CZ 13095

Thermal Maturity and Petroleum Generation History of Cretaceous and Tertiary Source Rocks, Bighorn Basin, Wyoming and Montana

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Abstract

The Bighorn Basin of Wyoming and Montana contains several potential Cretaceous and Tertiary petroleum source rocks with the necessary types and amounts of organic matter, and thermal maturity levels for significant oil and gas generation. Potential petroleum source rocks include the Cretaceous Thermopolis and Mowry Shales, Frontier Formation, Cody Shale, and Mesaverde and Meeteetse Formations, and the Tertiary (Paleocene) Fort Union Formation. Vitrinite reflectance trends for these source rocks indicate good potential for petroleum generation, accumulation, and possible overpressuring in "tight gas" reservoirs or basin-centered accumulations in the deeper parts of the basin.

Burial, thermal, and petroleum generation modeling was used to define the timing of oil and gas formation for the potential source rocks. In the deep trough of the basin the Lower Cretaceous Thermopolis Shale, the oldest unit considered, was buried to nearly 25,000 ft (7,625 m) at maximum burial 10 Ma, and reached temperatures of 327°F (164°C). Peak oil and gas generation in the Thermopolis occurred around 50 Ma. In contrast, at maximum burial 10 Ma, the Tertiary (Paleocene) Fort Union Formation, the youngest unit considered, was buried to around 17,000 ft (5,185 m), reached temperatures of 240°F (116°C), and peak hydrocarbon generation occurred around 10 Ma. Around the less thermally mature periphery of the basin, several of the source rocks have not achieved the proper thermal requirements for thermogenic gas generation but do have the potential for oil and biogenic gas generation.

Based on thermal maturity values and geothermal gradients, the Bighorn Basin is relatively "cool" compared to other Rocky Mountain foreland basins. Even in the deepest part of the basin, at reconstructed burial depths in excess of 20,000 ft (6,100 m), Cretaceous source rocks are still within the window for liquid hydrocarbon generation. Present-day geothermal gradients for the Bighorn Basin range from <1.0°F/100 ft (18.2°C/km) to >1.8 °F/100 ft (33°C/km). Relationships between vitrinite reflectance, depth of burial, and structure, indicate that geothermal gradients have remained fairly constant since the beginning of the Cretaceous.

Introduction

The Bighorn Basin, Wyoming and Montana (Figure 1), contains significant resources of natural gas in low permeability (tight) sandstone reservoirs. From 1995 through 1997, the U.S. Geological Survey conducted a geological characterization of the basin-centered gas resources of Bighorn Basin for the U.S. Department of Energy. One of the major components required for an assessment of hydrocarbon resources is determining the burial, thermal, and hydrocarbon generation history of potential source rocks in the basin. The purpose of this study is to characterize the thermal maturity of several important source rock intervals, model their petroleum generation history, and identify optimum areas for petroleum generation and accumulation in the Bighorn Basin. To accomplish this, our study utilizes (1) numerous vitrinite reflectance data presented in tabular form and as regional thermal maturity maps; (2) cross sections; (3) regional geothermal gradient data; and (4) burial, thermal, and petroleum generation modeling in the deep basin trough.

Vitrinite Reflectance

Vitrinite, a maceral derived from woody plant material, is common in coal and carbonaceous shale. Vitrinite reflectance (R_o) is a direct measurement of the proportion of light reflected from a polished vitrinite grain; it is related to the degree of thermal maturity of the rock and can be used to estimate hydrocarbon source-rock generation potential. One hundred ninety-five R_o samples from 23 wells and outcrop localities were utilized for this study (Table 1). The samples were prepared for R_o analysis by crushing, mounting in epoxy, and polishing. The mean R_o from randomly oriented indigenous vitrinite grains was determined using plane-polarized incident white light and a 546nm monochromatic filter in immersion oil, on a reflected light microscope with a nonrotating stage (Bostick, 1979; Bustin, 1986).

