Chapter 3

Cretaceous–Tertiary Composite Total Petroleum System (503402), Bighorn Basin, Wyoming and Montana

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Chapter 3 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

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Abstract

The Cretaceous–Tertiary Composite Total Petroleum System (TPS) produces oil and natural gas mainly from sandstone reservoirs in anticlinal traps around the margins of the Bighorn Basin, Wyoming and Montana. The reservoirs range from Early Cretaceous to Paleocene in age and are sourced by organic-rich Lower and Upper Cretaceous marine shales that contain both Type-II oil-prone and Type-III gas-prone organic matter, and by Upper Cretaceous and Paleocene coals that contain Type-III organic matter. New resource potential is expected to be mainly from conventional stratigraphic traps and from unconventional continuous-type accumulations.

The Cretaceous–Tertiary Composite TPS is subdivided into (1) three basin-centered gas assessment units (AU)—Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas AU (50340261), Cody Sandstone Continuous Gas AU (50340263), and Mesaverde Continuous Gas AU (50340264); (2) one fractured shale oil accumulation—Mowry Fractured Shale Continuous Oil AU (50340262); (3) two coalbed gas accumulations—Mesaverde-Meeteetse Coalbed Gas AU (50340281) and Fort Union Coalbed Gas AU (50340282); and (4) one conventional oil and gas AU—Cretaceous–Tertiary Conventional Oil and Gas AU (50340201). The Cretaceous–Tertiary Conventional Oil and Gas AU (50340201) and the Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas AU (50340261) both have established production; the other AUs have no production and are considered hypothetical. The mean estimate for undiscovered oil and gas resources that have potential for additions to reserves from Cretaceous and Tertiary rocks in the Bighorn Basin is about 18 million barrels of oil, 771 billion cubic feet of gas, and 5 million barrels of natural gas liquids.

Introduction

The Bighorn Basin Province (5034) is a large sedimentary and structural basin that formed during the Laramide orogeny (Late Cretaceous through Eocene). The basin covers approximately 10,400 mi^2 in north-central Wyoming and a small part of south-central Montana (fig. 1). 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 north margin as defined in this report includes a zone of faulting and folding referred to as the Nye-Bowler lineament (Wilson, 1936). The northwest and west margins are formed by the Beartooth Mountains and Absaroka Range, respectively. The earliest commercial hydrocarbon production from Cretaceous reservoirs in the basin was established at Garland field (1906) and Greybull field (1907) (Fox and Dolton, 1996). Since then, cumulative production from Cretaceous and Tertiary reservoirs is about 94 million barrels of oil (MMBO) and 830 billion cubic feet of gas (BCFG), primarily from sandstone reservoirs associated with anticlinal traps around the margins of the basin (fig. 1). The purpose of this report is to describe the geologic framework and petroleum geology, and to assess the undiscovered oil and gas resources of the Cretaceous and Tertiary rocks in the Bighorn Basin.

Structural and Tectonic Setting

Present-day structure of the Bighorn Basin developed primarily during the Laramide orogeny, a period of crustal instability that began during Late Cretaceous time and ended in early Eocene time (Gries, 1983a; Love, 1988). Many of the structures are the result of compressional deformation characterized by Precambrian basement-involved thrust faults (thick-skinned), wrench faults, and strongly folded and faulted anticlines and synclines. The northeast, east, and south margins of the basin are formed by basement-cored uplifts referred to as the Pryor, Bighorn, and Owl Creek Mountains, respectively (figs. 1, 2). These uplifts are flanked by highly folded and faulted sedimentary rocks that range from Cambrian to Paleocene in age, whereas the central part of the basin is covered by nearly flat-lying lower Eocene and undifferentiated Tertiary and Quaternary rocks that mask the structure of the older rocks in the central part of the basin (fig. 2).

The basin axis generally trends northwest-southeast but locally is north-south, and there is marked asymmetry with the steeper basin flank on the west (figs. 2, 3). In the footwall of the Oregon Basin fault, the basin axis roughly parallels the

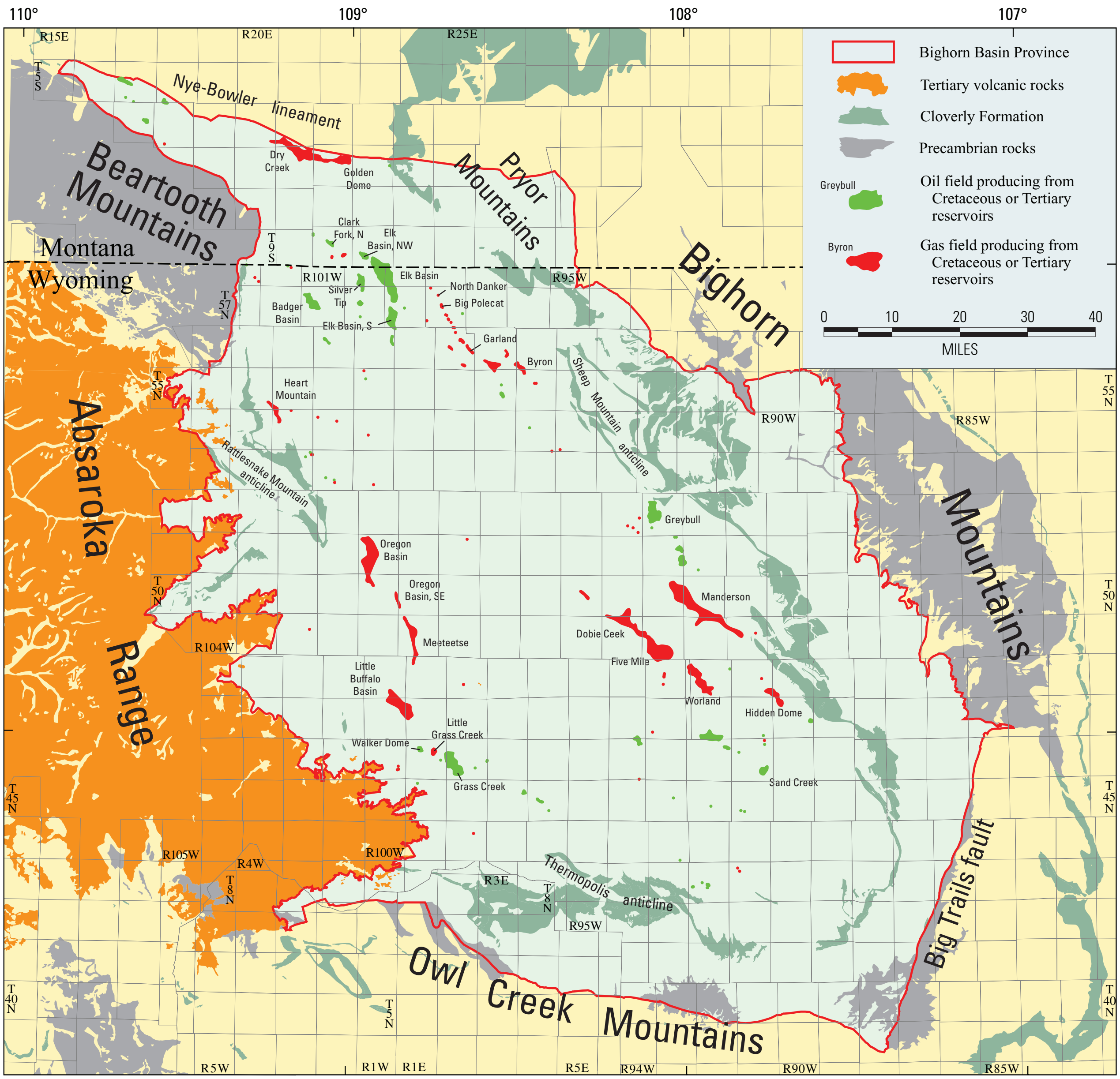

Figure 1. Index map showing location of the Bighorn Basin Province, major structural elements, and oil and gas fields that produce from Cretaceous and Tertiary reservoirs.

fault, but toward the north end of the Oregon Basin anticline it is offset to the northwest (Blackstone, 1986a) and lies west of the Oregon Basin thrust fault (fig. 3). The deep basin trough west of the Oregon Basin thrust fault is variously referred to as the Clark's Fork Basin or Clark's Fork sub-basin (Gingerich, 1983; Johnson and Finn, 1998a). In this area, the basin axis generally trends north-south and passes beneath the eastern edge of the Beartooth thrust near the Montana-Wyoming state line (fig. 3).

