	0.66	5.1	0.75	7.0
10	7.2	18.8	840	530	1.1	12	<0.01	0.09	600	1.9	26	7.2	12	170	0.45	0.29	4.2	0.52	7.0
11	6.9	21.2	860	550	1.7	11	<0.01	0.10	610	2.0	26	10	16	170	0.55	0.55	4.9	0.52	6.5
12	7.1	19.4	770	480	0.99	10	0.75	0.17	550	2.1	27	7.0	11	150	0.52	1.7	4.4	0.56	6.1
13	7.0	19.8	650	400	1.3	9.9	<0.01	0.08	460	1.8	20	5.8	8.2	130	0.32	0.70	4.5	0.38	6.2
14	7.1	15.9	640	390	1.6	6.3	0.73	0.04	440	2.4	19	7.3	9.8	130	0.37	2.4	4.3	0.35	6.0
15	6.9	21.4	990	620	1.1	9.0	0.73	0.07	680	2.5	33	11	19	200	0.71	0.42	4.7	0.65	6.9
16	7.1	17.7	770	470	1.6	10	17	0.09	490	2.4	32	5.9	13	150	0.23	0.58	5.3	0.56	5.7
17	7.6	11.7	3020	2010	ND	16	<0.01	0.11	2320	4.8	9.1	18	28	780	0.69	2.8	7.1	0.84	29
18	7.5	24.8	860	540	0.77	12	0.78	0.10	580	1.1	14	3.9	4.9	220	0.24	0.02	5.8	0.25	13
19	7.4	15.3	1090	780	1.2	8.9	8.6	0.08	890	2.5	44	8.6	21	240	0.62	0.12	3.9	0.85	7.4
20	7.2	17.1	1010	620	1.1	10	4.0	0.08	690	2.1	36	6.3	14	200	0.55	0.15	3.8	0.66	7.1
21	7.0	17.8	1660	1260	0.60	8.9	0.81	0.07	1520	5.3	69	15	46	360	1.4	0.82	4.8	1.9	8.2
22	6.8	16.1	1540	990	1.0	8.9	0.81	0.08	1130	4.0	57	13	36	300	0.95	0.71	4.2	1.3	7.7
23	7.6	15.6	1250	800	0.71	10	3.0	0.08	880	2.3	30	8.1	14	290	0.47	0.42	3.7	0.45	11
24	7.3	26.5	1610	1060	0.50	12	1.3	0.07	1220	3.4	50	14	22	350	1.6	0.55	5.6	0.92	10
25	7.3	14.9	1060	660	0.83	12	<0.01	0.04	720	2.0	50	9.6	18	200	0.97	0.63	4.3	1.0	6.3
26	7.1	18.6	650	390	1.2	9.2	0.82	0.05	420	1.7	19	7.3	9.5	130	0.38	0.26	4.5	0.40	6.1
27	7.2	19.3	780	510	0.67	17	0.03	0.09	570	1.4	23	6.3	11	170	0.47	0.30	4.8	0.52	7.3

Table 2. Continued.

