Chapter 6

Burial History, Thermal Maturity, and Oil and Gas Generation History of Petroleum Systems in the Wind River Basin Province, Central Wyoming

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Volume Title Page

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Chapter 6 of
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Burial History, Thermal Maturity, and Oil and Gas Generation History of Petroleum Systems in the Wind River Basin Province, Central Wyoming

By Laura N.R. Roberts, Thomas M. Finn, Michael D. Lewan, and Mark A. Kirschbaum

Abstract

Burial history, thermal maturity, and timing of oil and gas generation were modeled for eight key source rock units at nine well locations throughout the Wind River Basin Province. Petroleum source rocks include the Permian Phosphoria Formation, the Cretaceous Mowry Shale, Cody Shale, and Mesaverde, Meeteetse, and Lance Formations, and the Tertiary (Paleocene) Fort Union Formation, including the Waltman Shale Member. Within the province boundary, the Phosphoria is thin and only locally rich in organic carbon. Phosphoria oil produced from reservoirs in the province is thought to have migrated from the Wyoming and Idaho thrust belt.

Locations (wells) selected for burial history reconstructions include three in the deepest parts of the province (Adams OAB-17, Bighorn 1-5, and Coastal Owl Creek); three at intermediate depths (Hells Half Acre, Shell 33X-10, and West Poison Spider); and three at relatively shallow locations (Young Ranch, Amoco Unit 100, and Conoco-Coal Bank). The thermal maturity of source rocks is greatest in the deep northern and central parts of the province and decreases to the south and east toward the basin margins. The results of the modeling indicate that, in the deepest areas, (1) peak petroleum generation from Cretaceous rocks occurred from Late Cretaceous through middle Eocene time, and (2) onset of oil generation from the Waltman Shale Member occurred from late Eocene to early Miocene time.

Based on modeling results, gas generation from the cracking of Phosphoria oil reservoired in the Park City Formation reached a peak in the late Paleocene/early Eocene (58 to 55 Ma) only in the deepest parts of the province. The Mowry Shale and Cody Shale (in the eastern half of the basin) contain a mix of Type-II and Type-III kerogens. Oil generation from predominantly Type-II source rocks of these units in the deepest parts of the province reached peak rates during the latest Cretaceous to early Eocene (65 to 55 Ma). Only in these areas of the basin did these units reach peak gas generation from the cracking of oil, which occurred in the early to middle Eocene (55 to 42 Ma).

Gas-prone source rocks of the Mowry and Cody Shales (predominantly Type-III kerogen), and the Mesaverde, Meeteetse, Lance, and Fort Union Formations (Type –III kerogen) reached peak gas generation in the latest Cretaceous to late Eocene (67 to 38 Ma) in the deepest parts of the province. Gas generation from the Mesaverde source rocks started at all of the modeled locations but reached peak generation at only the deepest locations and at the Hells Half Acre location in the middle Paleocene to early Eocene (59 to 48 Ma). Also at the deepest locations, peak gas generation occurred from the late Paleocene to the early Eocene (57 to 49 Ma) for the Meeteetse Formation, and during the Eocene for the Lance Formation (55 to 48 Ma) and the Fort Union Formation (44 to 38 Ma).

The Waltman Shale Member of the Fort Union Formation contains Type-II kerogen. The base of the Waltman reached a level of thermal maturity to generate oil only at the deep-basin locations (Adams OAB-17 and Bighorn 1-5 locations) in the middle Eocene to early Miocene (36 to 20 Ma).

Introduction

This report summarizes the burial history, thermal maturity, and timing of petroleum generation at nine locations (table 1) for eight key petroleum system source rock intervals throughout the Wind River Basin Province. The Wind River Basin is a large Laramide (Late Cretaceous through Eocene) structural and sedimentary basin that encompasses about 7,400 square miles in central Wyoming (fig. 1). The basin boundaries are defined by fault-bounded Laramide uplifts that surround it, including the Owl Creek and Bighorn Mountains to the north, Wind River Range to the west, Granite Mountains to the south, and Casper arch to the east (fig. 1). The petroleum source rock intervals studied are (1) the Phosphoria-sourced oil modeled at the level of the Permian Park City Formation; (2) the Cretaceous Mowry Shale; (3) the Cody Shale; (4) the lower part of the Mesaverde Formation; (5) the Meeteetse Formation; (6) the Lance Formation; (7) the Tertiary (Paleocene) Fort Union Formation; and (8) the Waltman Shale Member of the Fort Union Formation (fig. 2). Data and interpretations from this report supported the assessment of undiscovered oil and gas resources of the Wind River Basin Province (Kirschbaum and others, 2005).

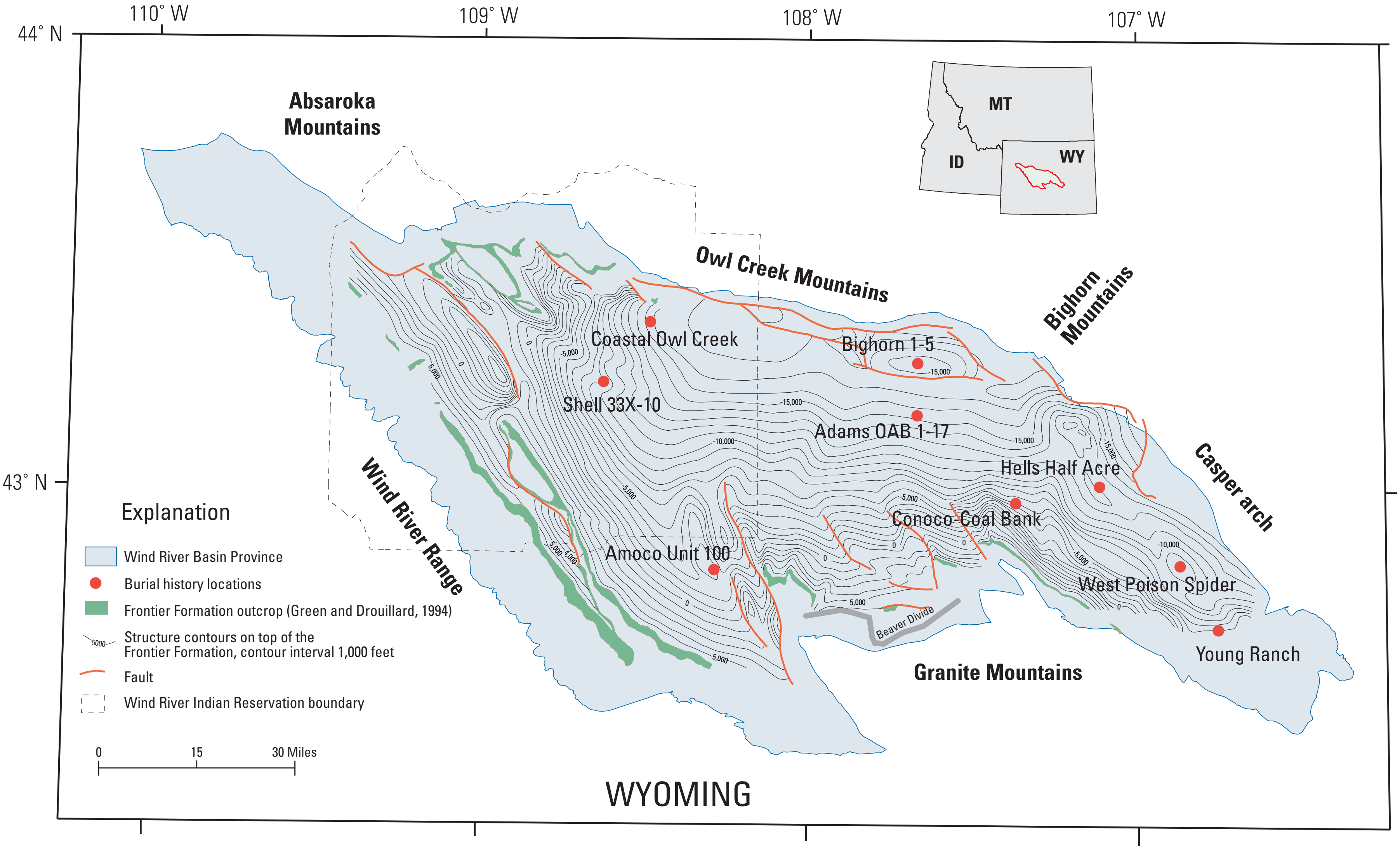

Figure 1. Base map of Wind River Basin Province showing nine burial history locations and structure contours on top of Frontier Formation. Modified from Johnson and others (1996).

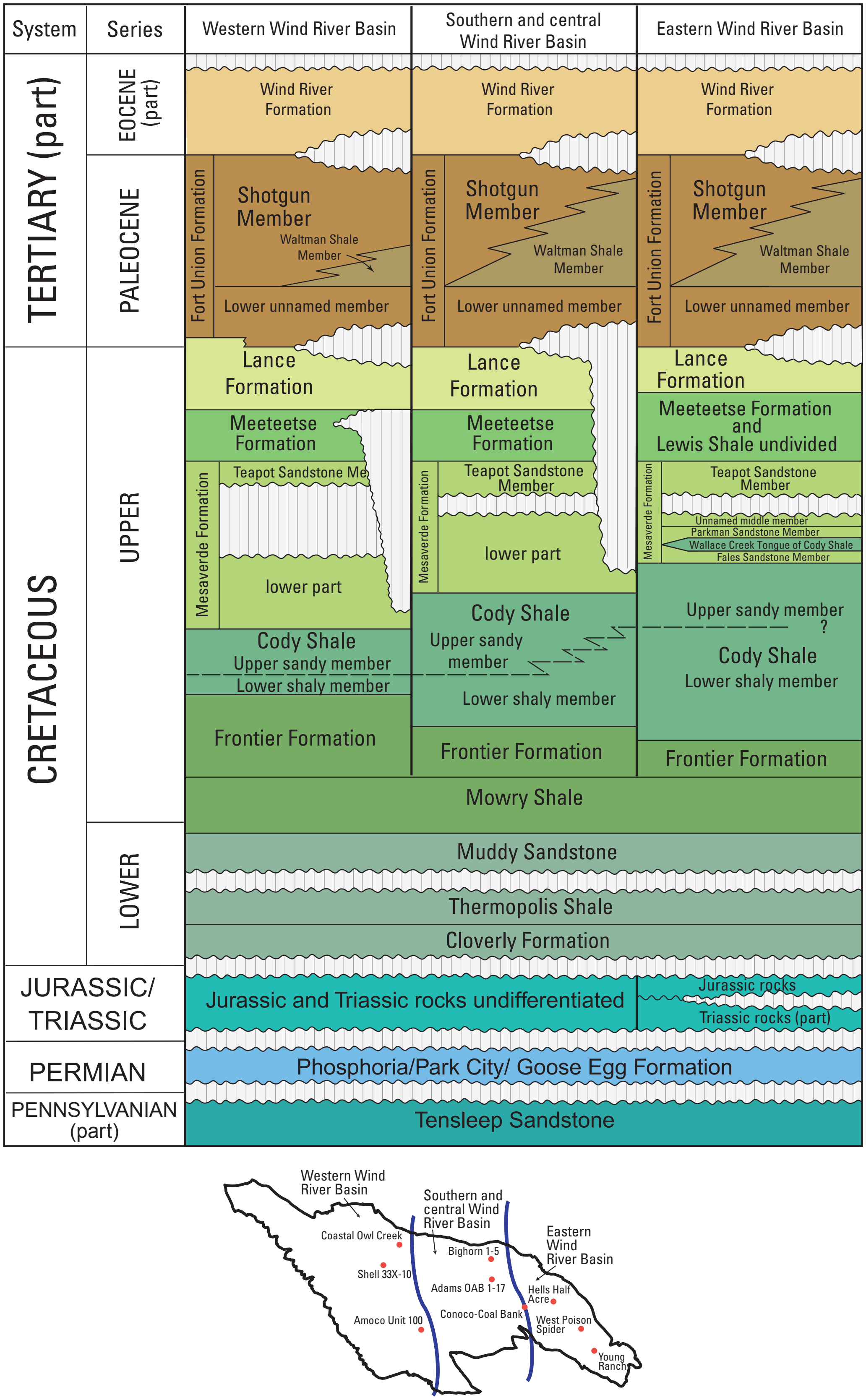

Figure 2. Generalized stratigraphic chart of Pennsylvanian (part) through lower Tertiary (part) rocks in Wind River Basin Province, central Wyoming. Time spans and thicknesses not shown in correct proportions. Hatching indicates time periods of erosion or nondeposition; wavy line represents unconformity. Inset map shows burial history locations and basin subdivisions.

