Chapter 6

Subsurface Stratigraphic Cross Sections Showing Correlation of Cretaceous and Lower Tertiary Rocks in the Bighorn Basin, Wyoming and Montana

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Chapter 6 of
Petroleum Systems and Geologic Assessment of Oil and Gas in the Bighorn Basin Province, Wyoming and Montana
By U.S. Geological Survey Bighorn Basin Province Assessment Team

U.S. Geological Survey Digital Data Series DDS–69–V

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Suggested citation:
Finn, T.M., 2010, Subsurface stratigraphic cross sections showing correlation of Cretaceous and lower Tertiary rocks in the Bighorn Basin, Wyoming and Montana: U.S. Geological Survey Digital Data Series DDS–69–V, 14 p.

ISBN: 1–4113–2667–5

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Subsurface Stratigraphic Cross Sections Showing Correlation of Cretaceous and Lower Tertiary Rocks in the Bighorn Basin, Wyoming and Montana

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Introduction

The stratigraphic cross sections presented in this report were constructed as part of a project conducted by the U.S. Geological Survey (USGS) to characterize and evaluate the undiscovered oil and gas resources of the Bighorn Basin (BHB) in north-central Wyoming and south-central Montana (fig. 1). The primary purpose of the cross sections is to show the stratigraphic framework and facies relations of Cretaceous and lower Tertiary rocks in this intermontane sedimentary and structural basin, which formed in the Rocky Mountain foreland during the Laramide orogeny (Late Cretaceous through early Eocene time). The BHB is nearly 180 mi long, 100 mi wide, and encompasses about 10,400 mi^2. The basin is structurally bounded on the northeast by the Pryor Mountains, on the east by the Bighorn Mountains, and on the south by the Owl Creek Mountains. The northern margin includes a zone of faulting and folding referred to as the Nye-Bowler lineament (Wilson, 1936). The northwestern and western margins are formed by the Beartooth Mountains and Absaroka Range, respectively (fig. 2).

The cross sections were constructed from borehole geophysical logs of 62 wells drilled for oil and gas exploration and production. The stratigraphic interval extends from the base of the Cretaceous into the lower Eocene (fig. 3). The datum for all sections is the top of the Teapot Sandstone Member of the Mesaverde Formation or equivalent strata. This datum was selected because it is easily identified on most well logs and is present throughout the basin.

In most wells, a gamma-ray or spontaneous-potential log was used in combination with a resistivity or conductivity log to identify and correlate units. The gamma-ray and spontaneous-potential logs are typically used to differentiate between sandstone and shale; however, in the Bighorn Basin the spontaneous-potential response is typically subdued in the sandstone intervals showing little curve deflection. In areas of greater drilling density, logs from wells located between control wells on the cross sections were used to aid in making correlations. Coal beds were identified from gamma-ray logs in combination with density and (or) sonic logs where available, and are shown as a long, heavy black bar on the depth track of each log. The heavy black bars representing coal beds only show the position of the coal bed(s) and are not proportional to true thickness. In addition to the stratigraphic information, oil and gas shows, oil- and gas-producing intervals, perforated intervals, and drillstem test intervals are also shown on the cross sections. This information was compiled from IHS Energy Group (2008) well data, the Wyoming Oil and Gas Conservation Commission Web site (2008), and drilling reports in the USGS well log files.

The locations of the six stratigraphic cross sections are as follows (fig. 4):

- Section *A–A′* extends for about 26 mi along the Nye-Bowler lineament (pl. 1).
- Section *B–B′* extends for 30 mi southeast from the Beartooth Mountain front to the southwest flank of Whistle Creek anticline (fig. 2) on the northeast margin of the basin (pl. 2).
- Section *C–C′* extends nearly east-west about 40 mi from Heart Mountain gas field to Emblem gas field (fig.2) (pl. 3).
- Section *D–D′* extends from near the southern end of the Oregon Basin anticline for about 50 mi to near the Greybull oil field (fig. 2) on the eastern margin of the basin (pl. 4).
- Section *E–E′* extends from near the southeast end of Grass Creek anticline northeast about 40 mi to near the southern end of the Five Mile trend (fig.2) (pl. 5).
- Section *F–F′* extends approximately 130 mi southeast from the Nye-Bowler lineament, through the Clark's Fork sub-basin and along the Five Mile trend to the Sand Creek anticline (fig. 2) near the southeastern margin of the basin (pl. 6, 2 sheets).

For sections *A–A′* to *F–F′* (pls. 1–6) the horizontal scale is about 1 in. = 1.25 mi and the vertical scale is about 1 in. = 500 ft.