Table 1 continued

	Well Name and location	Sample depth (ft)	R_o (%)	n	s.d.	Formation or Member
	composite					
	Michigan-Wisconsin	2,610	0.57	31	.03	Willwood (?)
CZ 16880	Pipeline	4,210	0.53	30	.03	Fort Union
	2-9 McCulloch Peak	5,490	0.57	31	.05	Fort Union
	Sec. 9, T. 54N., R. 101W.	5,525	0.54	20	.03	Fort Union
		6,050	0.60	30	.03	Lance
		7,380	0.65	30	.04	Lance
		8,750	0.68	30	.05	Lance
	CIG Exploration	9,670	0.68	30	.04	Lance
	#1 McCulloch Peak	9,725	0.67	30	.04	Lance
CZ 11035	Sec. 10, T. 54N., R. 101W.	10,805	0.91	30	.05	Mesaverde
	(plotted on map)	11,130	0.76	30	.03	Mesaverde
		11,555	0.66	35	.03	Mesaverde
		11,570	0.83	25	.06	Mesaverde
		12,030	0.76	35	.04	Mesaverde
		12,610	0.69	30	.04	Mesaverde
	Husky/Hamm	1,040	0.41	30	.03	Willwood (?)
CA00025	#1 Government	2,925	0.63	30	.03	Fort Union
	Sec. 21, T. 54N., R. 100W.	3,735	0.58	35	.02	Fort Union
		4,070	0.63	35	.03	Fort Union
		5,385	0.69	33	.04	Fort Union
		6,545	0.83	30	.04	Lance
		7,265	0.66	30	.03	Lance
		8,150	0.68	32	.02	Meeteetse
		8,470	0.76	30	.03	Meeteetse
		8,835	0.82	38	.03	Mesaverde
		9,645	0.75	30	.03	Mesaverde
	California Company	365	0.33	35	.05	Fort Union
CZ 08808	#1 Unit	985	0.56	40	.03	Fort Union
	Sec. 27, T. 53N., R. 100W.	1,920	0.62	30	.03	Fort Union
		2,935	0.62	40	.03	Lance
		3,355	0.68	35	.04	Meeteetse
		4,215	0.63	35	.02	Mesaverde
		5,290	0.85	30	.06	Cody Shale ?
	Sinclair Oil and Gas	2,925	0.53	30	.04	Willwood (?)
CZ 08687	#1 Government	3,620	0.54	40	.03	Fort Union
	Sec. 1, T. 53N., R. 96W.	4,400	0.73	30	.04	Fort Union
		5,150	0.70	20	.04	Lance
		5,940	0.79	20	.05	Lance
		6,650	0.72	14	.04	Meeteetse
		6,970	0.68	17	.03	Meeteetse
		8,205	0.70	15	.02	L. Mesaverde

Table 1 continued

	Well Name and location	Sample depth (ft)	R_o (%)	n	s.d.	Formation or Member
CZ00464	Sohio Petroleum	795	0.55	30	.03	Fort Union (?)
	Govt. Boyle #1	1,650	0.57	20	.05	Lance
	Sec. 18, T. 50N., R. 99W.	1,850	0.62	31	.04	Lance
		3,085	0.73	30	.05	Mesaverde
CZ 13095	Santa Fe Energy	3,340	0.61	30	.04	Willwood
	Tatman Mt. 1-20	4,590	0.71	30	.05	Fort Union
	Sec. 20, T. 49N., R. 96W.	5,190	0.70	30	.06	Fort Union
		5,610	0.70	30	.05	Fort Union
		6,295	0.77	30	.05	Fort Union
		6,800	0.76	30	.03	Fort Union
		7,210	0.69	20	.02	Fort Union
		7,910	0.73	30	.03	Fort Union
		8,505	0.81	30	.06	Fort Union
		9,105	0.82	30	.05	Lance
		9,725	0.94	30	.06	Lance
		10,230	0.84	30	.03	Lance
		10,925	0.90	22	.05	Meeteetse
		11,325	0.90	30	.05	Mesaverde
		11,965	0.97	30	.05	Mesaverde
		12,525	0.95	30	.04	Mesaverde
CZ 13385	American Quasar	2,970	0.66	30	.06	Willwood (?)
	26-1 Schuster Flats	3,975	0.63	15	.04	Fort Union
	Sec. 26, T. 49N., R. 95W.	4,605	0.66	30	.05	Fort Union
		5,080	0.69	30	.06	Fort Union
		5,580	0.68	30	.05	Fort Union
		6,010	0.73	30	.05	Fort Union
		6,610	0.82	30	.03	Fort Union
		7,215	0.83	35	.05	Fort Union (?)
		7,820	0.81	30	.04	Lance
		8,220	0.85	30	.04	Lance
		9,030	0.84	25	.03	Meeteetse
		9,625	0.84	15	.05	Mesaverde
		9,980	0.86	10	.03	L. Mesaverde
CZ13492	Excel Energy	2,730	0.57	30	.06	Fort Union
	1-11 Dobie Creek	4,855	0.80	26	.05	Lance
	Sec. 11, T. 49N., R. 94W.	6,215	0.80	30	.03	Meeteetse
		6,960	0.78	5	.03	Mesaverde
		7,390	1.03	18	.09	L. Mesaverde