Sample #	pH	Temp °C	Cond mS/cm	TDS mg/L	F mg/L	Cl mg/L	SO_4 mg/L	Br mg/L	Alkalinity mg/L	NH_4 mg/L	Ca mg/L	K mg/L	Mg mg/L	Na mg/L	Ba mg/L	Fe mg/L	Si mg/L	Sr mg/L	SAR
28	7.3	16.4	630	410	1.1	12	0.01	0.09	450	1.1	17	6.1	8.7	140	0.34	0.17	4.9	0.40	6.9
29	7.0	22.1	1200	810	0.88	7.1	1.8	0.02	930	2.5	59	8.0	19	250	0.77	0.84	5.1	1.2	7.1
30	7.4	28.7	470	270	1.4	5.4	0.04	0.03	290	1.1	5.9	3.8	1.6	110	0.14	0.30	5.8	0.10	10
31	7.2	15.8	660	420	1.2	9.4	2.9	0.05	460	1.4	18	5.9	7.8	150	0.33	0.28	4.2	0.36	7.3
32	7.1	15.9	750	460	1.0	7.9	1.1	0.03	500	1.3	18	5.1	8.2	170	0.26	0.36	4.1	0.32	8.3
33	7.3	13.8	1230	850	0.91	9.8	2.4	0.08	980	2.7	45	9.0	21	270	0.76	0.39	4.1	0.99	8.3
34	7.5	21.7	570	370	0.98	5.2	0.22	0.02	430	1.2	10	5.1	4.0	130	0.19	0.91	5.2	0.17	8.8
35	7.1	18.2	1300	800	0.79	9.0	0.06	0.04	900	2.5	46	11	22	260	0.86	0.79	4.6	0.94	8.0
36	7.3	14.5	1080	770	0.96	11	0.07	0.05	850	2.7	44	9.7	24	250	0.66	0.36	3.9	0.95	7.6
37	7.2	22.4	1430	940	0.80	11	0.83	0.05	1090	2.6	43	14	25	300	0.87	0.34	4.8	0.95	9.1
38	7.4	13.9	1070	720	0.99	9.5	0.08	0.06	810	2.1	32	8.4	18	240	0.52	0.27	4.1	0.70	8.4
39	7.7	18.4	1850	1240	0.51	11	0.12	0.06	1380	2.0	19	6.6	8.6	500	0.35	0.20	4.7	0.38	24
40	7.6	19.3	2320	1550	0.47	7.7	0.92	<0.02	1760	2.3	27	7.0	18	610	0.59	0.81	4.8	0.42	22
41	7.6	20.1	1860	1270	0.48	13	8.1	0.07	1410	2.6	20	7.3	12	510	0.47	0.80	5.2	0.30	22
42	7.5	23.7	2260	1550	1.4	18	0.07	0.09	1740	2.9	15	8.4	8.7	630	0.58	0.26	5.6	0.27	32
43	7.5	20.4	2810	2000	1.0	14	0.16	0.07	2260	3.4	24	11	15	800	0.75	0.55	5.1	0.33	32
44	7.4	18.7	1580	1050	0.64	11	0.16	0.06	1160	2.3	15	6.2	8.2	430	0.37	0.28	4.7	0.26	22
45	7.6	15.7	2050	1390	0.42	6.4	1.9	<0.02	1570	2.4	35	7.5	19	530	0.62	0.32	4.6	0.69	18
46	7.4	20.5	2380	1600	0.85	6.7	1.6	<0.02	1810	2.4	26	7.7	19	640	0.73	0.19	4.7	0.53	23
47	7.6	21.0	2080	1320	0.56	13	1.2	0.05	1440	3.1	19	8.3	14	540	0.54	0.03	5.1	0.29	23
Mean	7.3	19.6	1300	850	0.92	13	2.4	0.12	950	2.4	32	8.4	16	300	0.62	0.8	4.8	0.70	12

Table 3. Trace element concentrations in water produced with coalbed methane from wells in the Powder River Basin, WY. μg/L=microgram per liter.