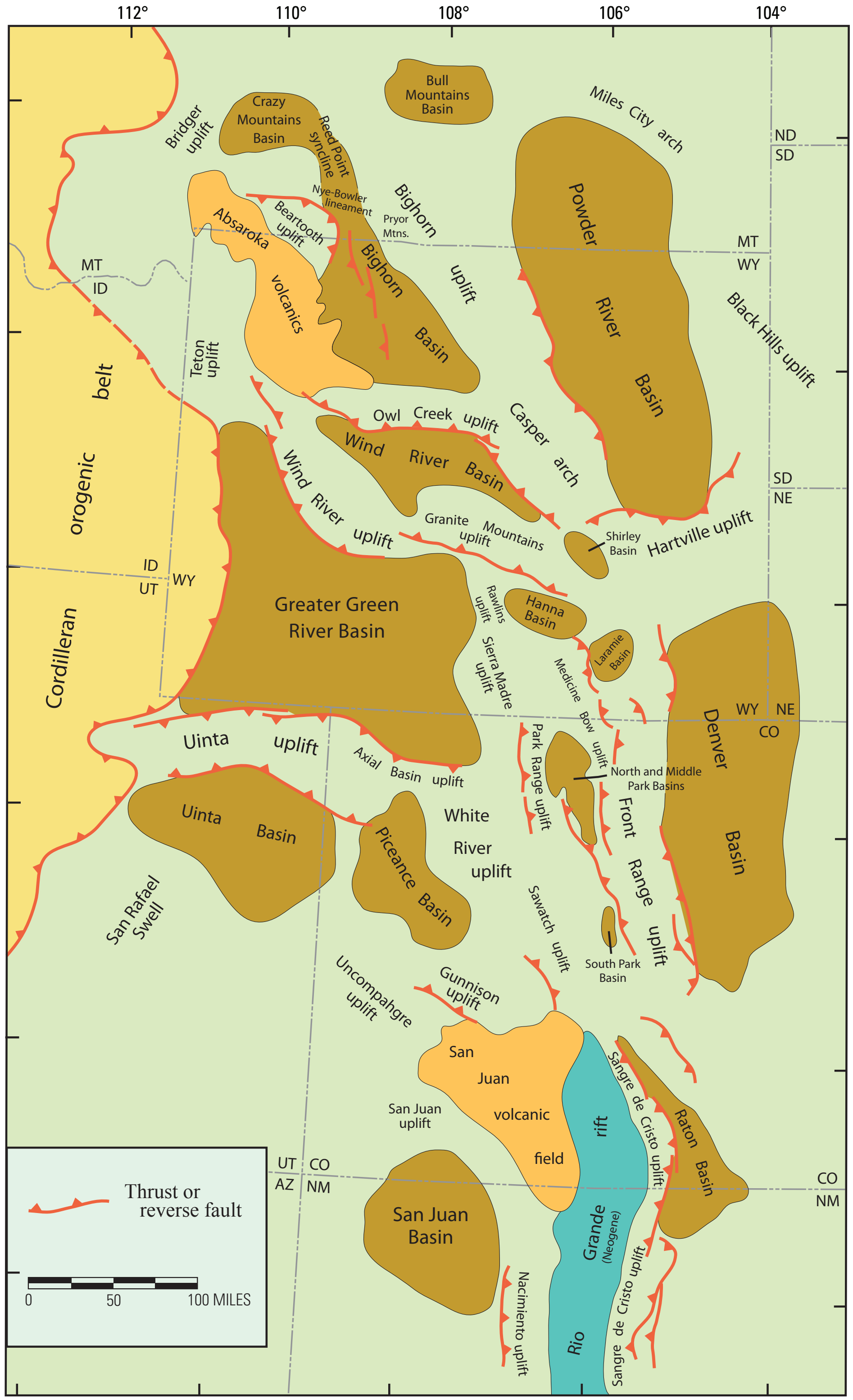

Figure 1. Map of the Rocky Mountain region extending from southern Montana to northern New Mexico showing the locations of Laramide sedimentary and structural basins (in brown) and intervening uplifts. Modified from Dickinson and others (1988).