Table 1. Information on wells used for burial history curves, Wind River Basin Province, Wyoming.

[Map name is shortened well name for use on figures, in tables, and for discussion in text. N, north; E, east; W, west; KB, Kelly bushing in feet; DF, derrick floor in feet; TD, total depth in feet]

Map name	Operator	Lease	Well	Section	Township	Range	Elevation	TD	County
Adams OAB 1-17	Adams Exploration	OAB	1-17	17	37N	90W	5,640 (KB)	18,839	Fremont
Bighorn 1-5	Monsanto Oil Ltd	Big Horn	1-5	5	38N	90W	5,508 (KB)	24,877	Fremont
Coastal Owl Creek	Coastal O&G Corp	Owl Creek-Tribal	1	26	5N	3E	5,105 (KB)	24,818	Fremont
Hells Half Acre	Union Oil Co Of Cal	Hells Half Acre	1-K-11	11	35N	86W	5,859 (KB)	22,431	Natrona
Shell 33X-10	Shell Oil Co	Govt-Tribal	33X-10	10	3N	2E	5,414 (DF)	19,235	Fremont
West Poison Spider	Union Oil Co Of Cal	Poison Spider W Unit	8	11	33N	84W	5,888 (KB)	17,945	Natrona
Young Ranch	Union Oil Co Of Cal	Young Ranch Unit	1-I-34	34	32N	83W	5,934 (KB)	13,787	Natrona
Amoco Unit 100	Amoco Prod Co	Unit	100	13	33N	96W	5,443 (KB)	12,778	Fremont
Conoco-Coa Bank	Diamond Shamrock	Conoco-Coal Bank	1-27	27	35N	88W	6,305 (KB)	12,334	Natrona

Previous studies of the burial/thermal history of the central part of the Wind River Basin were presented in Barker and Crysdale (1993), Barker and others (1993), Nuccio (1994), and Nuccio and Finn (1994). All wells examined in these previous studies are confined to the eastern half of the Wind River Indian Reservation, except the Carvner 22-15 well (Nuccio and Finn, 1994), which is one township east of the reservation. The results presented in Barker and Crysdale (1993) and Barker and others (1993) were only in regard to thermogenic gas generation from gas-prone source rocks of Late Cretaceous to Paleogene age. Nuccio (1994) and Nuccio and Finn (1994) presented burial history data beginning with the Fort Union Formation as the oldest unit considered in their reconstructions.

Methods—Burial History

One-dimensional (1-D) modeling of burial history and thermal maturity was performed at nine well locations (fig. 1, table 1) using PetroMod1D® (version 8.0) of Integrated Exploration Systems GmbH (IES), Germany (Integrated Exploration Systems, 2005). The well locations were chosen because the wells (1) were drilled to depths that penetrated a significant part of the geologic section of interest, (2) represent different geologic settings within the province, and (3) have measured vitrinite reflectance (R_o) and downhole temperature data to aid in calibrating maturation models.

Age

Ages of stratigraphic units older than the Cretaceous Cloverly Formation (table 2) were estimated using Love and others (1993) as a guide for the ages of stratigraphic units and ages of regional unconformities throughout the Wind River Basin Province. Table 2 shows the thickness, age, and generalized lithologic data used to construct the burial history curves. The ages at system and series boundaries were adjusted to the 1999 Geologic Time Scale (Palmer and Geissman, 1999). Ages of Cretaceous and younger stratigraphic units are from Finn (Chapter 9, pl. 1, this CD-ROM).

Thickness and Lithology

Thicknesses of the stratigraphic units in the subsurface were interpreted from geophysical well logs or were determined from tops of units recorded in the Petroleum Information/Dwights PetroROM well-history database (IHS Energy Group, 2002). The Adams OAB 1-17 well was drilled only to the depth of the upper sandy member of the Cody Shale. In order to model thermal maturity of the source rock intervals below this depth, we presumed thicknesses of the Cody Shale and intervals down to the base of the Tensleep Sandstone based on the thickness of those units in the Bighorn 1-5 well, located about 7 miles north. Thicknesses of eroded sections represented by unconformities in the subsurface were interpreted from cross sections generated from geophysical logs (Johnson, Chapter 10, this CD-ROM). Lithologies of the stratigraphic units also were interpreted from geophysical logs and published cross sections (Keefer, 1997) and were generalized for modeling purposes (table 2).

Table 2. Data used to generate burial history curves for nine locations, Wind River Basin Province, Wyoming.

[Models only include stratigraphic units from the base of the Tensleep Sandstone regardless of whether the well was drilled to deeper units. Mbr., Member; Fm., Formation; Ss., Sandstone; ft, feet; Ma, mega annum; %, percent; ss, sandstone; sh, shale; ls, limestone; slst, siltstone; dolo, dolomite. Heat flow and thermal gradient used to calibrate model are given for each location. mW/m2, milliWatts per square meter; °F, degrees Fahrenheit]

Adams OAB 1-17

System/Series, Unit, or Event	Present thickness (ft)	Age range (Ma)	Deposited, later eroded (ft)	Amount of erosion (ft)	Generalized lithology					
					%ss	%sh	%ls	%slst	%coal	%dolo
Erosion		15 - 0		4,800	50	50				
post-lower Eocene rocks	0	50 - 15	4,800		50	50				
lower Eocene rocks	4,525	55 - 50			50	50				
Fort Union Fm. (Shotgun Mbr.)	525	57 - 55			50	50				
Fort Union (Waltman Shale Mbr.)	2,120	59 - 57				100				
Fort Union Fm. (lower unnamed mbr.)	2,545	65.4 - 59			49	49			2	
Lance Fm.	4,695	70 - 65.4			50	50				
Meeteetsee Fm.	1,140	72 - 70			49	49			2	
Mesaverde Fm. (Teapot Ss. Mbr.)	60	74 - 72			100					
Hiatus	0	76 - 74								
Mesaverde Fm. (lower part)	1,180	81.5 - 76			49	49			2	
Cody Shale (upper sandy mbr.)	1,650	85 - 81.5			70	30				
Cody Shale (lower shaly mbr.)	2,472	88.5 - 85				100				
Frontier Fm.	588	97 - 88.5			30	70				
Mowry Shale	375	98.5 - 97				100				
Muddy Sandstone	35	101 - 98.5			50	50				
Hiatus	0	102 - 101								
Thermopolis Shale	165	104 - 102				100				
Cloverly Fm.	75	134 - 104			80	20				
Hiatus	0	144 - 134								
Jurassic and Triassic rocks	1,500	248 - 144				50	50			
Hiatus	0	253 - 248								
Phosphoria/Park City Fm.	210	278 - 253				60				40
Hiatus	0	290 - 278								
Tensleep Sandstone	390	310 - 290			60	40				

Heat flow 60 mW/m^2 Thermal gradient 1.74°F/100 feet

Note: Thickness and lithologic data below Mesaverde taken from Bighorn 1-5

Bighorn 1-5

System/Series, Unit, or Event	Present thickness (ft)	Age range (Ma)	Deposited, later eroded (ft)	Amount of erosion (ft)	Generalized lithology					
					%ss	%sh	%ls	%slst	%coal	%dolo
Erosion		15 - 0		5,000						
post-lower Eocene rocks	0	50 - 15	5,000		50	50				
lower Eocene rocks	2,580	55 - 50				50		50		
Fort Union Fm. (Shotgun Mbr.)	990	57 - 55			50	50				
Fort Union (Waltman Shale Mbr.)	2,054	59 - 57				100				
Fort Union Fm. (lower unnamed mbr.)	2,656	65.4 - 59				40		60		
Lance Fm.	5,140	70 - 65.4				60		40		
Meeteetsee Fm.	1,360	72 - 70				90			10	
Mesaverde Fm. (Teapot Ss. Mbr.)	45	74 - 72			100					
Hiatus	0	76 - 74								
Mesaverde Fm. (lower part)	1,095	81.5 - 76			50	50				
Cody Shale (upper sandy mbr.)	1,730	85 - 81.5			50	50				
Cody Shale (lower shaly mbr.)	2,360	88.5 - 85				100				
Frontier Fm.	580	97.5 - 88.5			30	70				
Mowry Shale	374	98.5 - 97.5				100				
Muddy Sandstone	36	101 - 98.5			50	50				
Hiatus	0	102 - 101								
Thermopolis Shale	165	104 - 102				100				
Cloverly Fm.	75	134 - 104			80	20				
Hiatus	0	144 - 134								
Jurassic and Triassic rocks	1,506	248 - 144			33	34	33			
Hiatus	0	253 - 248								
Phosphoria/Park City Fm.	206	278 - 253				60				40
Hiatus	0	290 - 278								
Tensleep Sandstone	401	310 - 290			60	40				

Heat flow 57 mW/m^2 Thermal gradient 1.77°F/100 feet

Table 2. Data used to generate burial history curves for nine locations, Wind River Basin Province, Wyoming.—Continued

[Models only include stratigraphic units from the base of the Tensleep Sandstone regardless of whether the well was drilled to deeper units. Mbr., Member; Fm., Formation; Ss., Sandstone; ft, feet; Ma, mega annum; %, percent; ss, sandstone; sh, shale; ls, limestone; slst, siltstone; dolo, dolomite. Heat flow and thermal gradient used to calibrate model are given for each location. mW/m2, milliWatts per square meter; °F, degrees Fahrenheit]

Coastal Owl Creek

System/Series, Unit, or Event	Present thickness (ft)	Age range (Ma)	Deposited, later eroded (ft)	Amount of erosion (ft)	Generalized lithology					
					%ss	%sh	%ls	%slst	%coal	%dolo
Erosion		15 - 0		4,600						
post-lower Eocene rocks	0	50 - 15	4,600		50	50				
lower Eocene rocks	7,100	55 - 50			50	50				
Fort Union Fm.	5,390	65.4 - 55			50	50				
Lance Fm.	2,860	70 - 65.4			70	30				
Meeteetse Fm.	1,130	72 - 70			49	49			2	
Mesaverde Fm. (Teapot Ss. Mbr.)	170	73.5 - 72			100					
Hiatus	0	78 - 73.5								
Mesaverde Fm. (lower part)	1,900	82.5 - 78			50	50				
Cody Shale (upper sandy mbr.)	1,500	85.5 - 82.5			50	50				
Cody Shale (lower shaly mbr.)	2,050	87.5 - 85.5				100				
Frontier Fm.	900	97 - 87.5			70	30				
Mowry Shale	550	98.5 - 97			30	70				
Muddy Sandstone	50	101 - 98.5			49	49			2	
Hiatus	0	102 - 101								
Thermopolis Shale	190	104 - 102			100					
Cloverly Fm.	400	134 - 104			50	50				
Hiatus	0	144 - 134								
Jurassic and Triassic rocks (part)	628	210 - 144			45	45	10			

Heat flow 49 mW/m^2 Thermal gradient 1.31°F/100 feet

Hells Half Acre

System/Series, Unit, or Event	Present thickness (ft)	Age range (Ma)	Deposited, later eroded (ft)	Amount of erosion (ft)	Generalized lithology					
					%ss	%sh	%ls	%slst	%coal	%dolo
Erosion		15 - 0		2,200						
post-lower Eocene rocks	0	50 - 15	2,200		30	70				
lower Eocene rocks	2,120	55 - 50			30	70				
Fort Union Fm. (Shotgun Mbr.)	650	57 - 55			30	70				
Fort Union Fm. (Waltman Shale Mbr.)	2,230	59 - 57				100				
Fort Union Fm. (lower unnamed mbr.)	2,450	65.4 - 59			50	50				
Lance Fm.	3,810	69.5 - 65.4			50	50				
Meeteetse Fm./Lewis Shale	1,460	72 - 69.5			49	49			2	
Mesaverde Fm. (Teapot Ss. Mbr.)	70	74 - 72			100					
Hiatus	0	76 - 74								
Mesaverde Fm. (middle mbr.)	560	77.5 - 76			30	70				
Mesaverde Fm. (Parkman Ss. Mbr.)	80	78 - 77.5			100					
Cody Shale (Wallace Creek Tongue)	218	79 - 78				100				
Mesaverde Fm. (Fales Mbr.)	202	79.5 - 79			100					
Cody Shale (upper sandy mbr.)	2,650	84 - 79.5			30	70				
Cody Shale (lower shaly mbr.)	2,000	88.7 - 84				100				
Frontier Fm.	780	97.5 - 88.7			30	70				
Mowry Shale	330	98.5 - 97.5				100				
Muddy Sandstone	60	101 - 98.5			100					
Hiatus	0	102 - 101								
Thermopolis Shale	130	104 - 102				100				
Cloverly Formation	60	134 - 104			100					
Hiatus	0	144 - 134								
Jurassic rocks	490	175 - 144				50		50		
Hiatus	0	208 - 175								
Triassic rocks (part)	1,130	248 - 208			50	50				
Hiatus	0	253 - 248								
Phosphoria/Park City Fm.	324	278 - 253				50	50			
Hiatus	0	290 - 278								
Tensleep Sandstone	306	310 - 290			100					