Sample #	Ag μg/L	Al μg/L	As μg/L	B μg/L	Be μg/L	Bi μg/L	Cd μg/L	Ce μg/L	Co μg/L	Cr μg/L	Cs μg/L	Cu μg/L	Hg μg/L	La μg/L	Li μg/L	Mn μg/L	Ni μg/L
1	< 1	<50	0.40	110	< 0.1	28	< 0.1	<10	0.24	< 1	< 0.1	5.2	<0.005	<10	31	71	7.0
2	< 1	<50	0.42	110	< 0.1	23	< 0.1	<10	0.14	< 1	< 0.1	7.3	<0.005	<10	35	59	5.4
3	< 1	<50	< 0.2	100	< 0.1	24	< 0.1	<10	0.22	< 1	< 0.1	5.0	<0.005	<10	24	93	9.8
4	< 1	<50	0.39	100	< 0.1	29	< 0.1	<10	0.18	< 1	0.11	7.6	<0.005	<10	39	79	9.0
5	< 1	<50	0.23	<100	< 0.1	22	< 0.1	<10	< 0.1	< 1	< 0.1	6.3	<0.005	<10	40	42	9.8
6	< 1	<50	0.67	<100	< 0.1	32	< 0.1	<10	< 0.1	< 1	0.12	4.2	<0.005	<10	67	50	5.7
7	< 1	<50	0.48	<100	< 0.1	23	< 0.1	<10	< 0.1	< 1	0.11	5.1	<0.005	<10	53	74	35
8	< 1	<50	0.29	<100	< 0.1	27	< 0.1	<10	0.10	< 1	< 0.1	5.5	<0.005	<10	37	90	27
9	< 1	<50	0.47	<100	< 0.1	<20	< 0.1	<10	< 0.1	< 1	0.11	4.0	<0.005	<10	59	12	5.0
10	< 1	<50	0.24	<100	< 0.1	19	< 0.1	<10	< 0.1	< 1	< 0.1	3.2	<0.005	<10	44	10	2.2
11	< 1	<50	0.30	<100	< 0.1	27	< 0.1	<10	< 0.1	< 1	< 0.1	3.4	<0.005	<10	63	8.0	4.7
12	< 1	<50	0.92	<100	< 0.1	27	< 0.1	<10	0.10	< 1	< 0.1	2.9	<0.005	<10	38	33	14
13	< 1	<50	2.6	<100	< 0.1	<20	< 0.1	<10	< 0.1	< 1	< 0.1	2.6	<0.005	<10	36	13	5.8
14	< 1	<50	0.63	<100	< 0.1	<20	< 0.1	<10	< 0.1	< 1	< 0.1	2.3	<0.005	<10	35	31	19
15	< 1	<50	0.27	<100	< 0.1	21	< 0.1	<10	< 0.1	< 1	< 0.1	3.6	<0.005	<10	47	12	3.3
16	< 1	<50	1.2	<100	< 0.1	<20	< 0.1	<10	< 0.1	< 1	< 0.1	2.8	<0.005	<10	42	16	4.7
17	< 1	<50	0.21	110	< 0.1	<20	< 0.1	<10	0.16	< 1	0.78	29	<0.1	<10	208	20	21
18	< 1	<50	< 0.2	<100	< 0.1	<20	< 0.1	<10	< 0.1	< 1	< 0.1	3.7	<0.1	<10	23	16	< 0.5
19	< 1	<50	0.34	<100	< 0.1	22	< 0.1	<10	0.12	< 1	< 0.1	4.5	<0.1	<10	55	7.0	5.4
20	< 1	<50	0.19	<100	< 0.1	21	< 0.1	<10	< 0.1	< 1	< 0.1	3.7	<0.1	<10	35	12	0.77
21	< 1	<50	0.49	<100	< 0.1	28	< 0.1	<10	0.13	< 1	0.20	7.4	<0.1	<10	70	20	8.6
22	< 1	<50	0.37	<100	< 0.1	25	< 0.1	<10	0.12	< 1	0.19	5.8	<0.1	<10	65	20	7.7
23	< 1	<50	< 0.2	<100	< 0.1	22	< 0.1	<10	< 0.1	< 1	< 0.1	5.0	<0.1	<10	54	47	3.1
24	< 1	<50	< 0.2	<100	< 0.1	26	< 0.1	<10	< 0.1	< 1	0.13	6.1	<0.1	<10	105	101	4.6
25	< 1	<50	< 0.2	<100	< 0.1	<20	< 0.1	<10	< 0.1	< 1	< 0.1	2.8	<0.1	<10	49	51	4.1
26	< 1	<50	0.88	105	< 0.1	<20	< 0.1	<10	< 0.1	< 1	< 0.1	1.9	<0.1	<10	34	7.0	1.4
27	< 1	<50	0.25	111	< 0.1	<20	< 0.1	<10	< 0.1	< 1	< 0.1	2.4	<0.1	<10	32	14	1.6
28	< 1	<50	< 0.2	112	< 0.1	<20	< 0.1	<10	< 0.1	< 1	< 0.1	1.9	<0.1	<10	34	1.8	0.87

Table 3. Continued.