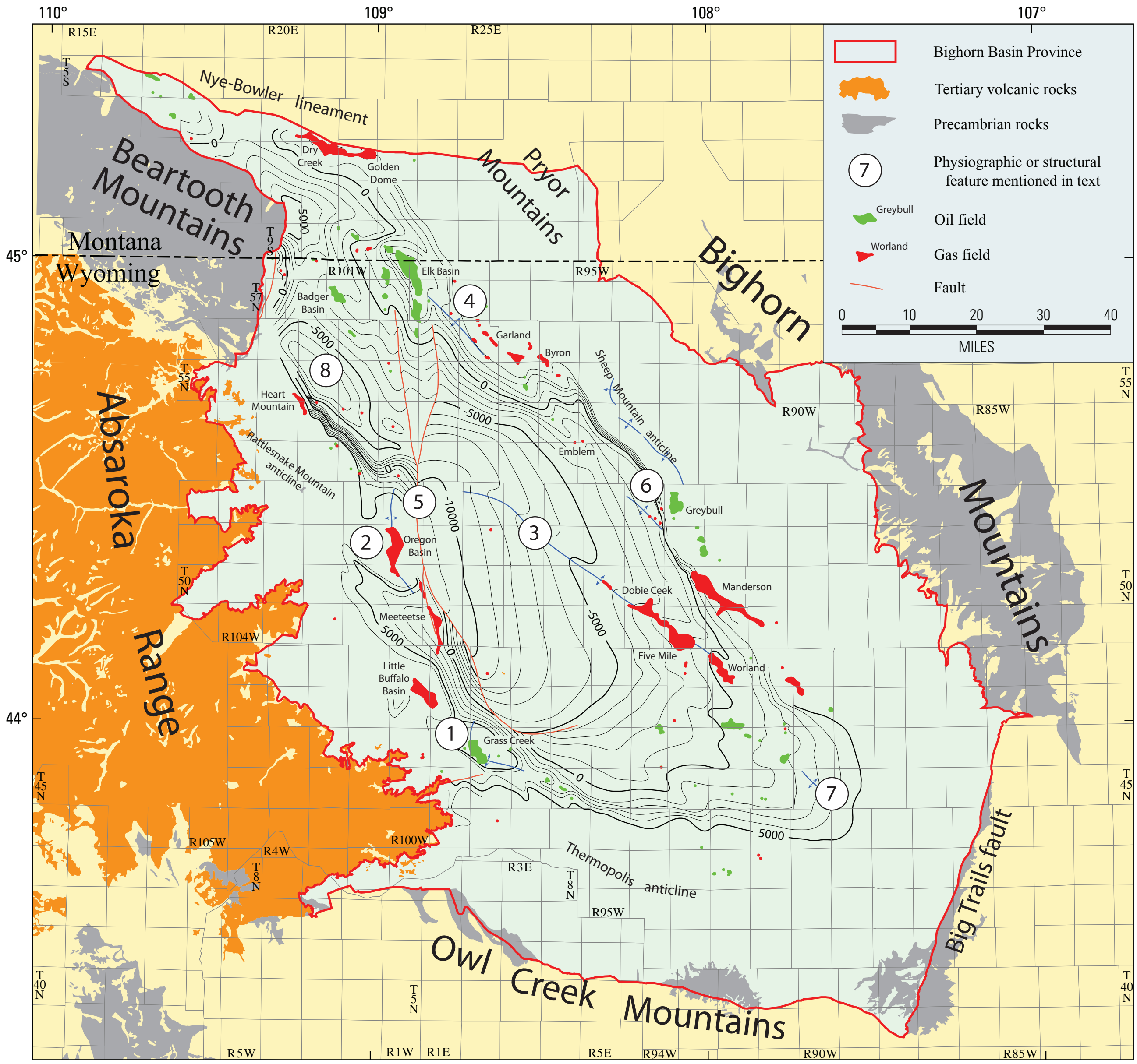

Figure 2. Index map of the Bighorn Basin showing major structural elements, and oil and gas fields that produce from Cretaceous and Tertiary reservoirs. Physiographic features referred to in the text: (1) Grass Creek anticline, (2) Oregon Basin, (3) Five Mile trend, (4) Whistle Creek anticline, (5) Oregon Basin fault, (6) Greybull, (7) Sand Creek anticline, and (8) Clark's Fork sub-basin. Structure contours drawn on top of the Teapot Sandstone Member of the Mesaverde Formation. Contour interval = 1,000 ft. Modified from Johnson and Finn (1998), and Ver Ploeg (1985).

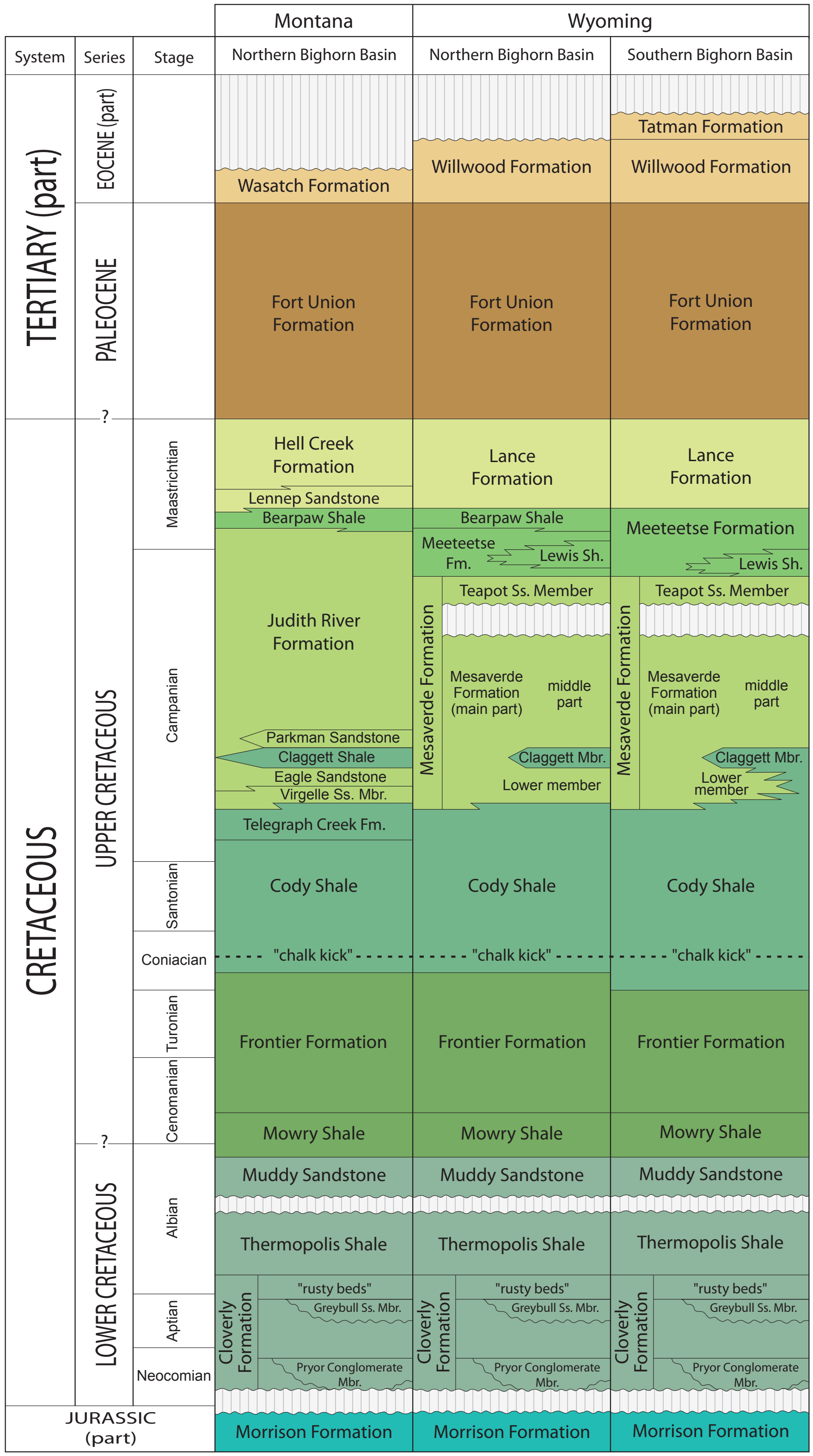

Figure 3. Stratigraphic chart of Cretaceous and lower Tertiary rocks in the Bighorn Basin, Wyoming and Montana. Modified from Keefer and others (1998), and Johnson and Finn (2004).