The northern boundary of the Bighorn Basin is formed by the Nye-Bowler lineament, a regional anticlinal trend extending about 60 mi east-southeast from the northern part of the Beartooth mountain front to the Pryor Mountains (figs. 2, 3). This trend consists of a series of highly faulted anticlines and domes that Wilson (1936) interpreted to overlie a left-lateral basement shear zone. The Nye-Bowler lineament forms the structural divide separating the Bighorn Basin to the south from the Reed Point syncline and Crazy Mountains Basin to the northwest (fig. 4). Important petroleum accumulations associated with the Nye-Bowler lineament include Golden Dome and Dry Creek gas fields (fig.1).

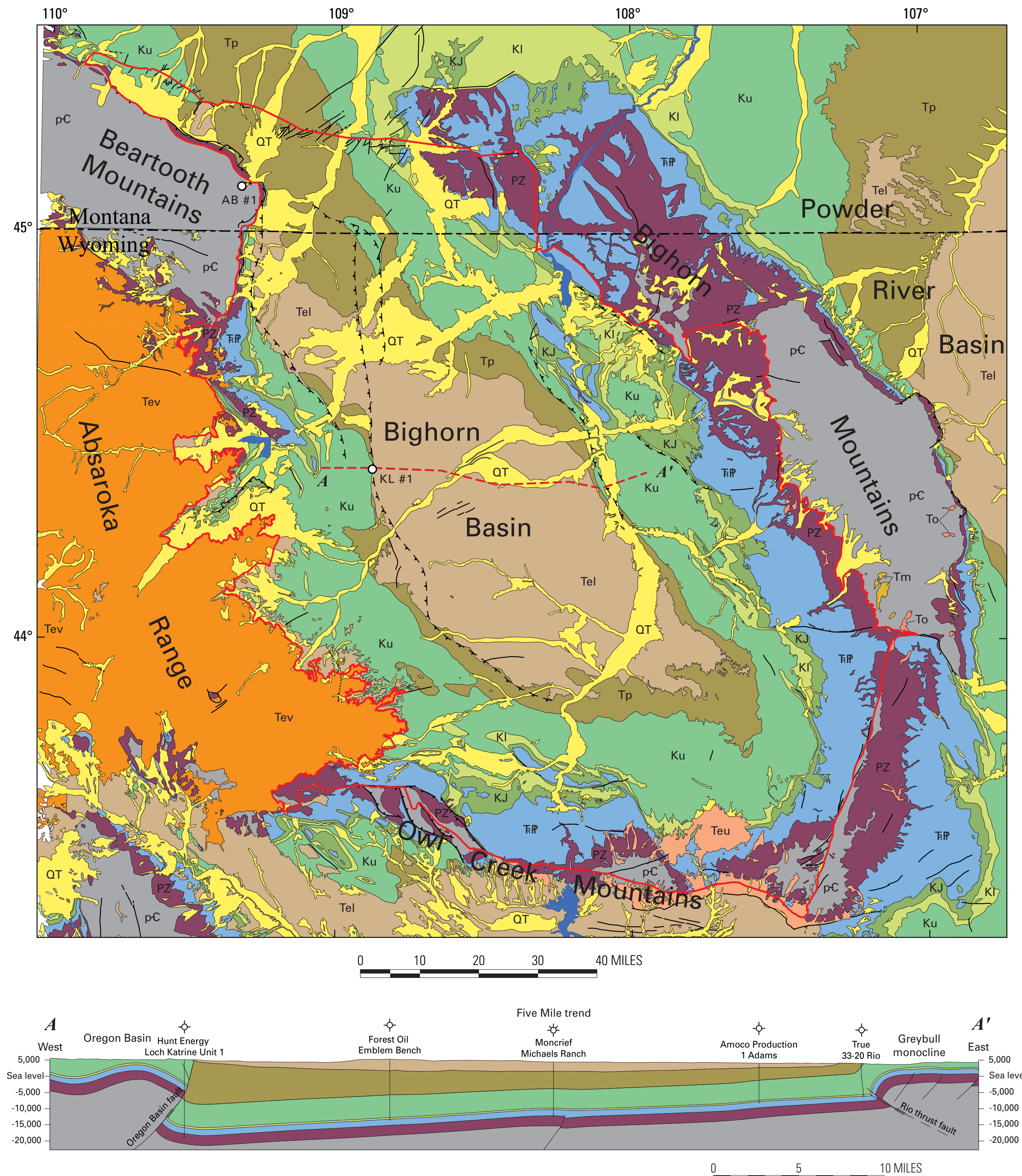

Figure 2 (above and facing page). Geologic map and cross section of Bighorn Basin, Wyoming and Montana. Geologic map modified from Green and Drouillard (1994) and Raines and Johnson (1995). Cross section modified in part from Blackstone (1986a) and Stone (2004a). Vertical scale of cross section is in feet. AB #1, Amoco Beartooth no. 1 well; KL #1, Hunt Loch Katrine no. 1 well.

EXPLANATION

- Bighorn Basin Province
- High-angle fault, dashed where concealed
- Thrust fault, dashed where concealed
- A – A′ Line of section
- Well location discussed in text

MAP UNITS

- Water features
- QT — Quaternary–Tertiary undifferentiated
- Tm — Miocene(?) sedimentary rocks
- To — Oligocene sedimentary rocks
- Teu — Upper Eocene sedimentary rocks
- Tev — Eocene volcanic rocks
- Tel — Lower Eocene sedimentary rocks
- Tp — Paleocene sedimentary rocks
- Ku — Upper Cretaceous sedimentary rocks
- Kl — Lower Cretaceous sedimentary rocks
- KJ — Lower Cretaceous–Jurassic sedimentary rocks
- TRP — Triassic–Pennsylvanian sedimentary rocks
- PZ — Mississippian–Cambrian sedimentary rocks
- p€ — Precambrian crystalline rocks

The northwest margin of the basin is formed by the Beartooth Mountains, a Precambrian-cored uplift of Laramide age that is thrust fault-bounded and flanked by steeply dipping-to-overturned sedimentary strata (Foose and others, 1961). The west margin is formed by the Absaroka Range, which is comprised mainly of Eocene andesitic volcanic and volcaniclastic rocks associated with large stratovolcanos (Sundell, 1993). These volcanic rocks are believed to unconformably overlie folded and faulted Paleozoic, Mesozoic, and lower Tertiary sedimentary rocks (Sundell, 1990).

Major thrust faults in the Bighorn Basin include the Beartooth fault, the Line Creek fault, and the Oregon Basin fault on the west side of the basin, the Elk Basin fault in the north-central part, and the Rio thrust fault on the east (fig. 3). The Beartooth fault is the major basin-bounding fault in the northwestern part of the basin (fig. 3). The fault plane dips to the west-southwest and displacement is generally to the east and northeast, thrusting the Beartooth Mountains over Paleozoic and Mesozoic sedimentary rocks with approximately 7.5 mi of overhang along the northwest margin of the basin (Bonini and Kinard, 1983). The fault was penetrated by the Amoco Beartooth #1 well (fig. 2), which was spudded in basement rocks on the Beartooth uplift approximately 1.5 mi west of the Precambrian contact. The well drilled through about 8,400 ft of granitic rock before it encountered the fault zone, then drilled through a complexly faulted and folded sequence of sedimentary rocks to a total depth of about 13,800 ft (Wise, 1997; 2000). The Line Creek fault, located in the western part of the basin (fig. 3), is an east-directed, west-dipping thrust fault that originates in Precambrian rocks and involves strata as young as the Paleocene Fort Union Formation (Blackstone, 1986a). The fault starts near the Montana-Wyoming state line, and extends south to southeast approximately 40 mi (fig. 3). According to Parker and Jones (1986) the maximum vertical and horizontal displacements on the Line Creek fault are estimated to be about 12,000 ft and 10,000 ft, respectively. The fault is buried beneath the Eocene Willwood Formation.