Table 1 continued

CZ07672

Well Name and location	Sample depth (ft)	R_o (%)	n	s.d.	Formation or Member
Tiger Oil	2,265	0.52	30	.05	Fort Union
#1 Holly Sugar	2,840	0.62	30	.05	Fort Union
Sec. 26, T. 47N., R. 93W.	3,510	0.58	30	.10	Lance
	4,215	0.62	30	.06	Lance
	4,740	0.62	12	.09	Meeteetse
	5,280	0.66	30	.05	Mesaverde
	5,865	0.72	30	.06	L. Mesaverde

Outcrop sample No. and location	Sample depth (ft)	R_o (%)	n	s.d.	Formation or Member
95-WY-10 SW1/4, NW1/4, Sec. 3, T. 56N., R. 99W.	surface	0.53	30	.04	Fort Union
95-WY-6L SW1/4, SW1/4, Sec. 24, T. 52N., R. 94W.	surface	0.54	30	.03	Fort Union
96-WY-21A SW1/4, SE1/4, Sec. 21, T. 47N., R. 97W.	surface	0.58	35	.04	Tatman
96-WY-21B SW1/4, SE1/4, Sec. 21, T. 47N., R. 97W.	surface	0.44	35	.03	Tatman
96-WY-14 SW1/4, SE1/4, Sec. 17, T. 45N., R. 96W.	surface	0.61	30	.04	Lance/ Meeteetse
96-WY-15A SW1/4, NE1/4, Sec. 27, T. 45N., R. 96W.	surface	0.55	29	.07	Lance

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Table 1 continued

	Well Name and location	Sample depth (ft)	R_o (%)	n	s.d.	Formation or Member
CA00006	American Quasar	7,845	0.63	30	.03	Fort Union
	Petroleum	9,015	0.68	30	.03	Fort Union
	#1 Sellars Draw Unit	9,215	0.76	20	.01	Fort Union
	Sec. 21, T. 48N., R. 98W.	12,310	0.73	22	.04	Fort Union
		12,535	0.80	30	.06	Lance
		14,175	0.95	18	.05	Meeteetse
		14,290	0.81	18	.06	Meeteetse
		14,385	0.86	31	.05	Meeteetse
		15,390	0.91	30	.04	Mesaverde
		16,080	1.12	30	.05	Mesaverde
		16,990	1.03	15	.06	Cody Shale ?
CZ 13608	American Quasar	4,335	0.67	30	.05	Fort Union
	Petroleum	5,730	0.62	20	.07	Fort Union
	1-21 Ridge Unit	8,220	0.74	30	.04	Fort Union
	Sec. 21, T. 48N., R. 97W.	9,680	0.79	30	.05	Fort Union
		10,695	0.87	30	.07	Fort Union
		11,365	0.85	30	.05	Lance
		11,980	0.88	30	.03	Lance
		12,611	0.95	30	.04	Meeteetse
		13,175	0.91	35	.04	Meeteetse
		13,720	0.89	30	.05	Mesaverde
		14,510	1.14	30	.06	Mesaverde
CZ 07967	Anderson Prichard	2,105	0.62	30	.05	Willwood
	#1 Unit	3,015	0.62	30	.05	Fort Union
	Sec. 33, T. 47N., R. 95W.	3,310	0.68	30	.06	Fort Union
		4,115	0.70	30	.03	Fort Union
		5,985	0.67	12	.04	Lance
		6,385	0.72	15	.13	Lance
		7,520	0.78	30	.07	Meeteetse
		8,050	0.77	17	.05	Mesaverde
		8,480	0.94	25	.05	Mesaverde
CZ 12638	National Coop.	5,625	0.59	30	.06	Lance
	1-31 Federal	6,405	0.61	10	.08	Meeteetse
	Sec. 31, T. 47N., R. 94W.	6,930	0.69	30	.04	Meeteetse
		7,445	0.63	14	.02	Mesaverde
		7,860	0.66	18	.04	Mesaverde
		7,955	0.71	40	.03	Mesaverde