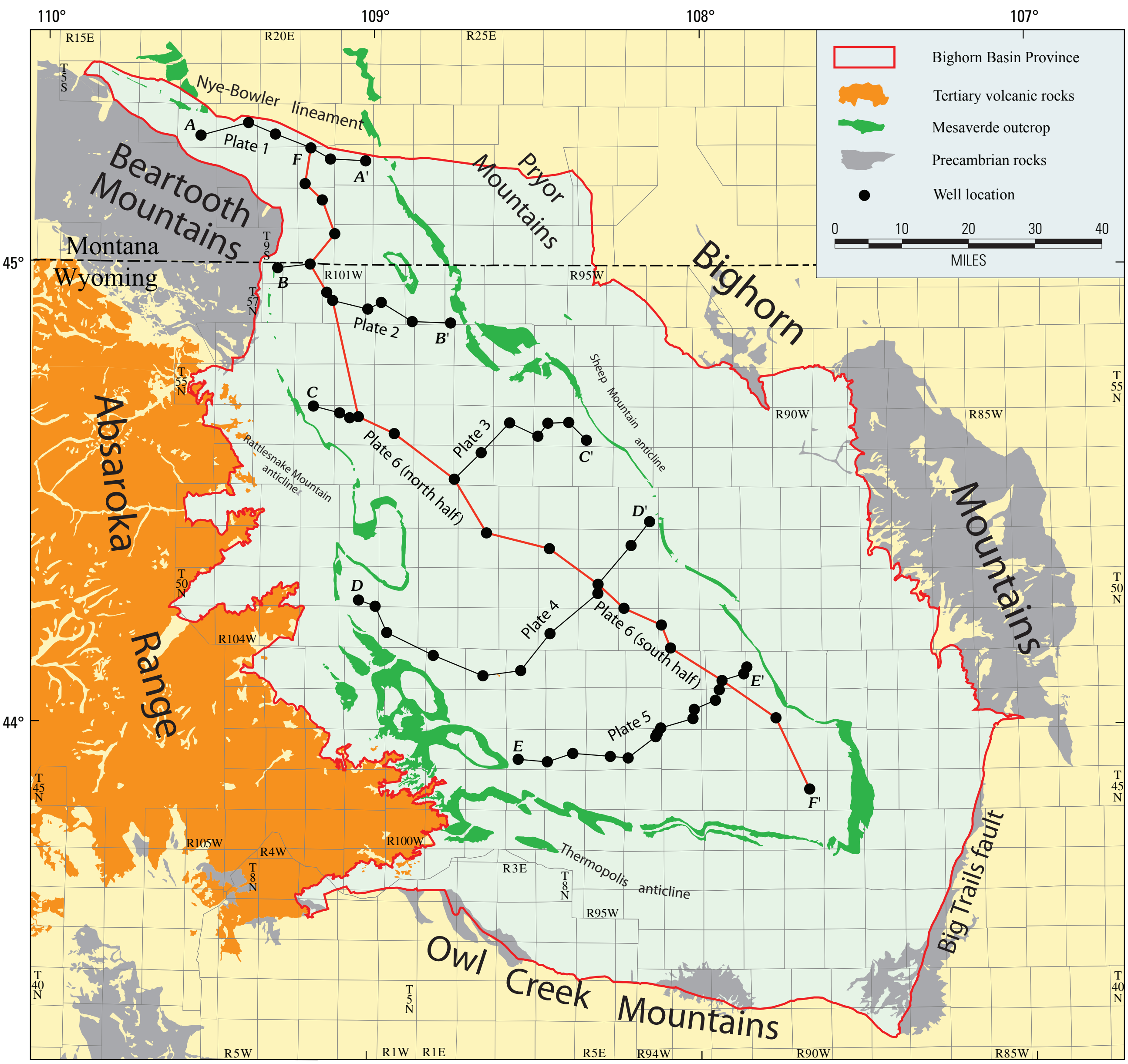

Figure 4. Index map of the Bighorn Basin showing the network of cross sections presented in this report. Section *A–A′*, plate 1; section *B–B′*, plate 2; section *C–C′*, plate 3; section *D–D′*, plate 4; section *E–E′*, plate 5; and section *F–F′*, plate 6.

Stratigraphy

The stratigraphic nomenclature used on these cross sections shows the change in nomenclature from the Wyoming part of the basin to the Montana part of the basin and is shown in figures 3 and 5. The Wyoming nomenclature is modified from Keefer and others (1998), the Montana nomenclature is modified from Johnson and Finn (2004) for the area in the vicinity of the Nye-Bowler lineament.

Lower Cretaceous Rocks

Cloverly Formation

The basal Cretaceous rocks in the Bighorn Basin are represented by the Cloverly Formation consisting of 210 to 385 ft of interbedded sandstone, variegated shale, claystone, and minor amounts of conglomerate (Keefer and others, 1998). The basal unit, where present, is referred to as the Pryor Conglomerate Member, has an irregular distribution, and is not distinguished separately from the overlying strata on the cross sections presented here. The Pryor is comprised of sandstone, conglomeratic sandstone, and black and gray chert pebble conglomerate. The middle part of the formation, referred to as the Little Sheep Mudstone and Himes Members by Moberly (1960) is comprised of variegated shale, and claystone, interbedded with thin sandstone beds that accumulated in floodplain, fluvial, and lacustrine environments. These units are overlain by very fine to medium-grained sandstone referred to as the Greybull Sandstone Member (Hintze, 1914; Mills, 1956; Keefer and others, 1998). The thickness of the Greybull is highly variable, ranging from 5 to 70 ft (Keefer and others, 1998), and is absent locally. The Greybull is latest Aptian to early Albian in age (Kvale and Vondra, 1993; May and others, 1995), and is interpreted to be a fluvial/estuarine channel deposit that accumulated in paleovalleys formed on a lowstand surface that developed on the nonmarine part of the Cloverly Formation during the initial Cretaceous marine transgression (Kvale and Vondra, 1993; Mitchell, 1997; Furer and others, 1997). The uppermost part of the Cloverly Formation, referred to as the “rusty beds” (Love and others, 1945), consists of finely laminated siltstone and shale with minor thin sandstone beds that accumulated in tidal flats during the continued transgression of the Cretaceous sea during Albian time (Moberly, 1960). The Greybull Sandstone Member and “rusty beds” have a combined thickness of about 100 ft throughout most of the basin but range up to around 160 ft. Based on fission track dating, the age of the Cloverly Formation is Early Cretaceous (Neocomian to Albian) (Heady, 1992; May and others, 1995; Zaleha, 2006).