Sample #	Ag µg/L	Al µg/L	As µg/L	B µg/L	Be µg/L	Bi µg/L	Cd µg/L	Ce µg/L	Co µg/L	Cr µg/L	Cs µg/L	Cu µg/L	Hg µg/L	La µg/L	Li µg/L	Mn µg/L	Ni µg/L
29	< 1	<50	1.3	<100	< 0.1	<20	< 0.1	<10	0.13	< 1	< 0.1	3.3	<0.1	<10	36	42	7.1
30	< 1	<50	< 0.2	<100	< 0.1	<20	< 0.1	<10	< 0.1	< 1	< 0.1	1.5	<0.1	<10	18	20	2.0
31	< 1	<50	< 0.2	<100	< 0.1	<20	< 0.1	<10	< 0.1	< 1	< 0.1	2.0	<0.1	<10	31	5.3	1.8
32	< 1	<50	0.48	<100	< 0.1	<20	< 0.1	<10	< 0.1	< 1	< 0.1	2.3	<0.1	<10	28	29	3.9
33	< 1	<50	0.20	<100	< 0.1	<20	< 0.1	<10	< 0.1	< 1	< 0.1	3.7	<0.1	<10	44	9.8	3.2
34	< 1	<50	< 0.2	<100	< 0.1	<20	< 0.1	<10	< 0.1	< 1	< 0.1	1.8	<0.1	<10	22	37	6.9
35	< 1	<50	< 0.2	<100	< 0.1	23	< 0.1	<10	0.10	< 1	< 0.1	3.8	<0.1	<10	58	39	6.6
36	< 1	<50	0.23	<100	< 0.1	<20	< 0.1	<10	0.10	< 1	0.11	3.4	<0.1	<10	50	24	3.3
37	< 1	<50	< 0.2	<100	< 0.1	<20	< 0.1	<10	< 0.1	< 1	0.10	4.2	<0.1	<10	80	38	3.2
38	< 1	<50	< 0.2	<100	< 0.1	<20	< 0.1	<10	< 0.1	< 1	< 0.1	3.3	<0.1	<10	47	7.2	2.5
39	< 1	<50	< 0.2	<100	< 0.1	<20	< 0.1	<10	0.13	< 1	< 0.1	7.4	<0.1	<10	77	45	2.6
40	< 1	<50	< 0.2	<100	< 0.1	20	< 0.1	<10	< 0.1	1.2	< 0.1	9.2	0.25	<10	84	30	7.8
41	< 1	<50	0.57	114	< 0.1	<20	< 0.1	<10	0.10	1.0	< 0.1	7.6	<0.1	<10	88	30	6.9
42	< 1	<50	< 0.2	217	< 0.1	<20	< 0.1	<10	0.13	< 1	0.12	9.4	<0.1	<10	122	6.8	2.8
43	< 1	<50	< 0.2	201	< 0.1	<20	< 0.1	<10	0.17	< 1	0.10	12	<0.1	<10	150	12	5.0
44	< 1	<50	< 0.2	104	< 0.1	<20	< 0.1	<10	< 0.1	< 1	< 0.1	6.3	<0.1	<10	64	22	3.0
45	< 1	<50	< 0.2	<100	< 0.1	<20	< 0.1	<10	< 0.1	< 1	< 0.1	8.2	<0.1	<10	72	82	3.0
46	< 1	<50	< 0.2	<100	< 0.1	<20	< 0.1	<10	< 0.1	< 1	< 0.1	9.7	<0.1	<10	99	9.6	2.2
47	< 1	<50	< 0.2	120	< 0.1	<20	< 0.1	<10	0.10	< 1	< 0.1	8.4	<0.1	<10	114	18	5.3

Table 3. Continued.