Heat flow 47 mW/m^2 Thermal gradient 1.33°F/100 feet

Table 2. Data used to generate burial history curves for nine locations, Wind River Basin Province, Wyoming.—Continued

[Models only include stratigraphic units from the base of the Tensleep Sandstone regardless of whether the well was drilled to deeper units. Mbr., Member; Fm., Formation; Ss., Sandstone; ft, feet; Ma, mega annum; %, percent; ss, sandstone; sh, shale; ls, limestone; slst, siltstone; dolo, dolomite. Heat flow and thermal gradient used to calibrate model are given for each location. mW/m2, milliWatts per square meter; °F, degrees Fahrenheit]

Shell 33X-10

System/Series, Unit, or Event	Present thickness (ft)	Age range (Ma)	Deposited, later eroded (ft)	Amount of erosion (ft)	Generalized lithology					
					%ss	%sh	%ls	%slst	%coal	%dolo
Erosion	0	15 - 0		3,000						
post-lower Eocene rocks	0	50 - 15	3,000		50	50				
lower Eocene rocks	3,740	55 - 50			50	50				
Fort Union Fm.	2,310	65.4 - 55			50	50				
Lance Fm.	1,530	70 - 65.4			50	50				
Meeteetse Fm.	1,340	72 - 70			50	50				
Mesaverde Fm. (Teapot Ss. Mbr.)	140	73.5 - 72			100					
Hiatus	0	78 - 73.5								
Mesaverde Fm. (lower part)	1,820	82.5 - 78			50	50				
Cody Shale (upper sandy mbr.)	1,970	85.5 - 82.5			50	50				
Cody Shale (lower shaly mbr.)	1,610	87.5 - 85.5				100				
Frontier Fm.	800	97 - 87.5			50	50				
Mowry Shale	430	98.5 - 97				100				
Muddy Sandstone	40	101 - 98.5			100					
Hiatus	0	102 - 101								
Thermopolis Shale	150	104 - 102				100				
Cloverly Fm.	220	134 - 104			50			50		
Hiatus	0	144 - 134								
Jurassic and Triassic rocks	1,920	248 - 144			50	50				
Hiatus	0	253 - 248								
Phosphoria/Park City Fm.	270	278 - 253				60	40			
Hiatus	0	290 - 278								
Tensleep Sandstone	335	310 - 290			100					

Heat flow 50 mW/m^2 Thermal gradient 1.31°F/100 feet

West Poison Spider

System/Series, Unit, or Event	Present thickness (ft)	Age range (Ma)	Deposited, later eroded (ft)	Amount of erosion (ft)	Generalized lithology					
					%ss	%sh	%ls	%slst	%coal	%dolo
Erosion		15 - 0		2,500						
post-lower Eocene rocks	0	51 - 15	2,500		30	70				
lower Eocene rocks	4,750	55 - 51			30	70				
Fort Union Fm.	1,650	65.4 - 55			40	60				
Lance Fm.	1,200	69.5 - 65.4			50	50				
Meeteetse Fm./Lewis Shale	1,500	72 - 69.5			30	70				
Mesaverde Fm. (Teapot Ss. Mbr.)	95	74 - 72			100					
Hiatus	0	76 - 74								
Mesaverde Fm. (middle mbr.)	405	77.5 - 76			40	60				
Mesaverde Fm. (Parkman Ss. Mbr.)	165	78 - 77.5			100					
Cody Shale (Wallace Creek Tongue)	275	79 - 78				100				
Mesaverde Fm. (Fales Mbr.)	15	79.5 - 79			100					
Cody Shale (upper sandy mbr.)	2,915	84 - 79.5			30	70				
Cody Shale (lower shaly mbr.)	1,250	88.7 - 84				100				
Frontier Fm.	775	97.5 - 88.7			40	60				
Mowry Shale	265	98.5 - 97.5				100				
Muddy Sandstone	40	101 - 98.5			100					
Hiatus	0	102 - 101								
Thermopolis Shale	110	104 - 102				100				
Cloverly Formation	85	134 - 104			100					
Hiatus	0	144 - 134								
Jurassic rocks	455	175 - 144			50			50		
Hiatus	0	208 - 175								
Triassic rocks (part)	956	248 - 208			50	50				
Hiatus	0	253 - 248								
Phosphoria/Park City Fm.	322	278 - 253				50	50			
Hiatus	0	290 - 278								
Tensleep Sandstone	248	310 - 290			100					

Heat flow 46 mW/m^2 Thermal gradient 1.29°F/100 feet

Table 2. Data used to generate burial history curves for nine locations, Wind River Basin Province, Wyoming.—Continued

[Models only include stratigraphic units from the base of the Tensleep Sandstone regardless of whether the well was drilled to deeper units. Mbr., Member; Fm., Formation; Ss., Sandstone; ft, feet; Ma, mega annum; %, percent; ss, sandstone; sh, shale; ls, limestone; slst, siltstone; dolo, dolomite. Heat flow and thermal gradient used to calibrate model are given for each location. mW/m2, milliWatts per square meter; °F, degrees Fahrenheit]

Young Ranch

System/Series, Unit, or Event	Present thickness (ft)	Age range (Ma)	Deposited, later eroded (ft)	Amount of erosion (ft)	Generalized lithology					
					%ss	%sh	%ls	%slst	%coal	%dolo
Erosion		15 - 0		1,700						
post-lower Eocene rocks	0	50 - 15	1,700		30	70				
lower Eocene rocks	3,575	55 - 50			30	70				
Fort Union Fm.	775	65.4 - 55			40	60				
Lance Fm.	680	69.5 - 65.4			50	50				
Meeteetse Fm./Lewis Shale	1,380	72 - 69.5			30	70				
Mesaverde Fm. (Teapot Ss. Mbr.)	65	74 - 72			100					
Hiatus	0	76 - 74								
Mesaverde Fm. (middle mbr.)	465	77.5 - 76			40	60				
Mesaverde Fm. (Parkman Ss. Mbr.)	150	78 - 77.5			100					
Cody Shale (Wallace Creek Tongue)	340	79 - 78				100				
Mesaverde Fm. (Fales Mbr.)	130	79.5 - 79			100					
Cody Shale (upper sandy mbr.)	2,265	84 - 79.5			30	70				
Cody Shale (lower shaly mbr.)	1,925	88.7 - 84				100				
Frontier Fm.	850	97.5 - 88.7			40	60				
Mowry Shale	275	98.5 - 97.5				100				
Muddy Sandstone	50	101 - 98.5			100					
Hiatus	0	102 - 101								
Thermopolis Shale	135	104 - 102				100				
Cloverly Formation	65	134 - 104			100					
Hiatus	0	144 - 134								
Jurassic rocks	475	175 - 144				50		50		
Hiatus	0	208 - 175								
Triassic rocks (part)	187	242 - 208			30	70				

Heat flow 51 mW/m^2 Thermal gradient 1.48°F/100 feet

Amoco Unit 100

System/Series, Unit, or Event	Present thickness (ft)	Age range (Ma)	Deposited, later eroded (ft)	Amount of erosion (ft)	Generalized lithology					
					%ss	%sh	%ls	%slst	%coal	%dolo
Erosion		15 - 0		4,500						
post-lower Eocene rocks	0.00	50 - 15	4,500		50	50				
lower Eocene rocks	1,100	55 - 50			50	50				
Erosion		58 - 55		1,000						
Fort Union Fm. (undivided)	1,125	65.4 - 58	1,000		50	50				
Erosion		67 - 65.4		1,000						
Lance Fm.	125	70 - 67	1,000		50	50				
Erosion		71.5 - 70		1,400						
Meeteetsee Fm.	0	72 - 71.5	600		50	50				
Mesaverde Fm. (Teapot Ss. Mbr.)	0	73.5 - 72	100		100					
Hiatus		78 - 73.5								
Mesaverde Fm. (lower part)	1,450	82.5 - 78	700		45	45			10	
Cody Shale (upper sandy mbr.)	2,340	85.5 - 82.5			40	60				
Cody Shale (lower shaly mbr.)	1,908	87.5 - 85.5				100				
Frontier Fm.	774	97 - 87.5			50	50				
Mowry Shale	408	98.5 - 97				100				
Muddy Sandstone	40	101 - 98.5			100					
Hiatus	0	102 - 101								
Thermopolis Shale	155	104 - 102			30	70				
Cloverly Fm.	222	134 - 104			100					
Hiatus	0	144 - 134								
Jurassic and Triassic rocks	1,915	248 - 144			50	50				
Hiatus	0	253 - 248								
Phosphoria/Park City Fm.	314	278 - 253					100			
Hiatus		290 - 278								
Tensleep Sandstone	274	310 - 290			100					

Heat flow 59 mW/m2 Thermal gradient 1.61°F/100 feet

Table 2. Data used to generate burial history curves for nine locations, Wind River Basin Province, Wyoming.—Continued

[Models only include stratigraphic units from the base of the Tensleep Sandstone regardless of whether the well was drilled to deeper units. Mbr., Member; Fm., Formation; Ss., Sandstone; ft, feet; Ma, mega annum; %, percent; ss, sandstone; sh, shale; ls, limestone; slst, siltstone; dolo, dolomite. Heat flow and thermal gradient used to calibrate model are given for each location. mW/m2, milliWatts per square meter; °F, degrees Fahrenheit]

Conoco-Coal Bank

System/Series, Unit, or Event	Present thickness (ft)	Age range (Ma)	Deposited, later eroded (ft)	Amount of erosion (ft)	Generalized lithology					
					%ss	%sh	%ls	%slst	%coal	%dolo
Erosion		15 - 0		2,900						
post-lower Eocene rocks	0	51 - 15	2,900		30	70				
lower Eocene rocks	700	55 - 51			30	70				
Fort Union Fm. (Shotgun Mbr.)	1,050	57 - 55			50	50				
Fort Union Fm. (Waltman Shale Mbr.)	950	59 - 57			50	50				
Fort Union Fm. (lower unnamed mbr.)	900	65.4 - 59			70	30				
Erosion		67 - 65.4		900						
Lance Fm.	500	69.5 - 67	900		50	50				
Meeteetse Fm./Lewis Shale	1,200	72 - 69.5			49	49			2	
Mesaverde Fm. (Teapot Ss. Mbr.)	50	74 - 72			100					
Hiatus	0	76 - 74								
Mesaverde Fm. (middle mbr.)	375	77.5 - 76			30	70				
Mesaverde Fm. (Parkman Ss. Mbr.)	105	78 - 77.5			70	30				
Cody Shale (Wallace Creek Tongue)	10	79 - 78				100				
Mesaverde Fm. (Fales Mbr.)	335	79.5 - 79			100					
Cody Shale (upper sandy mbr.)	2,525	84 - 79.5			30	70				
Cody Shale (lower shaly mbr.)	2,350	88.7 - 84				100				
Frontier Fm.	675	97.5 - 88.7			30	70				
Mowry Shale	350	98.5 - 97.5				100				
Hiatus	0	102 - 98.5								
Thermopolis Shale	175	104 - 102				100				
Cloverly Fm. (part)	84	110 - 104			100					
Heat flow 47 mW/m^2		Thermal gradient 1.31°F/100 feet								

Stratigraphic Intervals

The models included stratigraphic units from the base of the Pennsylvanian Tensleep Sandstone through the lower Eocene Wind River Formation at the surface. The Triassic and Jurassic stratigraphic units do not contain major petroleum source rocks and were, therefore, combined as one unit in the western, southern, and central parts of the basin and as two units separated by an unconformity in the eastern part of the basin (fig. 2). The Upper Cretaceous Mesaverde Formation consists of several members in the eastern part of the province, but in this study, only two are recognized in the central and western parts. The Upper Cretaceous Lewis Shale is only present in the northeastern and eastern parts of the province, and is included with the Meeteetse Formation in the models.