Thermopolis Shale

The Thermopolis Shale (known as the Skull Creek Shale in some other Rocky Mountain basins), as used in this report, refers to the lower shale tongue of the Thermopolis Shale of Lupton (1916), Mills (1956), and Haun and Barlow (1962) underlying the Muddy Sandstone, but excludes the “rusty beds” that are included with the underlying Cloverly Formation. The Thermopolis consists of 125 to 230 ft of marine shales and siltstones and represents continued deposition during sea-level rise in Albian (Early Cretaceous) time (Burtner and Warner, 1984; Hagen and Surdam, 1984). The Thermopolis consists of dark-gray to black shale, interbedded with thin layers of siltstone, sandy claystone, and bentonite. The basal contact is gradational with the underlying “rusty beds;” the upper contact may be sharp and unconformable or gradational with the overlying Muddy Sandstone.

Muddy Sandstone

The Muddy Sandstone is composed of very fine to medium-grained sandstone interbedded with minor amounts of shale, siltstone, carbonaceous shale, and coal of latest Albian (Early Cretaceous) age (Paull, 1962). The formation was deposited in fluvial, marginal marine, and estuarine environments and ranges in thickness from 7 to 125 ft (Finn and others, Chapter 3, this CD–ROM). The thickest accumulations are associated with an incised valley-fill complex that developed on the exposed surface of the Thermopolis Shale during sea-level lowstand (Dolson and others, 1991).

Upper Cretaceous Rocks

Mowry Shale

According to Keefer and others (1998), the Mowry Shale in the Bighorn Basin consists of two distinct units (pls. 1–6). The lower part is about 160 to 400 ft of soft fissile clay-rich shale similar to the Thermopolis Shale and is referred to as the upper Thermopolis Shale by several authors including Mills (1956), and Haun and Barlow (1962), and as the Shell Creek Shale by Eicher (1962). The upper part is about 240 to 400 ft of hard brittle siliceous shale. Numerous gray to tan bentonite beds are common throughout the unit and range in thickness from a fraction of an inch to about 7 ft (Byers and Larson, 1979). The siliceous shales are dark-brown to black, organic-rich, and contain an abundance of fish scales (Burtner and Warner, 1984). Locally, thin fine-grained sandstones occur in the middle to upper part of the siliceous part of the Mowry. These units, referred to informally as the “Kimball” and “Octh Louie” sands have produced oil from fields on the