The Oregon Basin fault, the major thrust fault along the west side of the basin, trends north-south to northwest-southeast for about 80 mi and separates the relatively undeformed central deep trough of the basin to the east from the highly deformed basin margin on the west (fig. 3). According to Blackstone (1986a,b) the fault plane dips 40° to 70° to the west-southwest, flattening with depth and possibly extending beneath many of the anticlines along the west and southwest margins of the basin that contain important petroleum accumulations. Blackstone (1986a) estimated that the displacement, although variable, ranges to as much as 25,000 ft in the vicinity of Oregon Basin. It is concealed beneath rocks of the lower Eocene Willwood Formation but was penetrated in the Hunt Oil Company Loch Katrine no. 1 well on the east flank of the Oregon Basin anticline (fig. 2), which was drilled to evaluate deep gas potential in the subthrust (Rountree, 1980). The well, spudded in sedimentary rocks west of the buried trace of the fault on the northeast flank of the Oregon Basin anticline, drilled through steeply dipping Mesozoic and

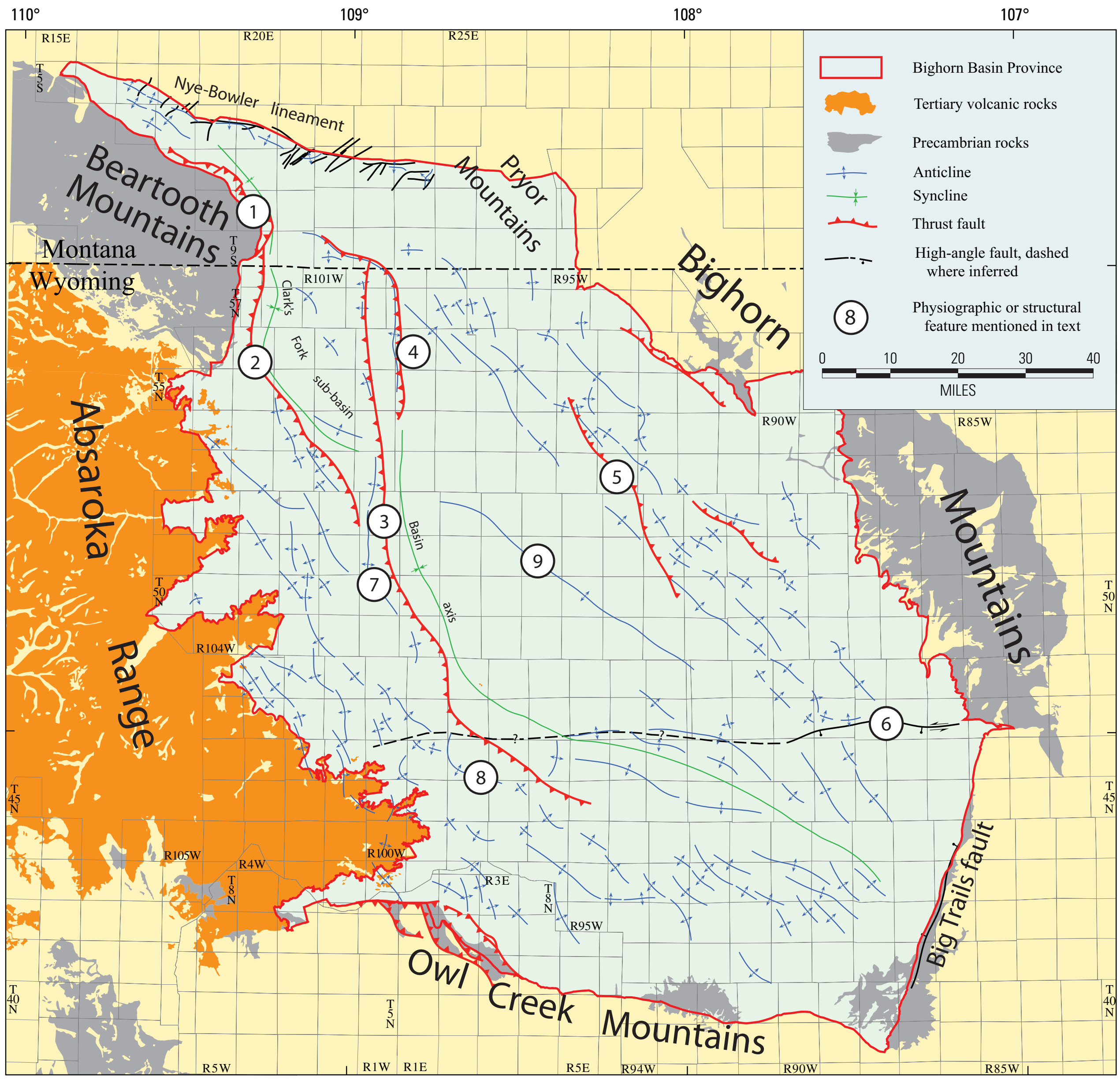

Figure 3. Tectonic map of Bighorn Basin, Wyoming and Montana, showing major structural features discussed in text (1) Beartooth thrust fault, (2) Line Creek thrust fault, (3) Oregon Basin thrust fault, (4) Elk Basin thrust fault, (5) Rio thrust fault, (6) Tensleep fault, western extension dashed where inferred, (7) Oregon Basin anticline, (8) Grass Creek anticline, and (9) Five Mile trend. Sources of data from Wilson (1936), Ver Ploeg (1985), and Stone (1993, 2004b).

Paleozoic sedimentary rocks until it encountered the fault zone at around 10,500 ft. Below the fault, the well penetrated several thousand feet of vertical to overturned Mesozoic rocks before drilling through a relatively flat-lying section of Mesozoic and Paleozoic sedimentary rocks to a total depth of 23,990 ft (fig. 2) (Parker and Jones, 1986; Blackstone, 1986a,b; Stone, 1985).

East of and parallel to the northern segment of the Oregon Basin fault is the Elk Basin fault (fig. 3) (Ryder, 1987; Stone, 1983), a west-dipping, east-directed thrust fault rooted in Precambrian crystalline rocks and terminating in Upper Cretaceous rocks in the subsurface (Ryder, 1987; Stone, 1983). The fault trends north-south about 25 mi but may extend southward several miles, merging with the Oregon Basin fault in the deep part of the basin trough (Talbot, 1996). Several important oil accumulations are associated with, and located on, the hanging wall of the Elk Basin thrust, including Elk Basin field that has an estimated grown accumulation size of about 20 MMBO in Cretaceous reservoirs (fig. 1). The most important thrust fault on the east side of the Bighorn Basin