Unconformities

Figure 2 shows the major unconformities that were used for the burial history reconstructions. The unconformities at the Permian-Triassic, Triassic-Jurassic (in the eastern part of the province), and Jurassic-Cretaceous boundaries and within the Lower Cretaceous (Love and others, 1993) probably do not represent enough erosion to significantly affect the thermal maturity of the reservoired oil of the underlying Phosphoria/Park City Formation (Fred Peterson, Scientist Emeritus, U.S. Geological Survey, oral commun., 2003). At least one hiatus (erosional event) occurred during deposition of the Upper Cretaceous Frontier Formation (Love and others, 1993), but, for the purpose of this study, was not considered critical to the thermal maturation of source rocks. We applied a hiatus for the unconformity at the base of the Teapot Sandstone Member of the Mesaverde Formation that occurred from 78 to 73.5 mega annum (Ma) in the western part of the province. The hiatus represents a shorter period of time and occurred later in the southern and eastern parts of the province from about 76 to 74 Ma (Finn, Chapter 9, this CD-ROM).

The Amoco Unit 100 location (fig. 1), is situated on the east flank of the Beaver Creek anticline, near the south margin of the basin; an erosional event took place from about 71.5 to 70 Ma, resulting in the Lance unconformably overlying the lower part of the Mesaverde (Johnson, Chapter 10, pl. 6, this CD-ROM).

We designated an erosional event at the base of the Paleocene at the Conoco-Coal Bank and Amoco Unit 100 locations that indicated removal of about 900 feet (ft) and 1,000 ft of the Lance, respectively, based on information from subsurface cross sections. We assumed continuous deposition across the Cretaceous-Tertiary boundary in other parts of the basin however, based primarily on the premise that unconformities at the basin margins become less significant toward the interior as is evidenced by the much greater thicknesses of the stratigraphic units involved.

Post-Lower Eocene Deposition and Erosion

Because no post-lower Eocene rocks are preserved in areas where the burial histories were reconstructed, we necessarily made assumptions in regard to estimates of post-lower Eocene sedimentation and erosion. Barker and Crysdale (1993), Barker and others (1993), Nuccio and Finn (1994), and Nuccio (1994) used the method described by Keefer (1970) to estimate the amount of erosion. Keefer (1970) contended that erosion amounts could be estimated by extending a line from an elevation of 11,000 ft on the high plateau surface of the Absaroka Range southeastward across the basin to an elevation of 7,000 ft at Beaver Divide. These two outcrop areas are where erosional remnants exist of post-lower Eocene rocks along the northwest and south edges of the basin, respectively. Assuming a uniform gradient between these two areas, the thickness of Tertiary rocks stripped from the central part of the basin was about 3,000 ft (Keefer, 1970).

In our initial modeling efforts we used the method of Keefer (1970) to estimate erosion of post-lower Eocene rocks. We found, however, that modeling the burial and thermal history at locations in the central part of the basin, and especially at new locations east and south of the previously published burial histories, resulted in poor calibration with measured R_o data. The calculated R_o values, as determined by EASY%R_o (Sweeney and Burnham, 1990) indicated that a greater amount of post-lower Eocene deposition was required than that estimated by Keefer (1970). Other evidence of erosional remnants in and beyond the Wind River Basin Province led to a possible refined surface of basin fill (fig. 3*A*, *B*). These include (1) one of the several high subsummit erosion surfaces in the Wind River Range (elevation about 11, 500 ft) such as that identified at Square Top Mountain (T. 38 N., R.108W.) by Blackwelder (1915) — these surfaces are interpreted as representing the maximum elevation of once continuous post-Laramide basin-fill deposits; (2) a locality of Miocene mammal fossils at an elevation of about 9,000 ft on top of Darton's Bluff (fig. 3*A*) (sec, 19, T. 48 N. R. 85 W.), in the Big Horn Mountains to the north (McKenna and Love, 1972); and (3) the fact that the summit of Garfield Peak (fig. 3*A*, *B*) (sec. 33, T. 33 N, R.87 W), which is a Tertiary intrusion at an elevation of about 8,250 ft, 15 miles east of Beaver Divide requires that the elevation of Beaver Divide for use in generating a surface of basin fill is too low and the elevation to the east of 8,250 ft is still probably a minimum. Based on this evidence, a trend surface grid was generated using EarthVision (Dynamic Graphics, Inc., 2005), with a first-order polynomial, that extends from surfaces in the southern Absarokas, across Square Top Mountain, and across Darton's Bluff (fig. 3 *A*). This surface passes over Garfield Peak, about 1,000 ft higher than the summit (fig. 3*B*). The eastward slope of the surface is consistent with interpretations of drainage patterns during the Oligocene (Lillegraven and Ostresh, 1988). Subtracting the grid of the modern topography (generated from a Digital Elevation Model) from this trend surface grid results in an isopach map of estimated eroded thickness of post-lower Eocene rocks (fig. 3*C*). The map indicates a thicker interval of basin fill in the southeastern part of the basin than that estimated using the Keefer (1970) method. This resulting isopach map was used as a guide for estimating thickness of erosion across the basin, consequently the actual values used in the modeling may not coincide with the value of the estimated erosion thickness at the plotted burial history location on the isopach map (fig. 3*C*). Using this method, during the period from about 50 to 15 Ma, the amount of post-lower Eocene deposition and the subsequent erosion amounts, from 15 Ma to the present, at the burial history locations is estimated to range from 1,700 ft in the southeastern part of the province to 5,000 ft in the northern part. These erosion estimates are not inconsistent with those reported by McMillan and others (2006) who used a similar method but whose area of study included the Rocky Mountain orogenic plateau.

Methods—Thermal History

For each of the nine burial history locations, bottom-hole temperatures, temperatures from drill stem tests, R_o data, and assumed paleosurface temperatures were used to calibrate thermal models. The temperature data were from records on log headers of the individual wells used in modeling. The bottom-hole temperatures were corrected according to Waples and others (2004). R_o data are from Pawlewicz (1993) for the Bighorn 1-5, Coastal Owl Creek, Shell 33X-10, and Amoco Unit 100 wells, and from Finn and others (2006) for the Hells Half Acre, West Poison Spider, Young Ranch, and Conoco-Coal Bank wells. Generally, R_o data from the coal-bearing Mesaverde, Meeteetse, Lance, and lower part of the Fort Union Formations were used preferentially in the thermal-history calibrations to avoid the problem of suppressed R_o (Price and Barker, 1985; Wenger and Baker, 1987). Suppressed R_o appears to be particularly common in the Cody Shale at all sample locations (plate 1).

The paleosurface temperature data through the Late Cretaceous (100 Ma) to the present for all the burial history locations were taken from Barker (2000), except that, on the basis of annual surface temperature near Riverton, Wyoming, we used a present-day temperature of 7˚ C (44.5˚ F). For the surface temperature history before 100 Ma, we used a constant paleosurface temperature of 20˚ C (68˚ F) from the beginning of deposition to 144 Ma and gradually decreasing the temperature to 17˚C (63˚ F) at 100 Ma based loosely on a module that is included with the PetroMod1D® software that calculates paleosurface temperature through time at chosen latitudes (Wrygala, 1989).

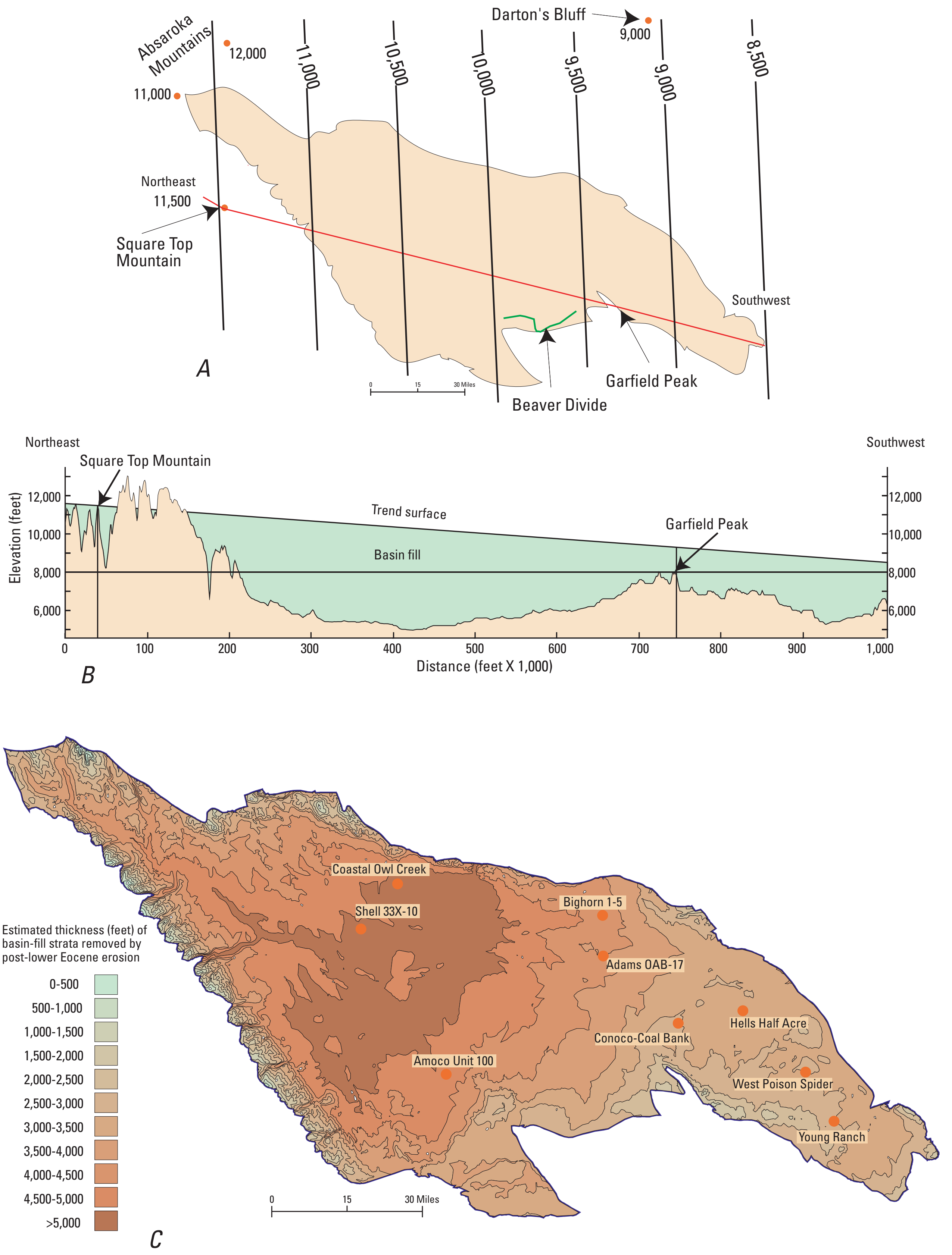

Figure 3. Maps and cross section showing method used to estimate post-lower Eocene deposition and erosion. *A*, trend surface using elevations of erosion surfaces in the Absaroka Mountains, at Square Top Mountain, and locality of Miocene vertebrates at Darton's Bluff. *B*, cross section showing estimated basin fill. *C*, isopach map of estimated post-lower Eocene erosion.

The heat flow value, which is an input parameter for the PetroMod1D® program, is used for the burial history reconstructions (table 2). A present-day heat flow at the base of the stratigraphic column at each modeled location was determined within the PetroMod1D® program by calibrating burial histories with the measured downhole temperatures (corrected) and the present-day and assumed paleosurface temperatures. Heat flow values used at the modeled well locations range from 46 to 60 milliWatts per square meter (mW/m^2), which is in agreement with the range of values documented by Decker and others (1980) for the eastern Wyoming basin area (25 to 67mW/m^2). Although heat flow probably varied through time, it was not necessary to make assumptions about when changes of heat flow occurred or the extent to which it changed through time. Assuming the buried depths and amounts of erosion to be geologically correct, using a constant heat flow through time resulted in an acceptable match between calculated and measured R_o values, as determined by EASY%R_o (Sweeney and Burnham, 1990).