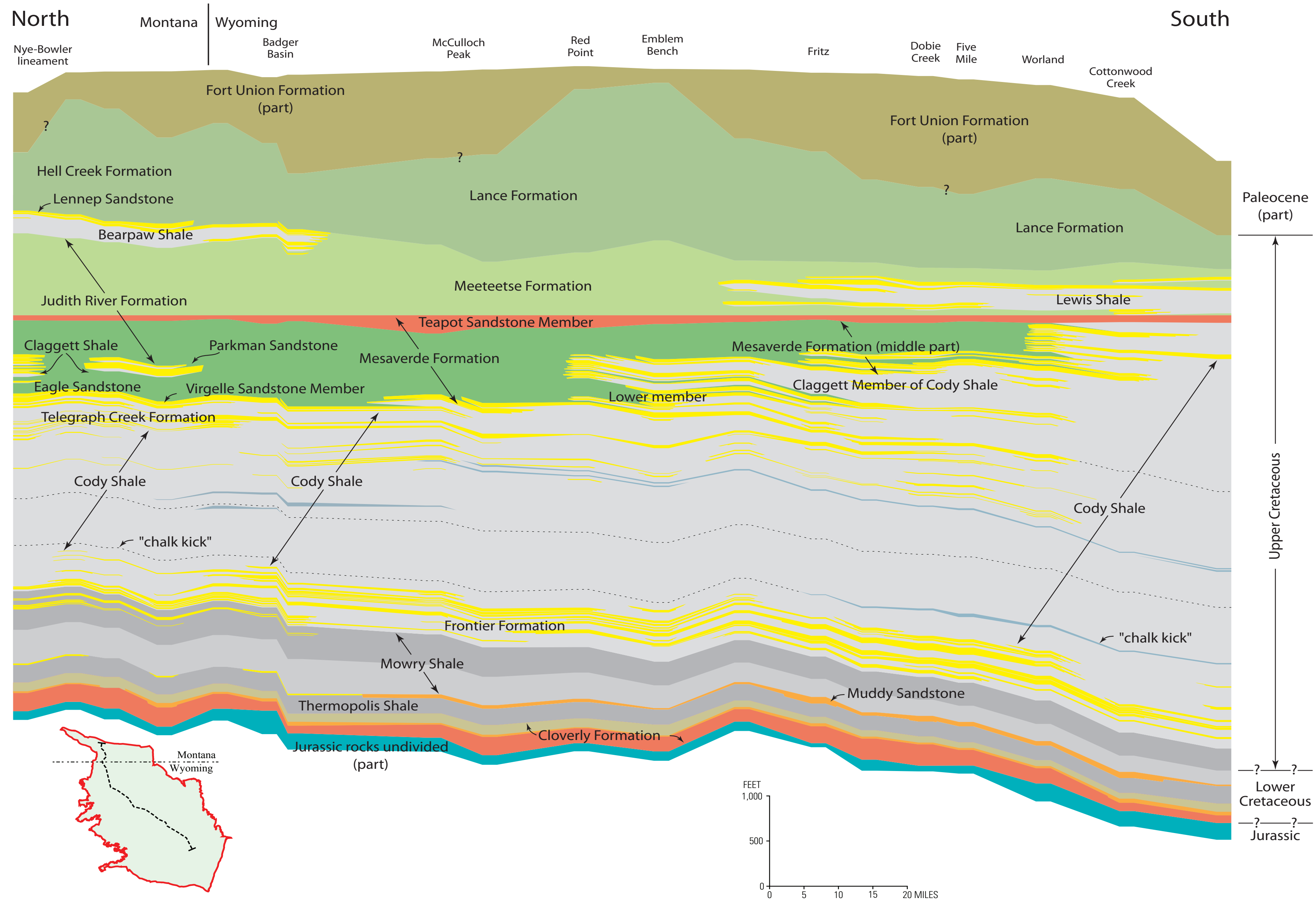

Figure 5. Regional northwest-southeast stratigraphic cross section of Cretaceous and Paleocene (part) rocks, Bighorn Basin, Wyoming and Montana. Colors represent different lithologies and environments of deposition: red, fluvial sandstone and conglomerate; yellow, marine and marginal marine sandstone and siltstone; orange, fluvial and estuarine sandstone; tan, tidal sandstone, siltstone, and shale; various shades of gray are marine shales; various shades of green are coastal plain and flood plain sandstones, shales, and coal; brown, sandstone, siltstone, shale, coal and conglomerate of continental origin.

east side of the basin (Pierce, 1948; Mills, 1956; Cardinal and others, 1989). Rubey (1931) defined the top of the Mowry Shale as the Clay Spur Bentonite Bed in the northwestern part of the Powder River Basin. However, in the Bighorn Basin, no definitive correlation can be made to the Clay Spur but, based on correlations with well logs in the northern Wind River Basin and the Powder River Basin, the top of the Mowry was placed at a distinctive high-gamma marker that is believed to be equivalent to the Clay Spur. The upper part of the Mowry Shale was deposited in marine environments ranging from prodelta deposits along the western margin of the seaway to fine-grained deposits that accumulated in an oxygen-starved offshore marine basin (Davis and others, 1989). The combined thickness for the lower and upper parts of the Mowry range from about 400 ft in the southeastern part of the basin to more than 800 ft near the Beartooth uplift (Finn and others, Chapter 3, this CD–ROM). Paleontologic evidence and radiometric dating indicate that the upper siliceous part of the Mowry is largely early Cenomanian (Late Cretaceous) in age (Cobban and Kennedy, 1989; Obradovich and others, 1996); however, radiometric dates for bentonite beds in the basal Mowry (Shell Creek equivalent) indicate an Albian (Early Cretaceous) age (Obradovich and others, 1996).

Frontier Formation

The Frontier Formation consists of sandstone, siltstone, shale, and bentonite that accumulated in a marine or marginal marine setting. In the western and northwestern parts of the basin, the Frontier also includes some nonmarine strata including minor amounts of carbonaceous shale and coal (Siemers, 1975; Merewether and others, 1975). The sandstones are generally believed to be deltaic or shoreface in origin (Hunter, 1952; Van Houten, 1962; Goodell, 1962; Siemers, 1975; Merewether and others, 1975; Merewether and others, 1998). Many of the sandstones are continuous for tens of miles, but are truncated due to erosion, mainly by marine flooding surfaces and appear to pinch out in all directions into marine shale (M.A. Kirschbaum, USGS, oral commun., 2008). The Frontier is early Cenomanian to early Coniacian (Late Cretaceous) in age with a major unconformity in the upper part of the unit (Merewether and others, 1975). The unconformity is based on the study of ammonite zones in surface sections and was not identified in the subsurface in this study.

Cody Shale

The Cody Shale in the Bighorn Basin consists of marine shale, sandstone, and siltstone deposited during a major marine transgressive-regressive cycle that extended from Coniacian to Campanian (Late Cretaceous) time (Kauffman, 1977). The Cody ranges in thickness from about 1,700 ft in the northern part of the basin to nearly 3,800 ft in the southeastern part of the basin (Finn and others, Chapter 3, this CD-ROM). The lower and upper contacts of the Cody are conformable and interfinger extensively with the underlying Frontier and overlying Mesaverde Formations. The Cody Shale consists of two main units, the lower main body and the upper Claggett Member (Keefer and others, 1998).

The main part interfingers with and extends from the top of the Frontier Formation to the base of the Mesaverde Formation and is composed of marine shale with increasing amounts of interbedded sandstone in the upper 500 to 1,200 ft (pls. 1–6). The upper sandy part in the Bighorn Basin is similar to but is somewhat less sandy than the upper sandy member of the Cody Shale in the Wind River Basin (see Finn, 2007; and Johnson, 2007, for correlation and descriptions of the Cody Shale in the Wind River Basin). Many of the sandstones in the upper part of the Cody are blanket-like, can be traced over many miles, and appear to pinch out into marine shale in all directions. The uppermost several hundred feet of the sandy part of the Cody is commonly referred to as the Telegraph Creek Formation in Montana (figs. 3, 5, and pl. 1). The Cody is poorly exposed in the Bighorn Basin, however limited outcrop descriptions by Johnson and others (1998) of uppermost Cody Shale indicate that the sandstones are very fine to medium-grained, exhibit a variety of bedding features including hummocky cross-bedding that indicates a nearshore marine origin, and in many cases are laterally persistent.