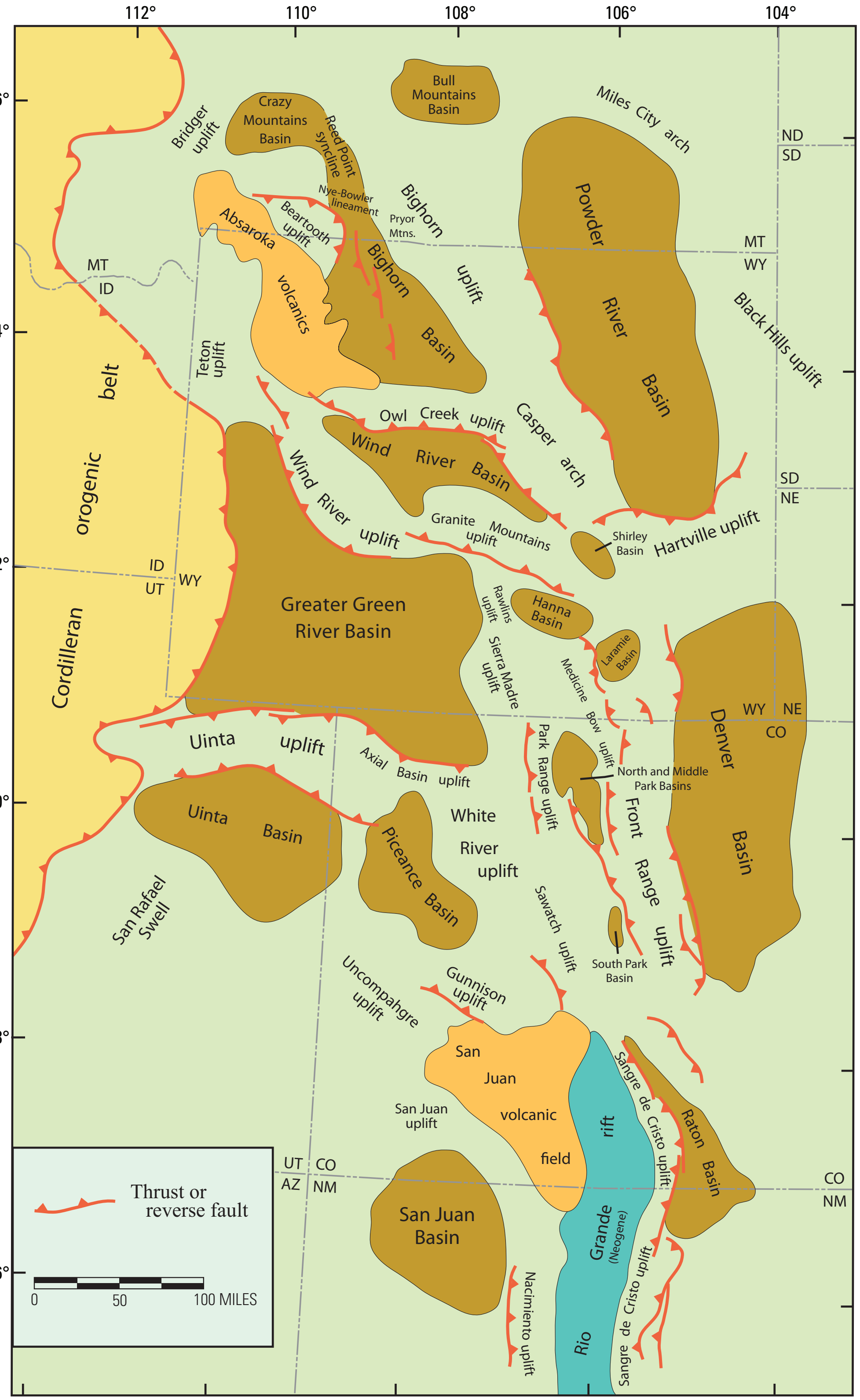

Figure 4. Map of Rocky Mountain region extending from southern Montana to northern New Mexico showing locations of Laramide sedimentary and structural basins (in brown) and intervening uplifts. Modified from Dickinson and others (1988).

is the Rio thrust named by Stone (2004a). It trends about 35–40 mi northwest-southeast, dips east-northeast, is west-southwest-vergent, and separates the relatively undeformed central deep part of the Bighorn Basin on the west from the highly deformed basin margin on the east (figs. 2, 3). The fault originates in Precambrian basement rocks, with displacements of around 3,000 to 4,000 ft, and dies out in Cretaceous rocks in the subsurface (Stone, 2004a).

The Tensleep fault, located in the southern part of the basin, is a major high-angle fault that, according to Allison (1983, 1986), extends from the Precambrian core of the Bighorn Mountains due west about 30 mi where it is obscured by Upper Cretaceous sedimentary rocks (figs. 2, 3). Stone (1969, 1985, 1993, 1999, 2004b) extended the fault into the subsurface across the southern part of the Bighorn Basin to the vicinity of Grass Creek anticline and possibly to the eastern edge of the Absaroka Range, effectively separating the central part of the deep basin trough from the deformed southern margin (fig. 3). The nature of the Tensleep fault is questionable and has been variously described as a near-vertical normal fault, downthrown to the south (Allison, 1983, 1986), and as a left-lateral wrench fault by Stone (1969, 1985, 1993).

Around the margins of the Bighorn Basin are numerous anticlines, many of which are located on the hanging walls of the Rio, Oregon Basin and Line Creek thrust faults (fig. 3) (Ver Ploeg, 1985; Blackstone, 1986a,b; Stone, 1985, 2004a). These folds involve sedimentary rocks ranging from Paleozoic through Paleocene in age, are typically asymmetric, commonly thrust fault-bounded along their steep flanks, and generally trend northwest-southeast. Blackstone (1986b) believed that many of these features originated as back-limb thrusts on the hanging wall of the Oregon Basin thrust fault. Many important oil and gas fields are associated with these features—for example, Oregon Basin, Little Buffalo Basin, and Grass Creek fields (fig. 1).

The deep central part of the Bighorn Basin is a relatively undeformed area that is bounded by the Oregon Basin fault on the west, the Rio thrust fault on the east, and possibly the western extension of the Tensleep fault on the south (fig. 3). This part of the basin is markedly asymmetric with regional dip to the west where the deep basin axis is adjacent to or overridden by the Oregon Basin thrust fault (fig, 3). According to Johnson and Finn (1998a), the elevation change at the Teapot Sandstone Member level is about 11,000 ft from east to west. The most prominent structural feature in the central part of the basin is referred to as the Five Mile trend by Fox and Dolton (1989, 1996), Johnson and Finn (1998a), and Stone (2004b). It extends about 50 mi northwest across the deep central part of the basin (fig. 3). The Five Mile trend is thrust fault-bounded on its northeast flank, plunges to the northwest and appears to die out in the deep part of the basin. Important fields along the Five Mile trend include Five Mile and Dobie Creek (fig. 1).

Depositional Setting

During much of Cretaceous time, the part of Wyoming and Montana that is now the Bighorn Basin was located near the western edge of the Rocky Mountain foreland basin, an elongate north-south structural depression that developed to the east of the tectonically active Western Cordilleran highlands. Throughout much of its history, the foreland basin was flooded by a broad epicontinental sea, referred to as the Western Interior Seaway (WIS) that developed in response to foreland basin subsidence and eustatic sea-level rise (Steidtmann, 1993) (fig. 5). At its maximum extent, the seaway extended a distance of more than 3,000 mi from the Arctic Ocean to the Gulf of Mexico (Kauffman, 1977).

Fluctuations in relative sea level and variations in sediment supply along the western shoreline of the seaway during much of Cretaceous time resulted in a complex pattern of intertonguing marine, marginal marine, and nonmarine deposits (fig. 6). Marine deposition ended near the close of the Cretaceous Period (early Maastrichtian), as the foreland basin gradually filled and the western shoreline of the seaway retreated eastward. The uppermost Cretaceous strata also record the onset of the Laramide orogeny (Dickinson and others, 1988; Johnson and others, 2004), a period of crustal instability and compressional tectonics that commenced in early Maastrichtian time and fragmented the Rocky Mountain foreland basin into numerous smaller structural basins that were flanked by rising basement-cored uplifts (fig. 4). Basins such as the Bighorn Basin subsided rapidly and became depocenters for thick accumulations of clastic debris eroded from the surrounding uplifts during latest Cretaceous and Paleocene time. During Eocene time, the basin continued to be filled with volcaniclastic debris that originated in the Yellowstone-Absaroka volcanic area to the west (Love, 1988). Volcanic activity ended by Oligocene time but basin filling continued as Oligocene and Miocene volcaniclastic sediments spilled over the crest of the Bighorn Mountains and were deposited in the Powder River Basin to the east (McKenna and Love, 1972). In middle Miocene time regional uplift initiated the exhumation of the surrounding uplifts and the excavation of the basin which continues to the present day (Love, 1988).