Methods—Petroleum Generation History

Timing of oil and gas generation was determined for the eight petroleum source rocks at the nine burial history locations. These source rocks are designated in table 3 as either gas- or oil-prone on the basis of available geochemical rock data and oil-to-rock correlations. The possibility of a designated gas-prone source rock being an oil-prone source rock as a result of changes in organic facies is noted by the "G/O" abbreviation. Similarly, the possibility of a designated oil-prone source rock being a gas-prone source rock as a result of changes in organic facies is noted by the "O/G" abbreviation. For example, the Mowry Shale contains a mix of Type-II and Type-III kerogen. The Mowry is considered predominantly oil prone at the burial history locations east of the central part of the Wind River Basin and predominantly gas prone westward where the western Mowry shoreline was relatively close, resulting in more terrestrial sediment input (Type-III) than to the east, which had predominantly marine sediment influence (Type-II) (Finn, Chapter 8, this CD-ROM).

Oil-Prone Source Rocks

Oil-prone source rocks like the Mowry and Cody Shales in the eastern half of the basin, and the Waltman Shale Member of the Fort Union Formation typically consist of marine clastic source rocks and contain Type-II kerogen (O/G and O in table 3) that generates low-sulfur oil. Oil generation from Type-II kerogen in source rocks of this study was modeled at the relevant burial history locations with hydrous pyrolysis kinetic parameters (table 4) (Roberts and others [2004] show details on why these particular parameters were used.) Source rock oil-generation kinetic parameters from hydrous pyrolysis experiments, combined with burial history and thermal maturity, determine the timing of the generation of expelled oil, where expulsion is considered a consequence of generation (Momper, 1978; Lewan, 1997; Lewan and Ruble, 2002).

Table 3. Source rocks and type of petroleum potential for burial history locations, Wind River Basin Province.

[Gc, gas from cracking of oil; G/O, predominantly gas from Type-III kerogen, possibly oil-prone; O/G, predominantly oil Type-II kerogen, possibly gas-prone; G, gas from Type-III kerogen; O, oil from Type-II kerogen; Fm., Formation; Sh., Shale; Double hyphens indicate source rock is not present]

Burial history location	Source rock								
	Phosphoria Fm.	Mowry Sh.	Cody Shale		Mesaverde Fm.	Meeteetse Fm.	Lance Fm.	Fort Union Fm.	Fort Union Fm. Waltman Sh. Member
			Shaly member	Sandy member					
Adams OAB 1-17	Gc	O/G	O/G	G	G	G	G	G	O
Bighorn 1-5	Gc	O/G	O/G	G	G	G	G	G	O
Coastal Owl Creek	no data	G/O	G	G	G	G	G	G	--
Hells HalfAcre	Gc	O/G	O/G	G	G	G	G	G	O
Shell 33X-10	Gc	G/O	G	G	G	G	G	G	--
West Poison Spider	Gc	O/G	O/G	G	G	G	G	G	--
Young Ranch	no data	O/G	O/G	G	G	G	G	G	--
Amoco Unit 100	Gc	G/O	G	G	G	G	G	G	--
Conoco-Coal Bank	no data	O/G	O/G	G	G	G	G	G	O

Although gas is generated during oil generation from oil-prone kerogen, the gas:oil ratios (GORs) are typically less than 1,000 cubic feet per barrel during the main stage of oil generation (Lewan and Henry, 2001). However, when the thermal stress gets high enough to initiate the already generated oil to crack to gas, the GORs begin to increase significantly (Lewan and Henry, 2001). Comparisons of various published kinetic models for gas generation by Henry and Lewan (2001) indicate that the mass of gas generated from the cracking of oil is 3 to 7 times greater than gas generated from source rocks with Type-II kerogen. Therefore, gas generation during oil generation from oil-prone kerogen was not modeled, but cracking of generated oil to gas was modeled. Hydrothermal-pyrolysis kinetic parameters used to determine the timing of gas generation from oil cracking are from Tsuzuki and others (1999; C_{15+} saturates) and are listed in table 4.

Phosphoria oil produced in the province is thought to have migrated from the Wyoming and Idaho thrust belt region into the Wind River Basin and accumulated in upper Paleozoic and lower Mesozoic reservoirs (Sheldon, 1967; Stone, 1967). Within the boundary of the Wind River Basin Province, the Phosphoria Formation is thin and only locally rich in organic carbon (Kirschbaum and others, Chapter 3, this CD-ROM). For this reason we do not present the results of modeling the timing of oil generation from Phosphoria source rocks, but present only the timing of cracking of Phosphoria-sourced oil pooled in the reservoirs of the Park City Formation. See Kirschbaum and others (Chapter 3, this CD-ROM) for interpretations regarding the timing of hypothetical oil generation from Type-IIS source rocks of the Retort Phosphatic Shale Member and Meade Peak Member of the Phosphoria Formation.

Each set of kinetic parameters listed in table 4 has transformation ratios that express the extent of oil generation from Type-II kerogen and oil cracking to gas. The transformation ratios are the decimal fraction of reaction completed (that is, 0.00 = no reaction; 1.00 = completed reaction) for the various source rocks at the burial history locations as determined by the kinetic parameters. Oil generation and oil cracking to gas are defined in this study by transformation ratios between 0.01 and 0.99. Immature source rocks and uncracked oils have transformation ratios less than 0.01, and source rocks and crude oils that have respectively completed oil generation and have completed cracking to gas have transformation ratios greater than 0.99. Peak oil generation and oil cracking to gas occur at a transformation ratio of 0.50 when the maximum rate of reaction is reached. The transformation ratios for oil generation and those for oil cracking are independent, and the two cannot be equated. Therefore, a transformation ratio of 0.50 for oil cracking occurs at a higher thermal maturity than a transformation ratio of 0.50 for oil generation.

Gas-Prone Source Rocks

Unlike oil-prone source rocks, the extent of gas generation in source rocks with Type-III kerogen can be equated to levels of R_o because this is measured on the macerals that generate the gas. An R_o value of 0.5 percent is typically prescribed for the start of gas generation from humic coals, based on field observations (Scott, 1993) and pyrolysis experiments (Tang and others, 1996). The putative threshold for the generation of sufficient gas to form economic accumulations or overpressuring ranges between 0.8 and 1.0 percent R_o, also based on field studies (Law, 2002) and pyrolysis experiments (Tang and others, 1996). Closed-system pyrolysis experiments indicate that the end of gas generation from Type-III kerogen occurs at R_o values between 1.8 and 2.0 percent (Saxby and others, 1986; Rohrback and others, 1984; Kotarba and Lewan, 2004). As described by Roberts and others (2004), we determined the timing of gas generation from gas-prone source rocks based on these empirical relations between R_o and gas generation. Accordingly, EASY%R_o was used to model gas generation from gas-prone source rocks, with the start and end of gas generation occurring at 0.5 and 2.0 percent R_o, respectively. Time of peak gas generation is defined as the age when the threshold value of 0.8 percent R_o is reached. Unlike oil generation and oil cracking to gas, the lack of an acceptable kinetic model for gas-prone source rocks means that the prescribed R_o values for the start, peak, and end of gas generation cannot be related to specific transformation ratios. Gas generation discussed in this report refers only to thermogenic gas and not biogenic gas.

Table 4. Hydrous-pyrolysis kinetic parameters used to determine timing of oil generation from Type-II kerogen and timing of oil cracking to gas.

[kcal/mol, kilocalorie per mole; m.y., million years]

Organic matter type	Product generated	Activation energy (E_o = kcal/mol)	Frequency factor (A_o = m.y.$^{-1}$)
Type-II kerogen[1]	Expelled oil	52.16	5.707×10^{26}
Crude oil (C_{15}+)[2]	Generated gas	76	3.419×10^{33}

[1]Lewan and Ruble (2002); [2]Tsuzuki and others (1999).

Results—Burial History

Table 5 lists information on the present-day depth, calculated maximum depth of burial, and calculated temperatures at maximum depth for the source rock intervals from the burial history reconstructions. Based on Van Houten (1964), Keefer (1970), Love (1988), Mears (1993), Nuccio and Finn (1994), and Beland (2002), 15 Ma (middle Miocene) was used for the time of maximum burial for all stratigraphic units at all of the modeled locations. Plate 1 presents the burial history curves from 120 Ma (late Early Cretaceous) to the present – the burial history prior to 120 Ma is comparatively consistent from location to location across the basin indicating fairly constant and relatively slow subsidence/sedimentation rates within a stable tectonic setting. The onset of the Laramide orogeny in the Late Cretaceous triggered the changes in sedimentation rates and created depocenters at different areas of the basin at different times. Following is a brief description of the burial history at each location (fig. 1): three in the deepest parts of the province (Adams OAB 1-17, Bighorn 1-5, and Coastal Owl Creek), three at intermediate basin depths (Hells Half Acre, Shell 33X-10, and West Poison Spider), and three at the shallowest locations (Young Ranch, Amoco Unit 100, and Conoco-Coal Bank).

Adams OAB 1-17 and Bighorn 1-5

The Adams OAB 1-17 location is on the gently sloping edge of the relatively deep part of the Wind River Basin trough and, along with the Coastal Owl Creek location, represents the greatest depth to which the source rocks were buried (pl. 1 and table 5). From 310 Ma to about 88 Ma, subsidence/sedimentation rates appear to have been fairly constant and relatively slow. The rate of deposition increased substantially between 88 and about 50 Ma resulting in a total of more than 21,000 ft of section represented by this period of time. A brief episode of nondeposition occurred between 76 and 74 Ma.

The Bighorn 1-5 location is on the Madden anticline in the north-central part of the Wind River Basin (fig. 1). The burial history here is very similar to that of the Adams OAB 1-17 location, except that the rate of sedimentation during Lance time was slightly higher and the rate of sedimentation during Wind River time resulted in almost 2,000 ft less strata on the crest of the anticline. In the last 15 million years (m.y.), more than 4,800 ft of rock may have been removed by erosion from these areas.

Coastal Owl Creek

The burial history reconstruction at Coastal Owl Creek, located near the trough of the Wind River Basin (fig. 1), represents the greatest depth to which source rocks were buried. Between 98.5 and about 97.5 Ma, a greater thickness of Frontier and Mowry sediments was deposited here than at any of the other burial history locations. A big difference in the burial history here, as compared with the Bighorn 1-5 location is that the Wind River Formation sediments deposited at this location (7,100 ft) were almost three times that at the Bighorn location (2,580 ft). This difference can probably be attributed to the growth of the Madden anticline during the early Eocene and the consequential thinning of Eocene rocks across the structure. After maximum burial from the addition of post-lower Eocene sediments, uplift and erosion caused the removal of an estimated 4,600 ft of section in the Coastal Owl Creek area.

Hells Half Acre

The Hells Half Acre location is situated in a syncline west of the Casper arch near the east margin of the Wind River Basin (fig. 1). The burial history here is most like that at the Adams OAB 1-17 location; however, sedimentation/subsidence rates began to decrease in this area at about the end of deposition of the Fort Union Formation resulting in an interval of Wind River rocks that is about half as thick as those at the Adams OAB 1-17 location. An estimated 2,200 ft of post-lower Eocene sediments were deposited and then eroded at this location. Cretaceous source rocks at Hells Half Acre were buried about 6,000 ft shallower than at Adams OAB but about 6,000 ft deeper than at Conoco-Coal Bank.

Shell 33X-10

The Shell 33X-10 location is on the southwest flank of the Wind River Basin trough (fig. 1). The burial history here (pl. 1) closely resembles that at Owl Creek, except that the rate of sediment accumulation was not as rapid during deposition of the Meeteetse through the Wind River Formations (72 to 50 Ma), resulting in about half the thickness of that interval here. Consistent with this trend, the thickness of post-lower Eocene deposition was estimated to be 1,600 ft less than that at the Owl Creek location.

West Poison Spider

The burial history at West Poison Spider (pl.1), located on an anticline in the southeastern part of the Wind River Basin (fig. 1), is virtually the same as that to the north at Hells Half Acre until about the end of Meeteetse deposition. At that time the sedimentation/subsidence rates began to decrease, and about one-third the thickness of Lance sediments was deposited as compared to Hells Half Acre. This trend of slower sediment accumulation continued until the Eocene, when a substantial increase in the sedimentation rate resulted in twice the thickness of the Wind River Formation than at Hells Half Acre and rivaled that deposited in the deep part of

Table 5. Present-day depth, calculated maximum depth of burial, and calculated temperature at maximum depth of intervals from burial history reconstructions, Wind River Basin Province, Wyoming.