According to Keefer and others (1998) the Claggett Member (known as the Claggett Shale in Montana) is a westward thinning tongue of marine shale and fine-grained sandstone that is split from the main part of the Cody Shale by the lower member of the Mesaverde Formation (Eagle Sandstone in Montana) (figs. 3, 5). The Claggett Member extends across the eastern and central parts of the basin, and thickens eastward from zero to nearly 500 ft thick at its eastern limit where it merges with the main part of the Cody Shale (fig. 5) (Finn, Chapter 3, this CD–ROM).

Mesaverde Formation

The Mesaverde Formation consists of basal regressive marginal marine sandstone, overlain by interbedded nonmarine sandstone, siltstone, shale, carbonaceous shale, and coal deposited in coastal plain and marginal marine environments as the western shoreline of the Cretaceous sea retreated eastward across the Bighorn Basin (Severn, 1961; Mackenzie, 1975; Klug, 1993; Johnson and others, 1998). The Mesaverde is Campanian (Late Cretaceous) in age and can be subdivided into a lower member, a middle or main part, and the Teapot Sandstone Member (figs. 3, 5) (Keefer and others, 1998; Johnson and others, 1998).

The lower member of the Mesaverde Formation, referred to as the Eagle Sandstone in Montana by Johnson and Finn (2004), is an eastward thinning wedge of marginal marine and nonmarine strata. It conformably overlies and interfingers with the upper sandy part of the Cody Shale and is separated from the middle member or main body of the Mesaverde by the

Claggett Member of the Cody Shale (fig. 5). The lower member is present in the central and eastern parts of the basin, and it consists of very fine to medium-grained sandstone, siltstone, shale, carbonaceous shale, and coal deposited as an eastward-prograding deltaic complex (Mackenzie, 1975; Johnson and others, 1998). The basal beds of the lower member consist of very fine to fine-grained sandstone that were deposited in a marginal marine setting and have been referred to as the Virgelle Sandstone Member in Montana by Johnson and Finn (2004) or as the Virgelle sandstones by Severn (1961). The basal sandstones grade upward into interbedded shale, carbonaceous shale, coal, and sandstone that were deposited in a delta plain setting (Mackenzie, 1975). The lower member is thickest at its western limit where it is generally around 400 to 500 ft thick but locally exceeds 800 feet (Finn and others, Chapter 3, this CD–ROM). It merges with the main part of the Mesaverde Formation to the west, and thins to zero to the east where it grades into the upper part of the Cody Shale (fig. 5). West of the Claggett pinchout, the lower and middle Mesaverde members merge as one unit simply referred to as Mesaverde Formation.

Where the Claggett is present, that part of the Mesaverde Formation overlying it is referred to as the main body of the Mesaverde Formation by Keefer and others (1998), whereas Johnson and others (1998) referred to it as the middle part. According to Johnson and Finn (2004) it is, in part, equivalent to the Parkman Sandstone and the lower part of the Judith River Formation in Montana (figs. 3, 5). It consists of interbedded sandstone, siltstone, shale, carbonaceous shale, and coal deposited in marginal marine, coastal plain, and fluvial environments (Severn, 1961; Mackenzie, 1975; Johnson and others, 1998). The basal strata of the middle member are very fine to fine-grained and have been interpreted as progradational units that accumulated as shoreface sandstones as the western shoreline of the seaway retreated eastward across the basin (Keefer and others, 1998; Johnson and others, 1998). The sandstones in the nonmarine part of the Mesaverde are very fine to medium-grained, lenticular, and originated as stream channel and crevasse splay deposits (Johnson and others, 1998). The Mesaverde generally thins from west to east where a combined thickness of the main part of the Mesaverde and Teapot Sandstone Member, excluding the lower member or Eagle Sandstone, ranges from greater than 1,200 ft in the southwestern part of the basin to less than 500 ft along the eastern margin of the basin (Finn and others, Chapter 3, this CD–ROM).

The Teapot Sandstone Member, the uppermost member of the Mesaverde Formation, consists of light-gray to white, fine- to coarse-grained sandstone, and minor amounts of gray mudstone (Johnson and others, 1998). Based on outcrop studies by Mackenzie (1975) and Johnson and others (1998), it is considered to be fluvial in origin throughout most of the basin; however, in the eastern part of the basin, Johnson and others (1998) described hummocky cross-bedding in the lower part of the unit indicating that it is in part marginal marine in origin. The thickness of the Teapot is highly variable and ranges from a few tens of feet to more than 300 ft (Keefer and others, 1998; Johnson and others, 1998).

Meeteetse Formation, and Lewis and Bearpaw Shales

The Meeteetse Formation, and Lewis and Bearpaw Shales are intertonguing marine, marginal marine, and nonmarine strata of latest Campanian and early Maastrichtian (Late Cretaceous) age (Gill and Cobban, 1966; Merewether, 1996) (figs. 3, 5). Johnson and Finn (2004) considered the Meeteetse/Lewis/Bearpaw interval in the Bighorn Basin to be equivalent to the upper part of the Judith River Formation and overlying Bearpaw Shale in Montana (figs. 3, 5). The marine strata in this interval are included with the Lewis and Bearpaw Shales, and the marginal marine and nonmarine strata with the Meeteetse Formation. The maximum combined thickness for the Meeteetse, Lewis, and Bearpaw interval ranges from more than 1,100 ft in the northern and southwestern parts of the basin to about 500 ft in the southeastern part (Finn and others, Chapter 3, this CD–ROM).