Sample #	P µg/L	Pb µg/L	Rb µg/L	Sb µg/L	Sc µg/L	Se µg/L	Sn µg/L	Th µg/L	Ti µg/L	Tl µg/L	U µg/L	V µg/L	W µg/L	Y µg/L	Zn µg/L	Zr µg/L
1	<50	0.43	9.0	< 2	2.0	<2	0.1	<20	<50	0.34	< 0.1	< 0.2	<20	<10	80	<50
2	<50	0.19	8.8	< 2	2.0	<2	1.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	12	<50
3	<50	< 0.1	6.4	< 2	3.0	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	6.7	<50
4	<50	0.23	9.0	< 2	3.0	<2	5.5	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	4.8	<50
5	<50	< 0.1	9.6	< 2	3.0	<2	0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	2.5	<50
6	<50	< 0.1	21	< 2	2.0	<2	0.2	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	2.3	<50
7	<50	< 0.1	19	< 2	1.0	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	2.5	<50
8	<50	< 0.1	16	< 2	1.0	<2	1.3	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	1.8	<50
9	<50	< 0.1	21	< 2	1.0	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	1.3	<50
10	<50	< 0.1	10	< 2	1.0	<2	0.8	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	< 1	<50
11	<50	< 0.1	19	< 2	1.0	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	< 1	<50
12	<50	< 0.1	12	< 2	2.0	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	< 1	<50
13	<50	< 0.1	9.7	< 2	2.0	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	4.6	<50
14	<50	< 0.1	12	< 2	2.0	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	< 1	<50
15	<50	< 0.1	20	< 2	2.0	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	< 1	<50
16	<50	< 0.1	9.5	< 2	3.0	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	1.6	<50
17	<50	< 0.1	38	< 2	2.0	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	9.8	<50
18	<50	< 0.1	5.2	< 2	< 0.1	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	2.7	<50
19	<50	< 0.1	11	< 2	< 0.1	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	5.6	<50
20	<50	< 0.1	7.6	< 2	< 0.1	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	1.1	<50
21	<50	< 0.1	19	< 2	1.0	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	4.1	<50
22	<50	< 0.1	18	< 2	1.0	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	3.8	<50
23	<50	< 0.1	8.8	< 2	< 0.1	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	4.7	<50
24	<50	< 0.1	19	< 2	1.0	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	3.6	<50
25	<50	< 0.1	12	< 2	0.4	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	1.2	<50
26	<50	< 0.1	11	< 2	0.5	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	< 1	<50
27	<50	< 0.1	8.1	< 2	0.5	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	< 1	<50
28	<50	< 0.1	6.7	< 2	0.4	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	< 1	<50

Table 3. Continued.

Sample #	P µg/L	Pb µg/L	Rb µg/L	Sb µg/L	Sc µg/L	Se µg/L	Sn µg/L	Th µg/L	Ti µg/L	Tl µg/L	U µg/L	V µg/L	W µg/L	Y µg/L	Zn µg/L	Zr µg/L
29	<50	0.12	11	< 2	0.7	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	< 1	<50
30	<50	< 0.1	4.1	< 2	1.0	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	< 1	<50
31	<50	< 0.1	6.3	< 2	0.6	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	1.1	<50
32	<50	< 0.1	5.5	< 2	0.6	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	1.8	<50
33	<50	< 0.1	9.6	< 2	0.4	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	1.2	<50
34	<50	< 0.1	5.2	< 2	0.7	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	< 1	<50
35	<50	< 0.1	14	< 2	0.6	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	2.8	<50
36	<50	< 0.1	10	< 2	1.0	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	2.7	<50
37	<50	< 0.1	18	< 2	1.1	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	1.7	<50
38	<50	< 0.1	9.2	< 2	1.0	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	1.2	<50
39	<50	< 0.1	8.0	< 2	1.4	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	1.0	<50
40	94	< 0.1	9.0	< 2	1.5	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	1.6	<50
41	83	< 0.1	9.1	< 2	1.5	<2	< 0.1	<20	<50	< 0.2	< 0.1	0.19	<20	<10	1.0	<50
42	71	< 0.1	11	< 2	1.5	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	< 1	<50
43	88	< 0.1	14	< 2	1.4	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	1.6	<50
44	<50	< 0.1	7.4	< 2	1.2	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	< 1	<50
45	<50	< 0.1	8.0	< 2	1.2	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	< 1	<50
46	<50	< 0.1	9.6	< 2	1.2	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	< 1	<50
47	<50	< 0.1	10	< 2	1.3	<2	< 0.1	<20	<50	< 0.2	< 0.1	< 0.2	<20	<10	1.4	<50