Stratigraphy

Figure 7 shows the stratigraphic nomenclature used in this report and the change in nomenclature from the Wyoming part of the Bighorn Basin to the Montana part. The Wyoming nomenclature is from Keefer and others (1998), and the Montana nomenclature is modified from Johnson and Finn (2004) for the area in the vicinity of the Nye-Bowler lineament (fig. 1). The change in nomenclature is also illustrated on the regional cross section in figure 6, and on the north-south stratigraphic cross section presented by Finn (Chapter 6, this CD–ROM).

Figure 5. Map showing extent of the Western Interior Seaway during Campanian time. Brown areas show approximate geographic distribution of land areas. Modified from Gill and Cobban (1973).

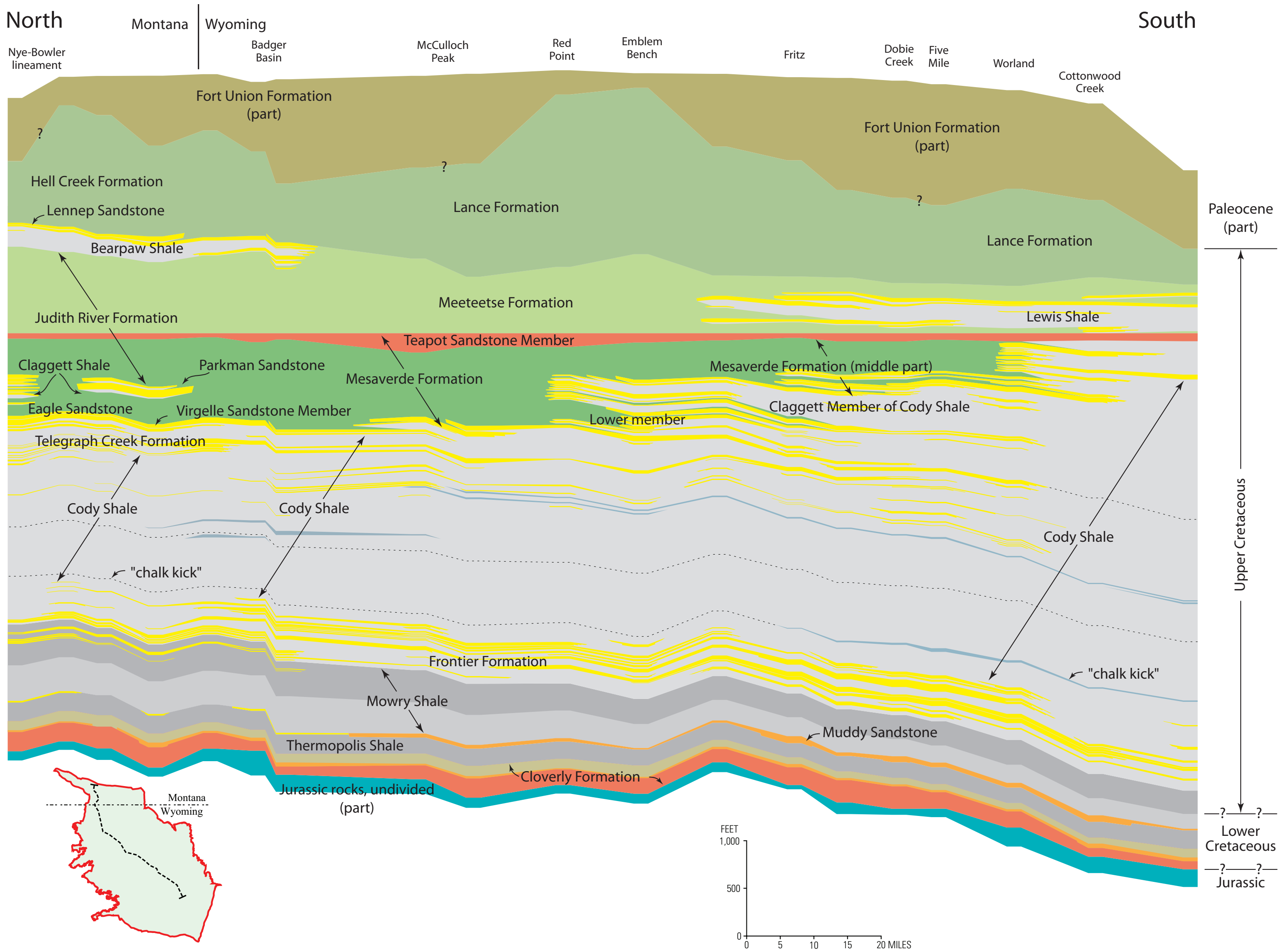

Figure 6. Regional northwest-southeast stratigraphic cross section of Cretaceous and Paleocene (part) rocks, Bighorn Basin, Wyoming and Montana. Colors represent different lithologies and environments of deposition: red, fluvial sandstone and conglomerate; yellow, marine and marginal marine sandstone and siltstone; orange, fluvial and estuarine sandstone; tan, tidal sandstone, siltstone, and shale; various shades of gray, marine shales; various shades of green, coastal plain and floodplain sandstones, shales, and coals; brown, sandstone, siltstone, shale, coal and conglomerate of continental origin.