The Meeteetse Formation is comprised of alternating thin beds of very fine to medium-grained sandstone, siltstone, shale, carbonaceous shale, and coal that accumulated in poorly drained coastal environments along the western shore of the Cretaceous seaway (Keefer and others, 1998). The Lewis Shale is a westward thinning tongue of marine shale and sandy shale interbedded with thin sandstone beds. It is present in the eastern part of the basin, ranges in thickness from more than 300 ft on the east side of the basin, and thins westward to zero where it grades into the Meeteetse Formation (Keefer and others, 1998). In the northern part of the basin the Bearpaw Shale overlies, and in part intertongues with, the Meeteetse Formation and represents the last stages of marine sedimentation in the Bighorn Basin. Where present, the Bearpaw is about 80 to 200 ft thick, and according to Johnson and others (1998) is comprised of fissile gray shale and thin beds of very fine grained sandstone.

Lance Formation

The Lance Formation, referred to as the Hell Creek Formation in Montana by Johnson and Finn (2004), consists of interbedded sandstone, shale, and some conglomerate; it represents the uppermost Cretaceous rocks in the Bighorn Basin. Minor amounts of coal are present locally, which Johnson (1998) concluded to be of minor importance. Sandstone is the predominant lithology throughout much of the basin with sandstone generally occurring in the lower part of the formation, whereas the upper part is interbedded sandstone and shale (Keefer and others, 1998; Johnson and others, 1998).

The sandstones are fine- to coarse-grained, locally conglomeratic, and were deposited in fluvial systems (Johnson and others, 1998). In the northern part of the basin, a sandstone interval in the basal part of the Lance, overlying the Bearpaw Shale, was interpreted as a shoreface deposit by Keefer and others (1998), and was believed to correlate with the Fox Hills Sandstone. Johnson and Finn (2004) referred to this marginal marine interval as the Lennep Sandstone in Montana (figs. 3, 5). The Lance is generally considered to be Maastrichtian (Late Cretaceous) in age; however, palynogical age determinations by Nichols (1998) indicate that locally it is, in part, earliest Paleocene in age. The onset of the Laramide orogeny and initial partitioning of the Rocky Mountain foreland basin into the smaller Laramide basins is indicated by the Lance thickness patterns in the Bighorn Basin, which range from less than 500 ft in the southeastern part of the basin to greater than 1,500 to 1,800 ft near the basin trough adjacent to and east of the Oregon Basin fault (Finn and others, Chapter 3, this CD–ROM).

Paleocene Rocks

Fort Union Formation

The Fort Union Formation, referred to as the Polecat Bench Formation by Bown (1975) is comprised of sandstone, siltstone, conglomeratic sandstone, conglomerate, carbonaceous shale, and coal (Bown, 1975; Johnson, 1998; Keefer and others, 1998; Roberts, 1998). The conglomerates accumulated mainly as alluvial fans along the northwestern margin of the basin (Hickey, 1980; Johnson and Middleton, 1990), and as a braidplain system that flowed northeast into the basin from surrounding highlands in the southwestern part of the basin (Kraus, 1985; Roberts and Stanton, 1994). The sandstones are very fine to coarse-grained and represent a variety of fluvial deposits, whereas the finer grained and carbonaceous deposits represent lacustrine and swamp deposits (Hickey, 1980; Yuretich and others, 1984; Roberts and Stanton, 1994; Hickey and Yuretich, 1997; Roberts, 1998). The thickness of the Fort Union indicates continued subsidence of the basin trough during the Laramide orogeny and reflects the present-day structural configuration of the basin. The Fort Union is generally less than 1,000 ft thick around the margins of the basin, thinning locally to about 300 ft in the north, and thickening to more than 7,500 feet in the structurally deepest central part of the basin. In outcrops around the margins of the basin, the Fort Union unconformably overlies the Lance and locally other older Upper Cretaceous rocks (Bown, 1975; Love and Christiansen, 1985; Keefer and others, 1998; Roberts, 1998). The Fort Union is Paleocene in age based on fossil pollen dating by Nichols (1998) and Roberts (1998), and by mammalian faunas reported by Gingerich (1983).

Lower Eocene Rocks

Willwood and Tatman Formations, undivided

Strata that represent the lowermost Eocene in the Bighorn Basin are assigned to the Willwood Formation and consist of variegated shales, sandstones, and conglomerate (Van Houten, 1944; Bown, 1980). Bown (1980) reported a maximum thickness of nearly 2,400 ft from exposures in the southern part of the basin. The lower Eocene Tatman Formation overlies and in part interfingers with the Willwood and is present only as isolated erosional remnants in the south-central part of the basin (Love and Christiansen, 1985; Bown, 1980). The Tatman ranges up to nearly 900 ft thick, and is composed of fine-grained sandstone and carbonaceous shale that accumulated in lakes and swamps (Van Houten, 1944). Keefer and others (1998) reported a combined thickness for the Willwood and Tatman Formations of up to about 5,000 ft in the subsurface along the deep axis of the basin. The combined thickness of the Fort Union and lower Eocene rocks ranges from less than 1,000 ft around the margins of the basin to greater than 12,000 ft near the basin axis and reflects the present-day structure of the basin (Finn and others, Chapter 3, this CD–ROM).

Acknowledgments

The author thanks Ron Johnson, Mark Kirschbaum, and Tom Judkins for numerous helpful discussions regarding the Cretaceous and Tertiary geology and stratigraphic nomenclature of the Bighorn Basin. The manuscript and plates benefited from reviews by Ron Johnson, Laura Biewick, Dick Keefer, Doug Nichols, and Gayle Dumonceaux, and their suggestions and comments are greatly appreciated.

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