[ND = no data. Double hyphens indicate source rock is not present. Depth values are in feet. Temperature values are degrees Fahrenheit. Fm., Formation; Mbr, Member]

Burial history location	**Source rock**							
	Phosphoria Fm.	Mowry Shale	Cody Shale	Mesaverde Fm.	Meeteetse Fm.	Lance Fm.	Fort Union Fm.	Fort Union Fm. Waltman Shale Mbr.
Adams OAB1-17								
Present-day depth	23,860	21,880	20,910	16,790	15,550	14,410	9,715	7,170
Maximum depth	28,610	26,630	25,660	21,570	20,270	19,190	14,480	11,920
Temperature	564	526	506	426	402	382	303	259
Bighorn 1-5								
Present-day depth	22,950	20,960	20,010	15,920	14,780	13,420	8,280	2,050
Maximum depth	27,930	25,880	24,990	20,880	19,770	18,380	13,270	10,610
Temperature	549	511	495	422	403	376	285	236
Coastal Owl Creek								
Present-day depth	ND	23,550	22,100	18,550	16,480	15,350	12,490	--
Maximum depth	ND	28,050	26,680	23,130	21,000	19,900	17,060	--
Temperature	ND	438	416	364	335	320	281	--
Hells Half Acre								
Present-day depth	21,800	19,610	18,500	13,850	12,720	11,260	7,450	5,000
Maximum depth	23,990	21,790	20,690	16,020	14,880	13,410	9,610	7,190
Temperature	383	354	338	273	258	239	191	161
Shell 33X-10								
Present-day depth	18,290	15,690	14,460	10,880	8,920	7,580	6,050	--
Maximum depth	21,280	18,640	17,440	13,850	11,900	10,540	9,010	--
Temperature	345	310	293	242	217	199	179	--
West Poison Spider								
Present-day depth	17,230	15,260	14,220	10,055	9,100	7,600	6,400	--
Maximum depth	19,680	17,700	16,680	12,540	11,590	10,070	8,890	--
Temperature	318	293	279	223	211	191	177	--
Young Ranch								
Present-day depth	ND	12,875	11,750	7,560	6,410	5,030	4,350	--
Maximum depth	ND	14,540	13,450	9,250	8,100	6,720	6,030	--
Temperature	ND	276	260	196	179	159	149	--
Amoco Unit 100								
Present-day depth	11,880	9,230	8,050	3,800	--	2,350	2,230	--
Maximum depth	16,350	13,680	12,500	8,270	--	6,860	6,700	--
Temperature	332	289	269	195	--	170	168	--
Conoco-Coal Bank								
Present-day depth	ND	12,075	11,050	6,175	5,300	4,100	3,600	2,700
Maximum depth	ND	14,950	13,900	9,060	8,180	6,990	6,480	5,580
Temperature	ND	258	244	176	165	150	143	132

the basin at the Adams OAB location. An additional 2,500 ft of post-lower Eocene sediments may have been deposited at West Poison Spider before the final erosional event.

Young Ranch

The Young Ranch location lies on the relatively steeply dipping northeast slope of the Wind River Basin in the southeast corner of the province (fig. 1). This location, along with Amoco Unit 100 and Conoco-Coal Bank, represents one of the areas where source rocks were buried the shallowest (pl. 1 and table 5); however, this location was apparently not affected by Late Cretaceous or Paleocene erosional events. The burial history here is very similar to the West Poison Spider and Hells Half Acre locations, except that since the beginning of Lance deposition and through Fort Union and Wind River deposition, the sedimentation/subsidence rate was slower than in those areas to the north, resulting in about 2,500 ft less total thickness of these units. An estimated 1,700 ft of post-lower Eocene rocks were eroded from this area.

Amoco Unit 100

The Amoco Unit 100 location is on the east flank of the Beaver Creek anticline (fig. 1), in the southern part of the Wind River Basin. Burial history began much as it did at the Owl Creek and Shell 33X-10 locations, but after deposition of the lower part of the Meeteetse Formation, an episode of local uplift resulted in erosion of the entire Meeteetse and about 800 ft of the underlying Mesaverde Formation. Sedimentation resumed during Lance time but another uplift in the same area caused erosion of all but the lower 125 ft of the Lance. A third erosional event occurred after deposition of about 2,000 ft of Fort Union that left only about 1,000 ft of Fort Union Formation lying on the lowermost Lance Formation (Johnson, Chapter10, this CD-ROM). The amount of post-lower Eocene deposition and subsequent erosion at this location is about 4,500, similar to that at Owl Creek.

Conoco-Coal Bank

The Conoco-Coal Bank location is on the northeast flank of the Rattlesnake Hills (fig. 1), near the south margin of the Wind River Basin. The burial history here is similar to that at the Amoco Unit 100 location, in that the depth of burial of source rocks is relatively shallow and an episode of uplift and erosion is recorded in the rocks by the partial erosion of the Lance Formation prior to Paleocene deposition (pl. 1, table 5). The history here is dissimilar to the burial history location to the northwest at the Adams OAB 1-17 in that it did not receive as large a volume of sediment during Fort Union and Wind River deposition — these rocks are about 6,000 ft thicker at the Adams OAB location. An estimated 2,900 ft of rock was eroded from the Conoco Coal Bank area after maximum burial from 15 Ma to the present (table 2).

Results—Maturation History

Maturation history is based on calibrating, or matching as closely as possible, the measured and calculated R_o for each burial history location. Plate 1 shows selected ranges of R_o superimposed on the burial history curves. As previously discussed, the range of 0.5 to 0.8 percent R_o represents the prescribed start to peak of gas generation from humic coals. The R_o values of 1.10 and 1.35 percent were added for information purposes only and represent intermediate maturities between peak (0.8 percent R_o) and end (2.0 percent R_o) of gas generation. All of the Upper Cretaceous and Paleocene source rocks, except for the Waltman Shale Member, are considered gas prone (mostly composed of Type-III kerogen) (table 3) or possibly oil prone (Mowry and Cody Shales in the eastern and central parts of the province), so R_o can be used to estimate extent of gas generation.

Results—Petroleum Generation History

The timing and extent of petroleum generation from the prescribed source rocks (table 3) at the nine burial history locations are listed in tables 6 and 7 and summarized in figures 4 and 5. With the exception of the Young Ranch, Amoco Unit 100, and Conoco-Coal Bank locations, the burial history curves represent relatively deep parts of the Wind River Basin Province. As a result, the other six curves represent the earliest timing and greatest extent of petroleum generation in the identified source rock intervals. Updip from these locations, the time at which petroleum generation occurred would be later and the extent of petroleum generation would be less, as evidenced by the aforementioned Young Ranch, Amoco Unit 100, and Conoco-Coal Bank burial history locations along the margins of the basin (fig. 1).

A vertical dashed line at 15 Ma on each of figures 4 and 5 represents the onset of major uplift, erosion, and subsequent cooling at all of the burial history locations. Based on kinetic and burial history modeling, rates of oil generation, oil cracking to gas, and gas generation were significantly reduced after that time, with negligible generation during the last 15 m.y.

As expected, the most extensive petroleum generation occurred at the locations where source rocks were most deeply buried, which include the Adams OAB 1-17, Bighorn 1-5, and Owl Creek locations (figs. 4 and 5). The Hells Half Acre, Shell 33X-10, and West Poison Spider locations, which represent intermediate burial depths, had moderately extensive petroleum generation, and the shallowest burial depths at the Young Ranch, Amoco Unit 100, and Conoco-Coal Bank locations, resulted in the least extensive petroleum generation. Burial depths at the Owl Creek location in the deep part of the Wind River Basin are slightly greater than at Bighorn 1-5 and Adams OAB 1-17, but because of a lower thermal gradient (table 2), the timing of petroleum generation at Owl Creek was later and the extent of petroleum generation was less (figs. 4 and 5).

Oil Generation from Source Rocks

Timing of the start, peak, and end of oil generation (transformation ratios of 0.01, 0.50, and 0.99, respectively) for Type-II source rocks was calculated at a horizon in the middle of the source rock intervals, except in the case of the Waltman Shale Member where the timing was calculated at the base of the source rock interval. The results are given in table 6 and shown in figure 4. The beginning of oil generation from the three oil-prone source rocks considered in this study (table 3) extended over a range of about 48 m.y. starting at 68 Ma for the Mowry to 20 Ma for the Waltman.

Timing of oil generation from the Cretaceous oil-prone source rocks followed the expected order of older rocks generating before younger rocks at any given location (table 6, fig. 4). Oil generation started at Adams OAB 1-17 and Bighorn 1-5 at 68 Ma for the Mowry Shale, and by 67 Ma for the Cody Shale. The same order follows at these locations for the end of oil generation with 60 Ma for the Mowry Shale, and 56 Ma for the Cody Shale. Oil generation peaked and ended for the Mowry at all of the locations except for those along the margin of the basin. The same is true for the Cody, where it is considered an oil-prone source rock, except that minor oil generation may continue at West Poison Spider (fig. 4).

The source rocks of the Waltman Shale Member are present only in four of the burial history locations (table 3) (Roberts and others, Chapter 5, this CD-ROM); however, oil generation started at only the two deepest locations, Adams OAB 1-17 and Bighorn 1-5, at 36 and 20 Ma, respectively. Oil generation from the Waltman Shale Member did not start until oil generation and oil cracking to gas had ended for the Mowry and Cody source rocks.

The oil-prone source rocks may still be generating a minor amount of oil at the West Poison Spider, Young Ranch, Amoco Unit 100, and Conoco-Coal Bank locations.

Oil Cracking to Gas

Timing of the start, peak, and end of oil cracking to gas (transformation ratios of 0.01, 0.50, and 0.99, respectively) is given in table 6 and shown in figure 4. These transformation ratios pertain to generated oils that are retained in the host source rock or in immediately adjacent reservoirs. In the case of generated Phosphoria oils that migrated from outside the province, the transformation ratios pertain to oil that may have migrated long distances into the Park City Formation and immediately adjacent reservoirs.

Figure 4 shows that a distinct time gap exists between the end of oil generation and the start of oil cracking to gas. The duration of this gap is dependent on the conditions of the thermal-burial history and ranges from 21 m.y. for Mowry oil at Hells Half Acre to 1 m.y. for Cody oil at Bighorn 1-5.

Timing of cracking of oil for the Phosphoria at Owl Creek, Young Ranch, and Coal Bank (table 3) could not be determined because the wells did not penetrate the Park City Formation; however, the oil did crack to gas at Owl Creek because oil from the younger, less deeply buried Mowry source rocks cracked to gas. No gas was generated from cracked Phosphoria oils at the Shell 33X-10, West Poison Spider, and Amoco Unit 100 locations (table 6). Because Young Ranch and Coal Bank have a similar burial history to those locations that did not generate gas from the cracking of Phosphoria oil, it is unlikely that cracking occurred at Young Ranch and Coal Bank.

The Adams OAB 1-17 and Bighorn 1-5 locations have the greatest potential for gas from oil cracking because oils from the Phosphoria, Mowry, and Cody source rocks would have been cracked to gas by 43 Ma. An overall ranking of the burial history locations in the order of decreasing potential for gas generation from the cracking of oil is: Adams OAB 1-17 and Bighorn 1-5 > Coastal Owl Creek > Hells Half Acre. An important caveat to this ranking is that, with the exception of the Phosphoria, the likelihood of retaining generated oil in or adjacent to the source rock is assumed to be the same for all of the oil-prone source rocks at all of the locations.

Gas Generation from Source Rocks

Extent of gas generation from gas-prone source rocks is directly related to R_o values based on empirical observations and not a specific kinetic model. As a result, timing of gas generation is directly related to R_o values (that is, start = 0.5 percent R_o, peak = 0.8 percent R_o, and end = 2.0 percent R_o), and the burial history curves for R_o (pl. 1) equate gas generation from gas-prone source rocks. The timing of the start, peak, and end of gas generation for each of the gas-prone source rock intervals is given in table 7 and shown in figure 5.

The most complete gas generation in the Wind River Basin Province occurred in the gas-prone source rocks in the deepest basin settings at Adams OAB 1-17, Bighorn 1-5, and Coastal Owl Creek (fig. 5). Gas generation from the Mowry and Cody Shales peaked as early as 67 Ma and ended by 44 Ma at these locations. Gas generation from the Mesaverde, Meeteetse, and Lance Formations started in the latest Cretaceous (Mesaverde at Bighorn 1-5) to early Eocene (Lance at Coastal Owl Creek) and had peaked by 48 Ma. These results are consistent with those obtained by Barker and Crysdale (1993) for the Owl Creek location. Only at these deep basin locations did the source rocks of the Fort Union

Table 6. Timing of oil generation for Type-II source-rocks and timing of oil cracking to gas, Wind River Basin Province, Wyoming.