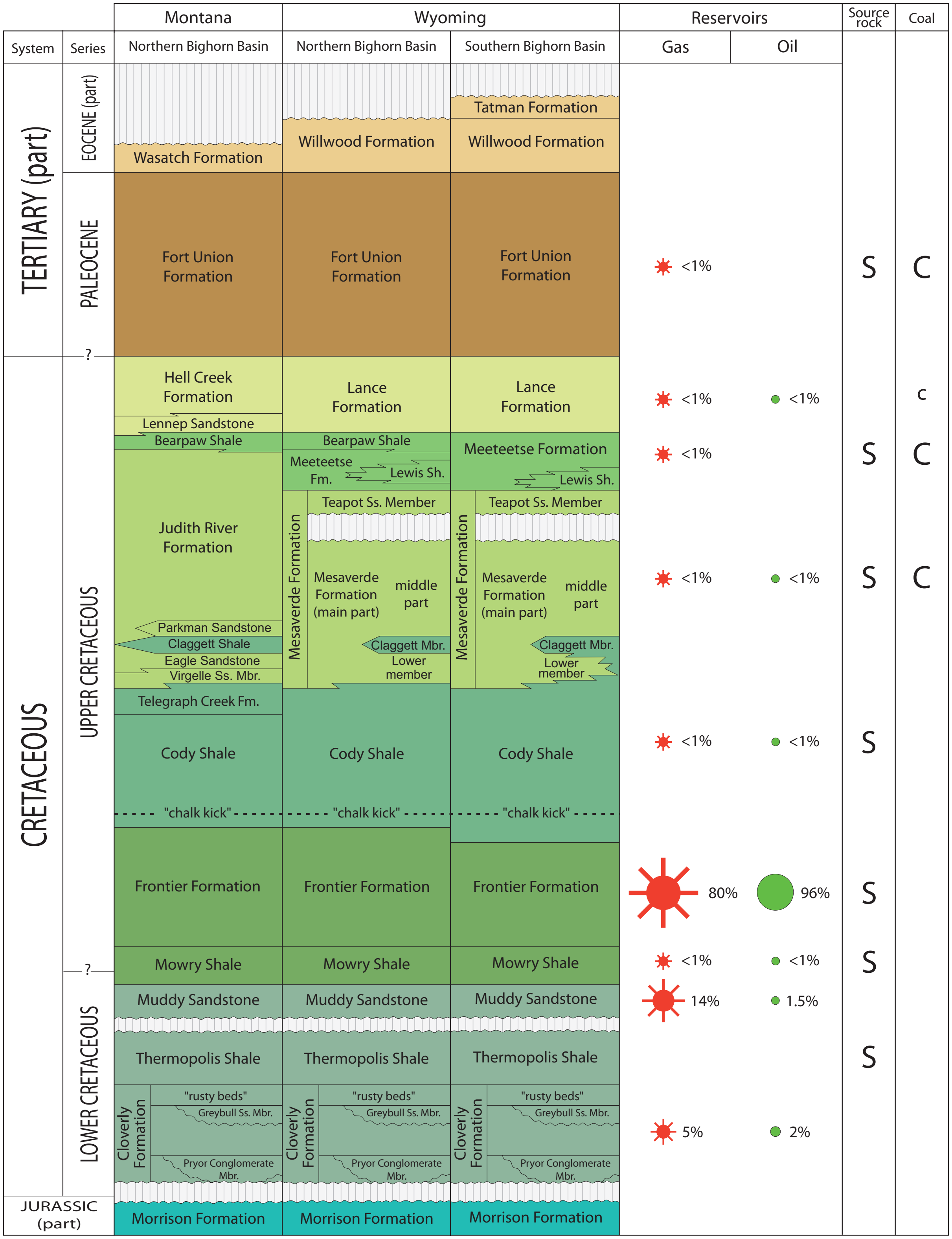

Figure 7. Stratigraphic chart showing the Jurassic to lower Tertiary rocks in the Bighorn Basin, Wyoming and Montana. Major and minor oil and gas reservoirs indicated by green or red circles, respectively, with relative importance shown by size and percentage of production. Source rocks indicated with the letter “S”. Coal-bearing units indicated with the letter “C”, with relative importance shown by size. Modified from Keefer and others (1998); Johnson and Finn (2004); and Finn, Chapter 6, this CD-ROM.

Cloverly Formation

The basal Cretaceous rocks are represented by the Cloverly Formation, which consists of 210 to 385 ft of interbedded sandstone, variegated shale, claystone, and minor amounts of conglomerate (Keefer and others, 1998) (fig. 7). The basal unit, where present is the Pryor Conglomerate Member, consists of sandstone, conglomeratic sandstone, and black and gray chert-pebble conglomerate and has an irregular distribution. The middle part of the formation is comprised of variegated shale and claystone interbedded with thin sandstones that accumulated in flood-plain, fluvial, and lacustrine environments; Moberly (1960) included these strata in his Little Sheep Mudstone and Himes Members. 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), but is locally absent. It represents the initial marine transgression during Albian time 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 (Mitchell, 1997; Furer and others, 1997). The uppermost part of the Cloverly Formation referred to as the “Rusty beds” by Love and others (1945), as the “Rusty Beds Member” by Keefer and others (1998), and in this report as the “rusty beds”, consist 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 “rusty beds” are included in the lower part of the overlying Thermopolis Shale by numerous authors (for example, Mills, 1956; Eicher, 1962). The Greybull Sandstone Member and “rusty beds” have a combined thickness of about 100 ft throughout most of the basin but range to as much as 160 ft. These units are referred to together as the Sykes Mountain Formation by Moberly (1960). Based on fission track dating, the age of the Cloverly Formation ranges from 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 part of the Thermopolis Shale of Lupton (1916), Mills (1956), and Haun and Barlow (1962); it overlies the “rusty beds” of the Cloverly Formation and underlies the Muddy Sandstone. The Thermopolis consists of 125 to 230 ft of marine shales and siltstones and represents continued deposition during sea-level rise in Albian time (Burtner and Warner, 1984; Hagen and Surdam, 1984). The shales are dark gray to black, organic-rich and contain 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

In this report, the Muddy Sandstone refers to a sandstone-dominated interval located stratigraphically between the Thermopolis Shale and the overlying Mowry (Shell Creek) Shale (fig. 7). The unit is between about 7 and 125 ft thick (fig. 8) and consists of predominantly sandstone interbedded with lesser amounts of mudrock, and minor amounts of carbonaceous shale and coal. It is thickest in the southeastern part of the basin where it is dominated by sandstone and thinnest to the north-northwestern part of the basin where it consists of thin sandstones enclosed by marine shale. The age of the Muddy is latest Albian based on fossil evidence and radiometric dates obtained from strata just above and below the Muddy (Eicher, 1962; Obradovich, 1993).

According to the USGS database on stratigraphic names, the name Muddy was a driller’s term for “muddy” sands in the Thermopolis Shale of the Bighorn Basin and other areas of Wyoming (Hintze, 1915, p. 20–21; Geolex, 2008). No type area was designated, but a reference section was suggested by Eicher (1960) for exposures near the Greybull field in Bighorn County, Wyoming. Eicher (1960, 1962) used the term Muddy Sandstone, following previous workers, and provided extensive discussions of the Formation. Paull (1962) interpreted depositional environments to include deltaic, bar, back-bar, continental, and offshore marine environments. In their regional study, Dolson and others (1991) considered the Muddy to be a valley-fill complex and interpreted a lowstand shoreline in the vicinity of the Bighorn Basin. Long (1999) defined two parts to the Muddy, including valley-fill sandstones and shale and trangressive marine sandstone. In the present study, several cores and outcrops were interpreted to indicate a variety of environments—from freshwater to marine—within a complex valley-fill succession unit that unconformably overlies a lower offshore-marine section, generally included in the Thermopolis Shale.

Mowry Shale

The Mowry Shale was defined by Darton (1904) for exposures in the northwestern part of the Powder River Basin, and the top of the unit was revised by Rubey (1931) to include the Clay Spur Bentonite Bed. In the Bighorn Basin no definitive correlation can be made to the Clay Spur, but based on a comparison with well logs in the northern Wind River Basin and the Casper arch area, we placed the Mowry-Frontier contact at a distinctive high-gamma geophysical log response (Finn, Chapter 6, this CD–ROM; and Johnson, Chapter 7, this CD–ROM), which is stratigraphically lower than the contact of Goodell (1962) or of Van Houten (1962). According to Keefer and others (1998), the Mowry Shale in the Bighorn Basin consists of two distinct units. The lower unit consists of