Table 1 continued

	Well Name and location	Sample depth (ft)	R_o (%)	n	s.d.	Formation or Member
CZ 11643	Michigan-Wisconsin Pipeline #1 Gilmore Hill Unit Sec. 15, T. 52N., R. 98W.	5,890	0.57	30	.03	Fort Union
		9,450	0.71	30	.04	Fort Union
		10,555	0.77	35	.04	Lance
		12,940	0.82	25	.03	Meeteetse
		13,335	0.93	30	.03	Mesaverde
CZ 11052	Gulf Oil #1 Otto Federal Sec. 26, T. 52N., R. 95W.	1,835	0.74	19	.07	Willwood
		2,565	0.70	12	.10	Willwood (?)
		3,200	0.63	23	.04	Fort Union
		3,795	0.63	30	.07	Fort Union
		4,500	0.83	30	.08	Fort Union
		5,780	0.75	16	.04	Lance
		6,395	0.79	35	.05	Lance
		7,110	0.79	32	.07	Meeteetse
		7,665	0.67	11	.02	Mesaverde
CZ 16565	Hunt/Impel #1 Katrine Loch Sec. 2, T. 51N., R. 100W.	1,845	0.60	30	.03	steeply-
		6,505	0.72	30	.04	dipping
		9,025	0.67	20	.03	and
		10,985	0.68	30	.02	deformed
		12,540	1.18	15	.04	beds
		13,710	1.47	25	.04	
		14,830	1.10	30	.04	Lance
		15,875	1.04	15	.04	Meeteetse
		17,050	1.40	30	.07	Mesaverde
CZ 15928	Forest Oil #1 Emblem Bench Sec. 2, T. 51N., R. 98W.	4,115	0.65	30	.04	Fort Union
		4,715	0.64	30	.02	Fort Union
		5,735	0.75	35	.06	Fort Union
		6,320	0.70	30	.03	Fort Union
		6,830	0.76	30	.06	Fort Union
		7,365	0.86	30	.05	Fort Union
		7,850	0.81	8	.02	Fort Union
		8,660	0.85	30	.05	Fort Union
		9,450	0.86	30	.05	Fort Union
		9,940	0.95	30	.06	Fort Union
		10,540	0.95	30	.04	Fort Union
		11,035	0.98	15	.05	Fort Union
		11,350	0.93	30	.02	Lance
		12,915	0.95	30	.05	Meeteetse
		13,475	0.98	30	.05	Meeteetse
		14,660	1.17	30	.05	Mesaverde

Table 1—Vitrinite reflectance (R_o) data for the Bighorn Basin. [n, number of readings per sample; s.d., standard deviation; Sec., Section; T., Township; R., Range; _____(?)_____ , contact uncertain; ?, formation uncertain; *composite*, two wells combined; L. Mesaverde, lower member of Mesaverde Formation].

	Well Name and location	Sample depth (ft)	R_o (%)	n	s.d.	Formation or Member
			MONTANA			
	Amoco	8,550	0.84	35	.03	Fort Union ?
BZ08461	#1 Burlington	10,240	0.75	3	.01	Meeteetse
	Northern	12,125	0.80	30	.03	Mesaverde
	Sec. 11, T. 9S., R. 20E.	12,320	1.12	21	.08	Mesaverde
	composite					
	Mountain States	2,220	0.51	35	.04	Fort Union
	#1 NP "A"	3,015	0.57	35	.05	Fort Union
BZ00904	Sec. 33, T. 9S., R. 21E.	3,995	0.58	30	.02	Fort Union
	(Montana)	4,430	0.58	30	.02	Fort Union
	(plotted on map)	5,145	0.61	35	.07	Lance
		5,430	0.60	36	.04	Lance
	Gas Producing	6,120	0.50	30	.03	Meeteetse
	Enterprises	6,965	0.76	36	.06	Meeteetse
CZ10832	#23-58-102 B.N.	7,175	0.67	30	.03	Meeteetse
	Sec. 23, T. 58N., R. 102W.	7,650	0.62	8	.03	Mesaverde
	(Wyoming)	7,865	0.67	26	.03	Mesaverde
		8,210	0.71	30	.04	Mesaverde
		8,500	0.72	40	.03	Mesaverde
		8,660	0.73	30	.03	Mesaverde
			WYOMING			
	General Petroleum	1,560	0.69	30	.03	Fort Union
CA00865	Corp.	1,710	0.64	30	.04	Fort Union
	Badura #2	4,580	0.71	25	.02	Meeteetse
	Sec. 7, T. 57N., R. 101W.	4,750	0.82	35	.04	Meeteetse
		5,820	0.74	16	.03	Mesaverde
		6,070	1.05	3	.01	Mesaverde
	Stanolind Oil and Gas	6,385	0.54	30	.02	Meeteetse
CZ16679	#1 Unit	6,890	0.60	17	.03	Meeteetse
	Sec. 8, T. 55N., R. 100W.	7,825	0.74	30	.04	Mesaverde