[Start, peak, and end of oil generation and of oil cracking to gas are represented by transformation ratios of 0.01, 0.50, and 0.99, respectively. Age values are Ma (mega annum). Hyphen indicates timing of Phosphoria oil generation was not included in this study; timing of Phosphoria oil cracking to gas was modeled for Park City reservoirs. Blank cell indicates horizon did not attain minimum transformation ratio. Values in brackets are transformation ratio at the present time (0 Ma).]

Adams OAB 1-17

Source rock	Oil generation						Oil cracking to gas					
	Start	(%Ro)	Peak	(%Ro)	End	(%Ro)	Start	(%Ro)	Peak	(%Ro)	End	(%Ro)
Phosphoria/Park City Formation	-	-	-	-	-	-	58	1.75	55	2.38	53	2.77
Mowry Shale	68	0.68	64	0.93	60	1.14	56	1.74	52	2.36	51	2.69
Cody Shale	66	0.63	59	0.91	56	1.30	54	1.58	50	2.31	43	3.1
Waltman Shale (base)	36	0.69			0[0.18]	0.83						
Bighorn 1-5												
Phosphoria/Park City Formation	-	-	-	-	-	-	63	1.66	58	2.38	56	2.71
Mowry Shale	68	0.66	65	0.92	64	1.13	59	1.65	55	2.37	53	2.74
Cody Shale	67	0.63	63	0.93	58	1.28	57	1.50	51	2.38	46	3.05
Waltman Shale (base)	20	0.70			0[0.02]	0.73						
Coastal Owl Creek												
Mowry Shale	62	0.69	55	0.91	52	1.17	49	1.73	42	2.42	28	2.85
Hells Half Acre												
Phosphoria/Park City Formation	-	-	-	-	-	-	50	1.77			0[0.34]	2.41
Mowry Shale	63	0.69	56	0.91	54	1.12	33	1.81			0[0.02]	1.95
Cody Shale	58	0.68	53	0.92	48	1.22	No gas					
Waltman Shale (base)	No oil											
Shell 33X-10												
Phosphoria/Park City Formation	-	-	-	-	-	-	No gas					
Mowry Shale	54	0.69	48	0.92	39	1.13	No gas					
West Poison Spider 8												
Phosphoria/Park City Formation	-	-	-	-	-	-	No gas					
Mowry Shale	52	0.69	45	0.91	27	1.12	No gas					
Cody Shale	51	0.68	31	0.92	0[0.72]	0.99						
Young Ranch												
Mowry Shale	51	0.69	39	0.91	0[0.91]	1.05						
Cody Shale	48	0.67			0[0.21]	0.82						
Amoco Unit 100												
Phosphoria/Park City Formation	-	-	-	-	-	-	No gas					
Mowry Shale	51	0.69	26	0.91	0[0.89]	1.04						
Conoco-Coal Bank												
Mowry Shale	51	0.67			0[0.28]	0.86						
Cody Shale	44	0.63			0[0.05]	0.72						
Waltman Shale (base)	No oil											

Table 7. Timing of gas generation for Type-III source rocks, Wind River Basin Province, Wyoming.

[Age values are in Ma (mega annum). Depth values are calculated depth of burial at which vitrinite reflectance (%R_o) value was reached (in feet). Temp. is temperature at burial depth in degrees Fahrenheit. Double hyphen indicates horizon did not attain %R_o value. 'e' indicates source rock was eroded.]

	Source Rock																	
Burial history location	**Mowry Shale**			**Cody Shale**			**Mesaverde Formation**			**Meeteetse Formation**			**Lance Formation**			**Fort Union Formation**		
	Age	**Depth**	**Temp.**	**Age**	**Depth**	**Temp.**	**Age**	**Depth**	**Temp.**	**Age**	**Depth**	**Temp.**	**Age**	**Depth**	**Temp.**	**Age**	**Depth**	**Temp.**
Adams OAB 1-17																		
0.5%R_o - Start	78	7,160	192	71	7,210	186	64	8,860	200	61	8,690	197	59	8,800	197	53	8,460	202
0.8%R_o - Peak	65	13,740	281	64	13,340	278	56	13,570	279	55	13,000	276	53	13,400	280	44	11,410	269
2.0%R_o - End	54	19,760	396	53	20,160	402	46	18,510	390	38	18,000	378	25	18,290	372	--	--	--
Bighorn 1-5																		
0.5%R_o - Start	76	7,270	187	70	8,070	192	66	8,810	207	65	8,330	202	62	7,950	199	53	7,700	198
0.8%R_o - Peak	67	13,370	284	66	13,310	284	59	12,140	276	57	12,630	279	55	12,380	278	38	10,720	261
2.0%R_o - End	57	19,590	398	56	19,280	396	48	17,680	391	43	16,940	380	23	17,680	370	--	--	--
Coastal Owl Creek																		
0.5%R_o - Start	71	9,240	187	67	10,390	197	59	10,940	196	55	11,160	199	54	11,870	204	51	11,920	205
0.8%R_o - Peak	58	16,570	274	55	16,620	275	51	18,150	283	49	17,500	281	48	16,510	276	39	14,650	262
2.0%R_o - End	48	24,820	395	44	23,790	389	--	--	--	--	--	--	--	--	--	--	--	--
Hells Half Acre																		
0.5%R_o - Start	69	10,070	196	67	10,670	198	58	11,490	198	56	11,260	200	54	10,440	198	45	8,240	188
0.8%R_o - Peak	58	17,080	275	57	17,120	277	48	14,740	269	40	13,830	258	--	--	--	--	--	--
2.0%R_o - End	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Shell 33X-10																		
0.5%R_o - Start	69	9,540	194	65	9,670	192	52	10,130	201	49	9,490	197	44	8,570	188	26	8,300	176
0.8%R_o - Peak	51	15,540	277	49	15,130	275	--	--	--	--	--	--	--	--	--	--	--	--
2.0%R_o - End	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
West Poison Spider																		
0.5%R_o - Start	66	9,800	189	60	9,730	185	51	10,680	199	49	9,730	196	43	8,590	186	29	8,170	175
0.8%R_o - Peak	50	15,990	274	47	15,080	271	--	--	--	--	--	--	--	--	--	--	--	--
2.0%R_o - End	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Young Ranch																		
0.5%R_o - Start	69	8,840	194	65	8,320	185	47	8,060	191	36	7,340	179	--	--	--	--	--	--
0.8%R_o - Peak	48	13,390	271	42	12,490	260	--	--	--	--	--	--	--	--	--	--	--	--
2.0%R_o - End	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Amoco Unit 100																		
0.5%R_o - Start	80	7,680	197	75	7,100	188	27	7,080	182	e	e	e	--	--	--	--	--	--
0.8%R_o - Peak	41	10,980	259	28	11,290	257	--	--	--	e	e	e	--	--	--	--	--	--
2.0%R_o - End	--	--	--	--	--	--	--	--	--	e	e	e	--	--	--	--	--	--
Conoco-Coal Bank																		
0.5%R_o - Start	68	9,710	192	59	9,350	184	24	8,480	173	--	--	--	--	--	--	--	--	--
0.8%R_o - Peak	34	13,800	256	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2.0%R_o - End	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

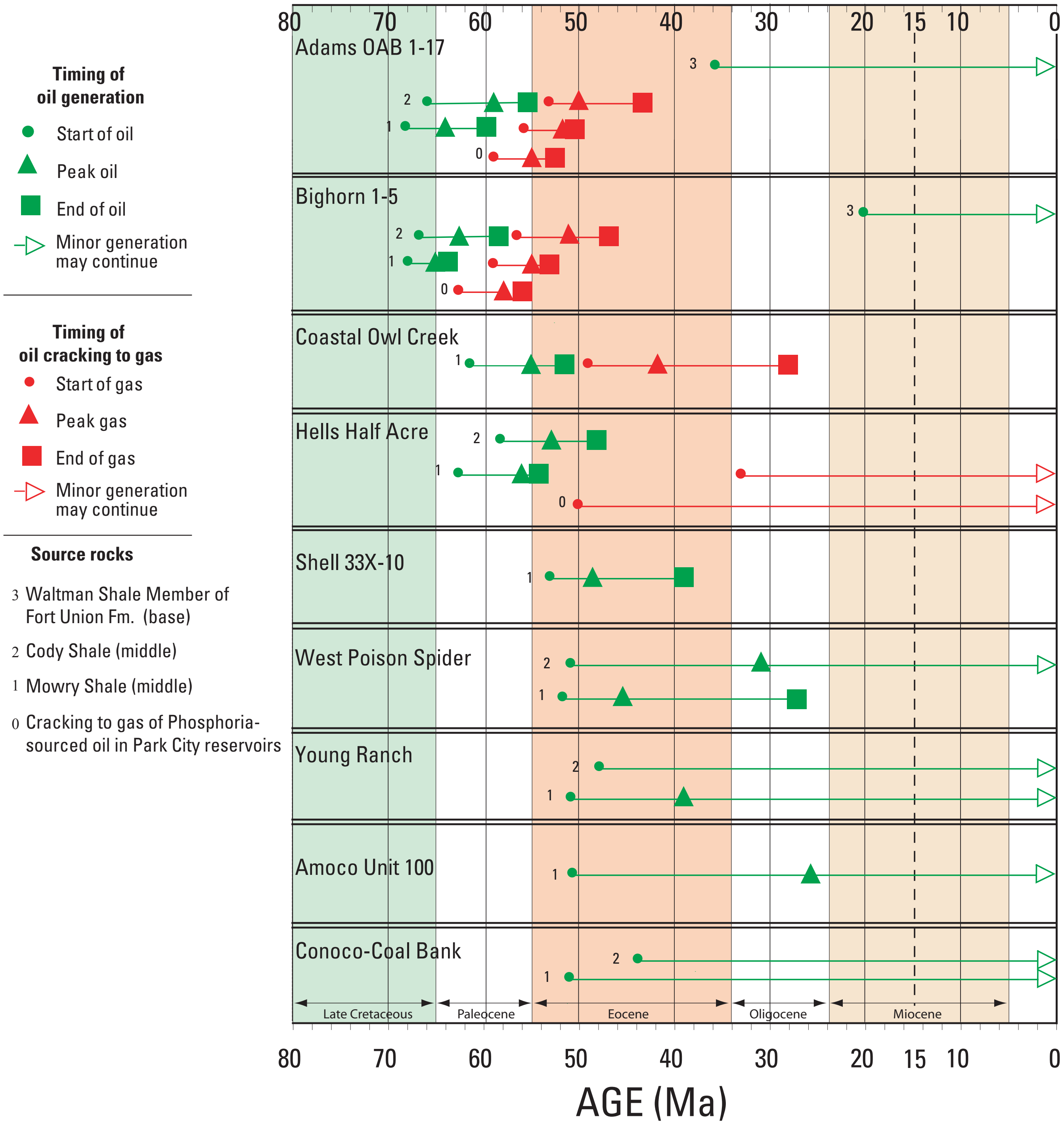

Figure 4. Timing of oil and gas generation from Type-II source rocks by source rock and burial history location. Vertical dashed line at 15 Ma represents beginning of major uplift, erosion, and subsequent cooling. If oil generation or oil cracking to gas has not ended by present day based on the models, the rate of these reactions was significantly reduced with negligible generation during the last 15 m.y.