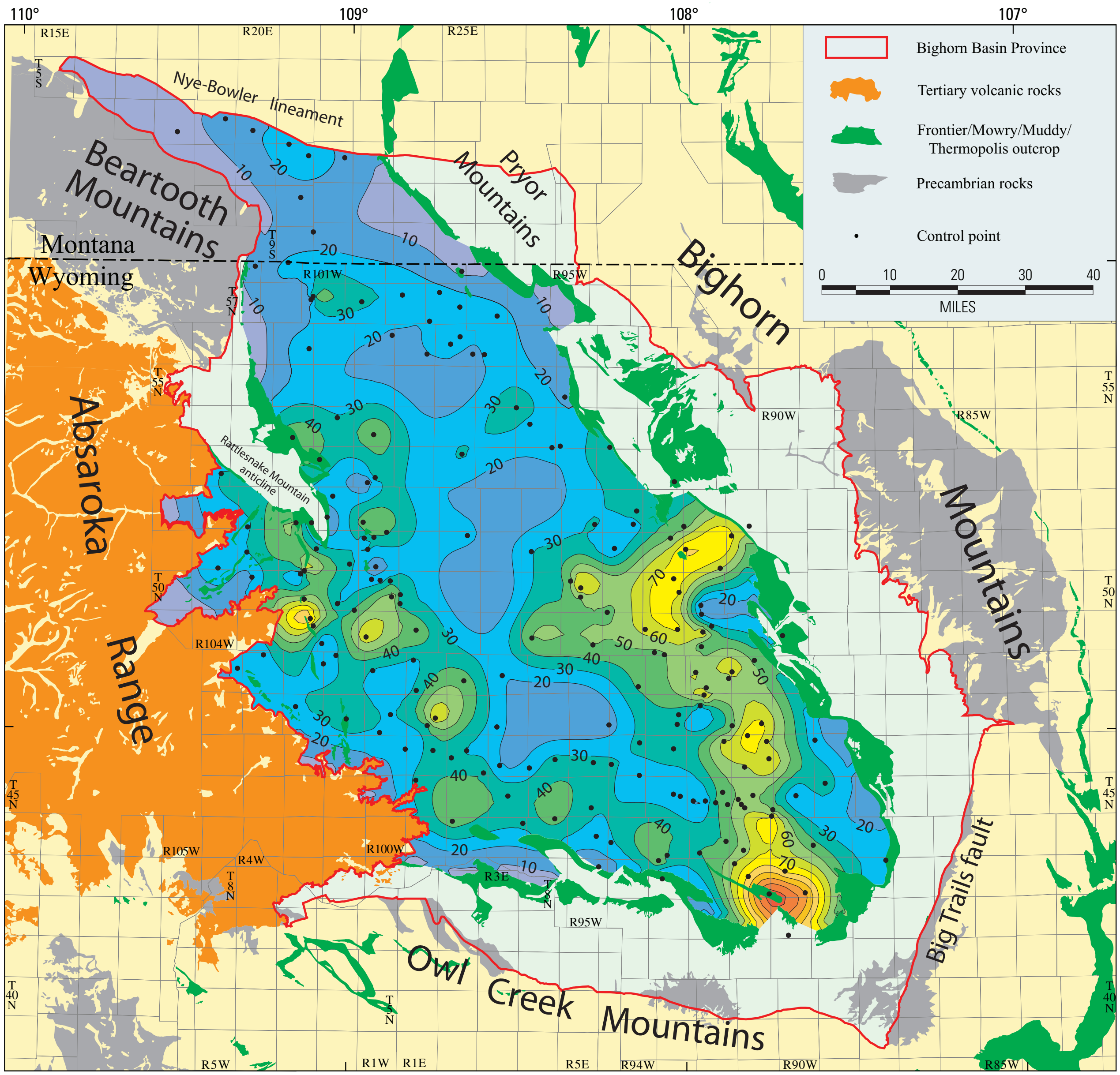

Figure 8. Isopach map of the Muddy Sandstone, Bighorn Basin, Wyoming and Montana; thickness interval 10 ft.

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 unit consists of about 240 to 400 ft of hard brittle siliceous shale. Numerous gray to tan bentonite beds are common throughout the Mowry, ranging in thickness from less than one 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, there are thin fine-grained sandstones 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 east side of the basin (Pierce, 1948; Mills, 1956; Cardinal and others, 1989). Davis (1987) also described two sandstone bodies in the Mowry Shale along the east and northeast sides of the basin. These sandstones are fine- to medium-grained, as much as 15 ft thick, and form elongate bodies that Davis (1987) believed were deposited during a fall in sea level. The

Mowry Shale is marine in origin with a combined thickness for the lower and upper parts ranging from about 400 ft in the southeastern part of the basin to more than 800 ft near the Beartooth Mountains (fig. 9). Paleontologic evidence and radiometric dating indicate that the upper siliceous part of the Mowry is largely early Cenomanian 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 marine and minor marginal-marine shale, siltstone, and sandstone that are generally interpreted to be deltaic or shoreface in origin (Hunter, 1952; Van Houten, 1962; Goodell, 1962; Siemers, 1975; Merewether and others, 1975; Merewether and others, 1998). Minor amounts of carbonaceous shale and coal are present in the northwestern part of the basin (Siemers, 1975; Merewether and others, 1975). The Frontier is early Cenomanian to early Coniacian in age and contains at least one major unconformity in the upper part (Merewether and others, 1975). The lower contact is placed at the top of the Mowry, and the upper contact is typically placed at the top of the uppermost sandstone below the Cody Shale. A thin distinctive marker is present in the lower part of the overlying Cody Shale (fig. 7), especially in the southeastern part of the basin, and it probably represents a carbonate or chalk zone equivalent to the Upper Cretaceous Niobrara Formation. The main Frontier interval, as defined between the top of the Mowry and chalk marker, ranges in thickness from 450 ft in the western part of the basin to about 1,075 ft in the southeastern part of the basin (fig. 10).

There are at least six main sandstone units within the Frontier, but not all are present at any one locality. They are continuous locally for tens of miles but are subject to truncation due to erosion, mainly by marine-flooding surfaces. The maximum thickness of individual sandstones range to as much as 130 ft (see Finn, Chapter 6, this CD–ROM; and Johnson, Chapter 7, this CD–ROM).

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 time (Kauffman, 1977). The formation ranges in thickness from about 1,700 ft in the northern part of the basin to nearly 3,800 ft in the southeastern part (fig. 11). The lower and upper contacts are conformable and interfinger extensively with the underlying Frontier and overlying Mesaverde Formations (fig. 6).

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 Fomation and is composed of marine shale with increasing amounts of interbedded sandstone in the upper 500–1,200 feet (fig. 6) (see Finn, Chapter 6, this CD–ROM). The upper sandy part is similar to, but somewhat less sandy than, the upper sandy member of the Cody Shale in the Wind River Basin (see Finn, 2007a, and Johnson, 2007, for descriptions and correlation 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 (see Finn, Chapter 6, this CD–ROM; and Johnson, Chapter 7, this CD–ROM). The uppermost several hundred feet of the sandy part of the Cody that directly underlies the Mesaverde Formation is commonly referred to in Montana as the Telegraph Creek Formation (figs. 6, 7). The Cody is poorly exposed, however, limited outcrop studies by Johnson and others (1998) of uppermost Cody Shale indicate that the sandstones are very fine to medium-grained, generally laterally persistent, and exhibit a variety of bedding features including hummocky cross-bedding, which indicates a near-shore marine origin.

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. 6, 7). The Claggett Member extends across the eastern and central parts of the Bighorn 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 (figs. 6, 12) (see Finn, Chapter 6, this CD–ROM).

Mesaverde Formation

The Mesaverde Formation consists of a 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 formation is Campanian in age and can be subdivided into a lower member, a middle or main part, and the Teapot Sandstone Member (fig. 6) (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) and as the Eagle Formation of the Mesaverde Group by Severn (1961) and Mackenzie (1975), is an eastward-thinning wedge of marginal marine and nonmarine strata (figs. 6, 7). 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 (figs. 6, 7). The lower member is present in the central and eastern parts of the basin, where it consists of very fine to medium-grained sandstone, siltstone,