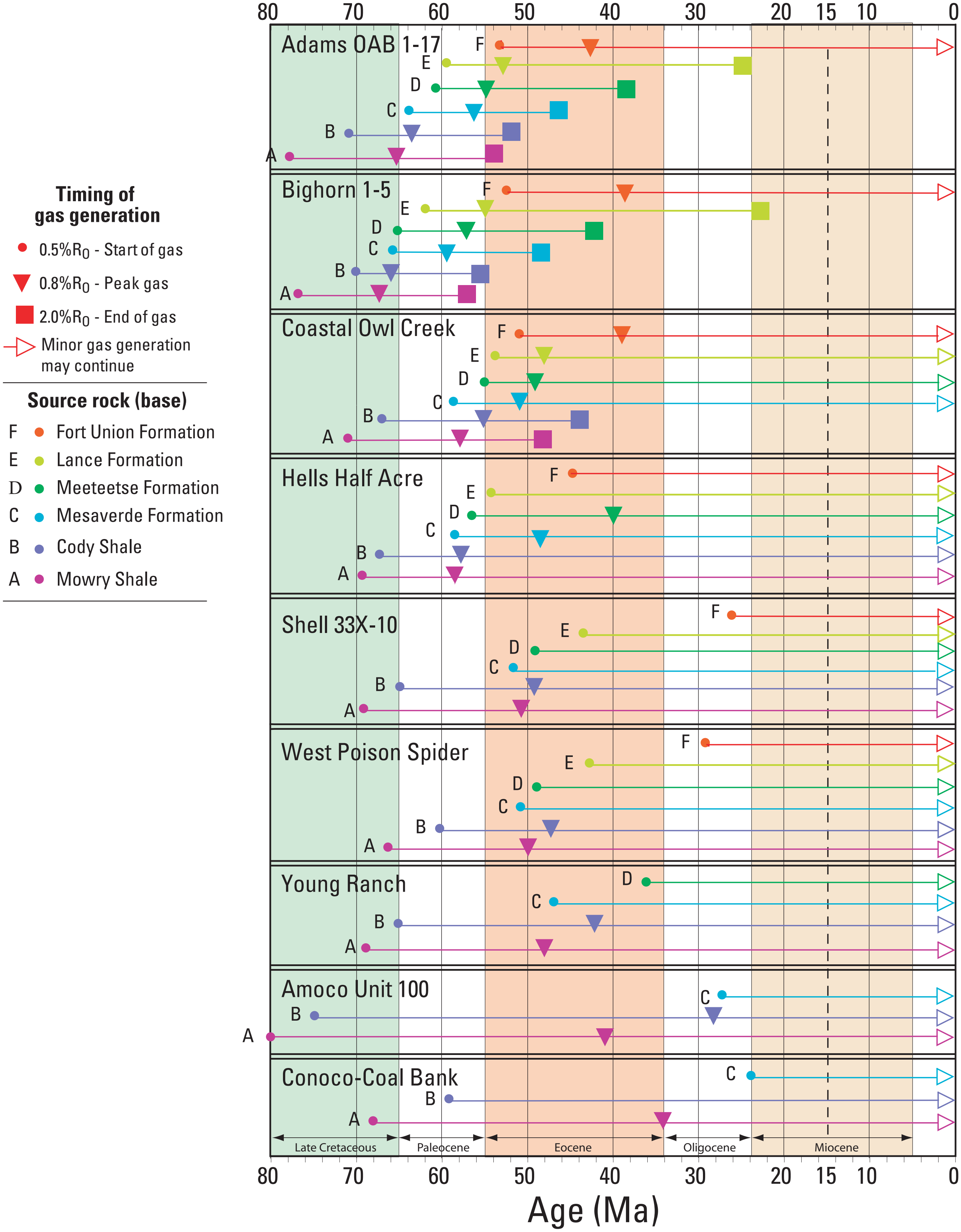

Figure 5. Timing of gas generation from Type-III source rocks by source rock and burial history location. Vertical dashed line at 15 Ma represents beginning of major uplift, erosion, and subsequent cooling. If gas generation has not ended by present day based on the models, the rate of gas generation was significantly reduced with negligible generation during the last 15 m.y.

Formation reach peak generation, which occurred between 44 and 38 Ma.

At locations where gas-prone source rocks were buried to intermediate depths, gas generation from the Mowry and Cody Shales reached peak generation in about the middle Eocene at the Shell 33X-10 and West Poison Spider locations; whereas, at Hells Half Acre the peak generation of these source rocks was earlier, during the late Paleocene, and the Mesaverde and Meeteetse Formations reached the R_o maturity level during the Eocene. Gas generation started in the Mesaverde, Meeteetse, Lance, and Fort Union Formations at virtually the same time at both the Shell 33X-10 and West Poison Spider locations, that is 52, 49, 44, and 29 Ma, respectively.

As expected at locations where gas-prone source rocks were buried to the shallowest depths, the gas generation history involves fewer source rocks that reach the maturity level to generate gas. Also, the time span from onset to peak gas generation for those source rocks that did generate gas is significantly greater. These consequences are based in part on the erosional events that took place along the margins of the basin. Results of modeling indicate that timing of the start of gas generation from the Mowry (80 Ma) and the Cody Shales (75 Ma) at the Amoco Unit 100 location, where these two source rocks were buried to shallower depths than any of the other locations, are more in accordance with those from the deeper basin settings than with the other locations. However, the only measured R_o data available for this well are from the Mesaverde Formation (pl. 1), therefore, the calculated R_o at the stratigraphic level of the Mowry may be suspect and could be lower. The only burial history location where the Cody did not reach peak gas generation is at Conoco-Coal Bank. The onset of gas generation from the Mesaverde source rocks at these locations is later than at the intermediate or deeper basin settings, ranging from 47 to 24 Ma. Source rocks of the Meeteetse, Lance, and Fort Union Formations did not reach the maturity level to initiate gas generation at either Amoco Unit 100 or Conoco-Coal Bank.

Summary

Burial history, thermal maturity, and timing of petroleum generation have been modeled for eight petroleum source rock intervals at nine locations throughout the Wind River Basin Province. The results indicate that burial history, thermal maturity, and timing of petroleum generation vary widely, depending on location within the province and on source rock type and age. This information is important for delineating areas of petroleum generation and for assessing the undiscovered petroleum resources of the province.

Results of modeling for the Phosphoria Formation indicate that, in the deep parts of the province, the generation of gas from the cracking of Phosphoria reached a peak in the late Paleocene/early Eocene (58 to 55 Ma). No gas was generated from cracked Phosphoria oils in the shallower parts of the basin.

The start of oil generation for the Mowry Shale, from a mix of Type-II and Type-III kerogen, occurred from 68 Ma in the deeper parts of the basin and ended at most locations by 27 Ma except at locations along the basin margins where continued generation of oil is a possibility today. In the deepest parts of the province, the generation of gas from the cracking of Mowry oil peaked between 55 and 42 Ma. Gas-prone source rocks of the Mowry may have reached peak generation as early as 67 Ma; gas generation had ended in the deep basin settings by 48 Ma.

Results for the Cody Shale, a mix of Type-II and Type-III kerogen, indicate that the start of oil generation occurred from 67 to 44 Ma, depending on location, and ended at only the deep basin locations and at the Hells Half Acre location by 48 Ma. The cracking of Cody-sourced oil to gas started and ended only at the deep basin locations. It began from about 57 Ma and ended by 43 Ma. Gas-prone source rocks of the Cody may have begun generating gas as early as 75 Ma, reached a peak at most locations except Conoco-Coal Bank, but ended in only the deep parts of the province by 44 Ma.

The Mesaverde, Meeteetse, and the Lance Formations all contain Type-III kerogen. For the Mesaverde Formation, gas generation took place at all locations starting at 66 Ma, reaching peak generation at all the deep-basin locations and Hells Half Acre, but ending only at Adams OAB 1-17 and Bighorn 1-5 by 46 Ma. The earliest age for the onset of gas generation from source rocks of the Meeteetse Formation was at Bighorn 1-5 at 65 Ma, and the latest was at Young Ranch at 36 Ma. The only locations where gas generation ended for Meeteetse source rocks was at Adams OAB 1-17 and Bighorn 1-5, at 38 and 43 Ma, respectively. Results indicate that the start of gas generation from Lance Formation source rocks occurred at all but the shallow locations from 62 to 43 Ma and peaked between 55 and 48 Ma at the deepest locations.

Source rocks of the Fort Union Formation that contain Type-III kerogen began generating gas at all but the shallow locations between 53 and 26 Ma. The onset of oil generation from the Type-II source rocks of the Waltman Shale Member of the Fort Union Formation in the deep basin locations occurred from 36 to 20 Ma.

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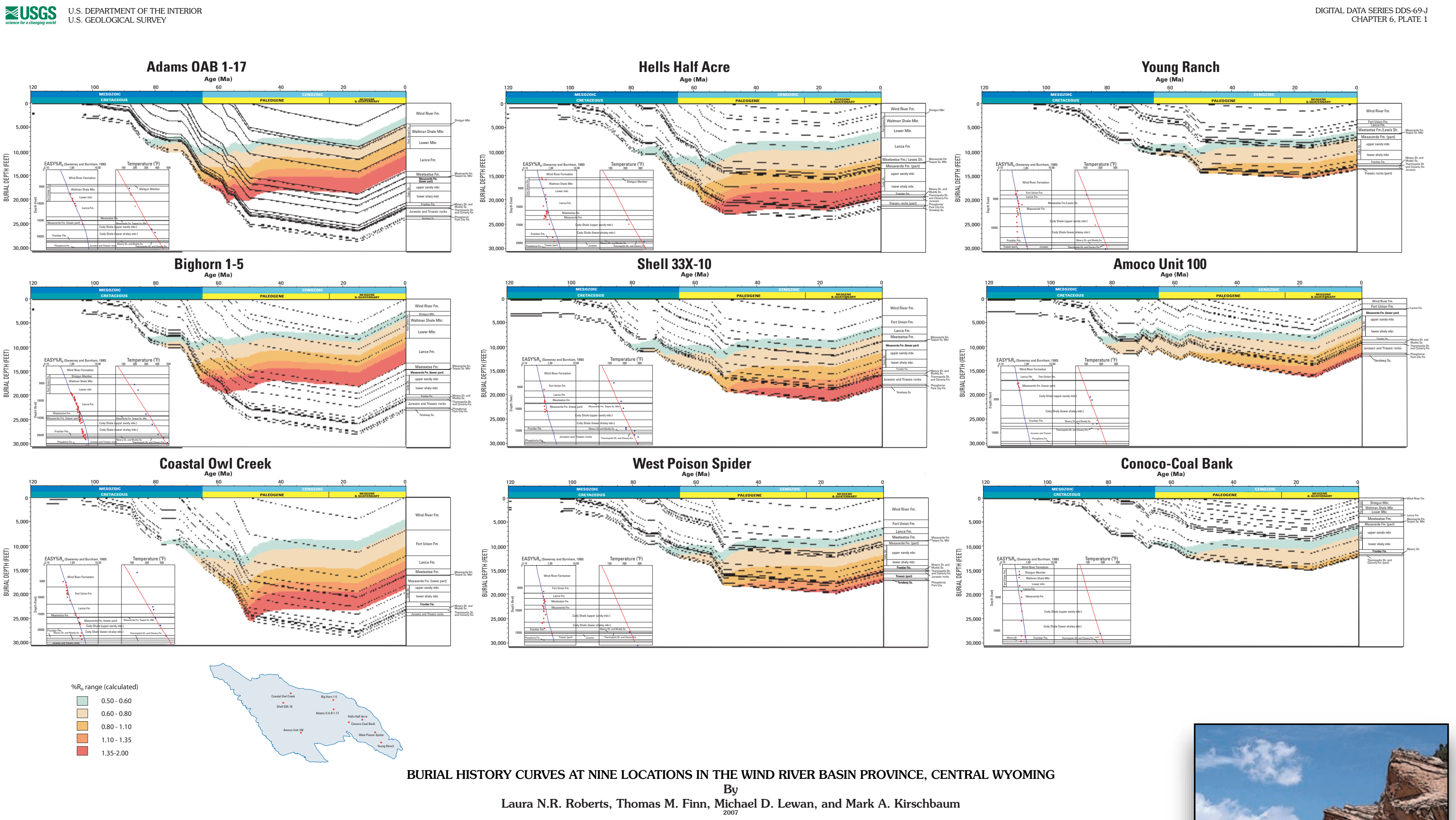
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CHAPTER 6, PLATE 1

BURIAL HISTORY CURVES AT NINE LOCATIONS IN THE WIND RIVER BASIN PROVINCE, CENTRAL WYOMING
By
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Plate 1. Burial history curves at nine locations in the Wind River Basin Province, central Wyoming. Data used to construct the curves are presented in table 2. Ages are given in millions of years before present (Ma, mega annum). Abbreviations: Fm., Formation; Mbr., Member; Ss., Sandstone; Sh., Shale. Calibration of models, using vitrinite reflectance (R_0) and down-hole temperature, is shown with each associated burial history curve. Red dots on the left graph are measured R_0 values. Purple dots on the right graph are down-hole temperatures (corrected, in degrees Fahrenheit); brown dots are temperatures from drill stem tests. Colors on the burial history curves represent calculated R_0 with burial depth and time (see color key). Inset map shows burial history locations in the province. (Click on image to open full size, high resolution image for viewing and printing).

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