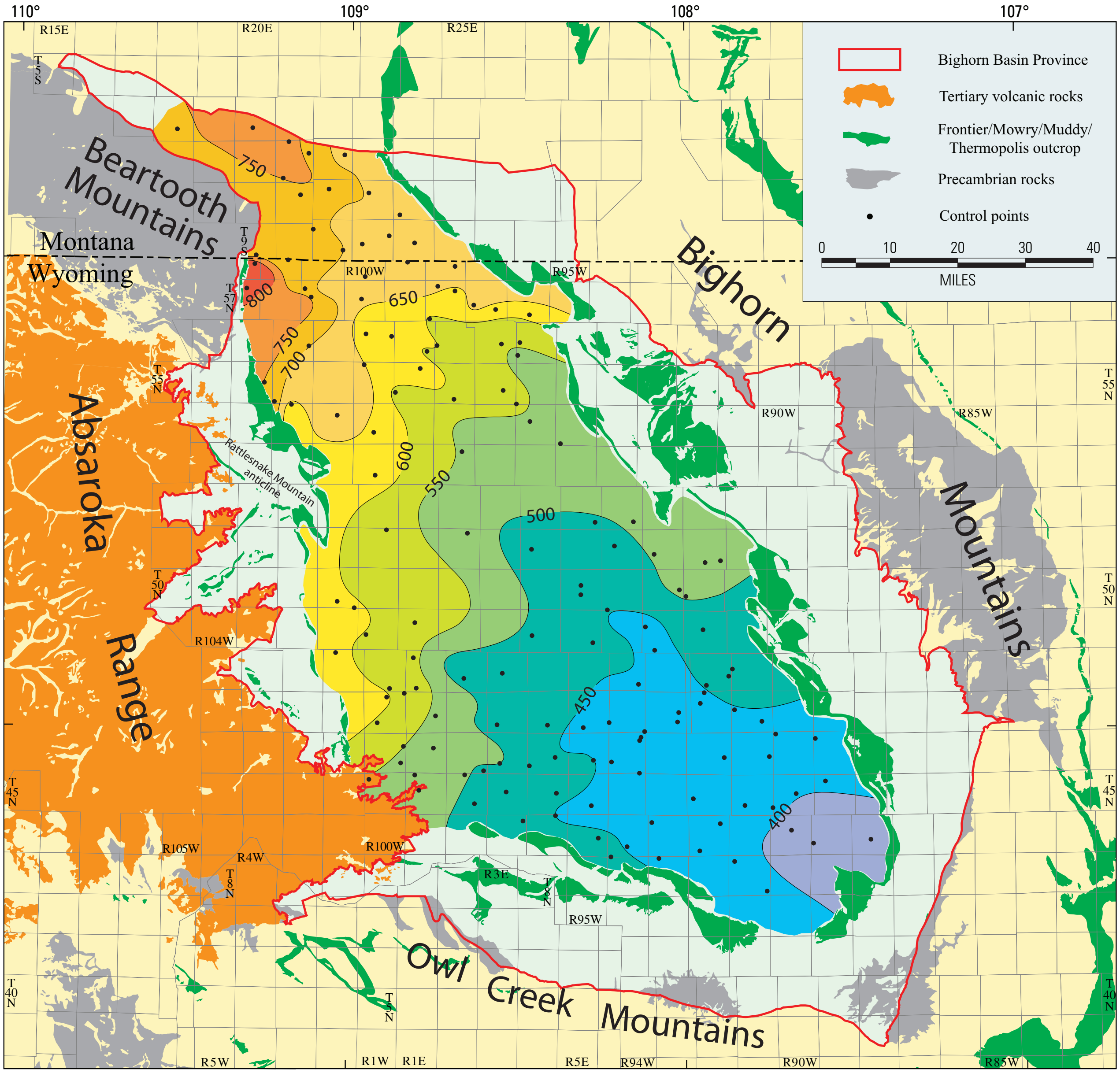

Figure 9. Isopach map of the Mowry Shale, Bighorn Basin, Wyoming and Montana; thickness interval 50 ft.

shale, carbonaceous shale, and coal deposited as an eastward-prograding deltaic complex (Mackenzie, 1975; Johnson and others, 1998). The basal beds are 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 upwards 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 400–500 ft thick but locally exceeds 800 ft (fig. 13) (see Finn, Chapter 6, this CD–ROM). It merges with the main part of the Mesaverde Formation to the west, and thins to zero to the east where is grades into the upper part of the Cody Shale (fig. 6). West of the Claggett pinchout, the lower and middle Mesaverde members merge as one unit simply referred to as Mesaverde Formation.

Where the Claggett Shale is present, that part of the Mesaverde Formation overlying it is referred to as the main body of the formation by Keefer and others (1998) and as the

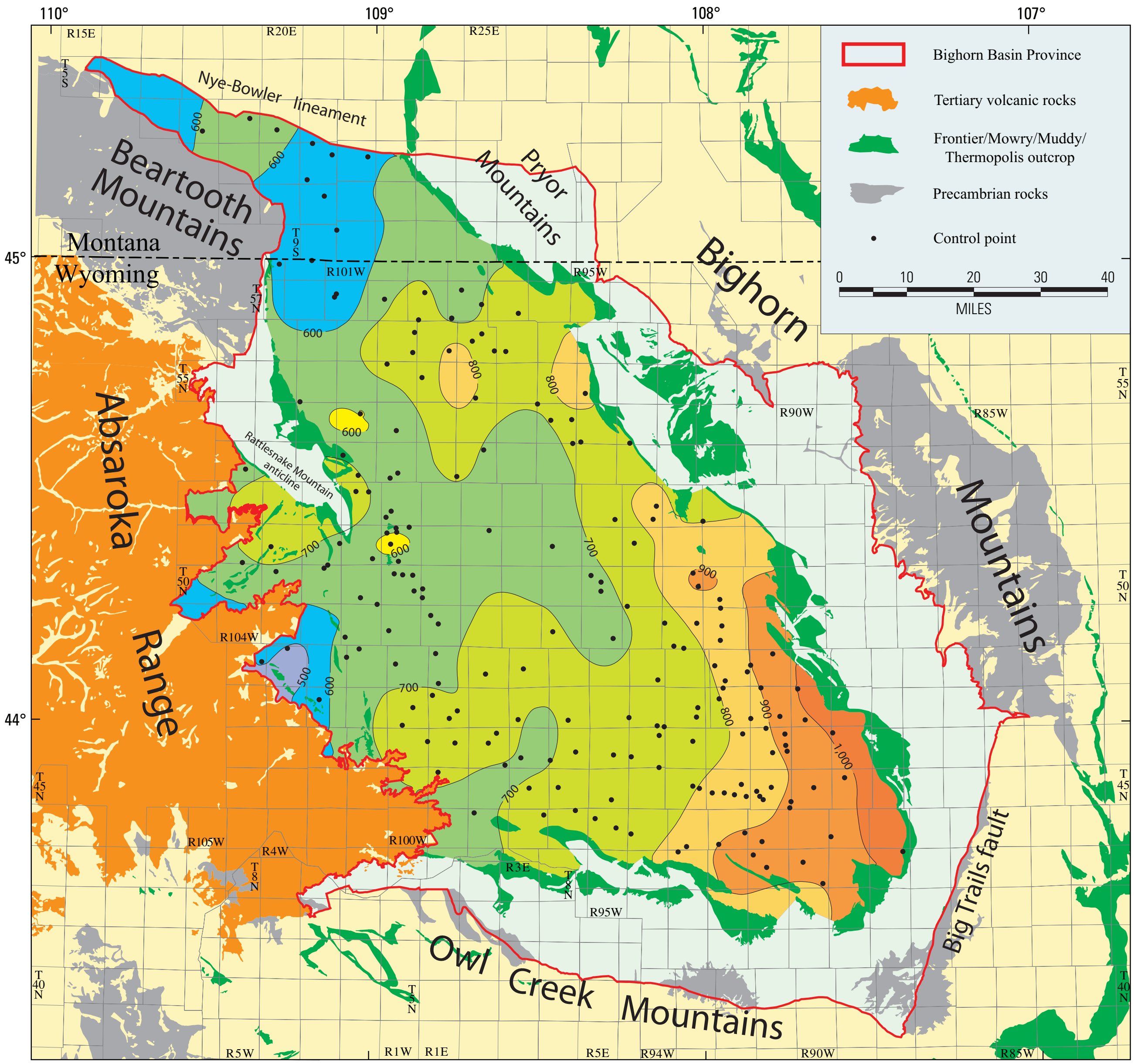

Figure 10. Isopach map of the Frontier Formation, Bighorn Basin, Wyoming and Montana; thickness interval 100 ft.

middle part by Johnson and others (1998). 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. 6, 7). Severn (1961) referred to this interval, together with the overlying Teapot Sandstone Member as the Judith River Formation, and Mackenzie (1975) referred to it as the Judith River Formation of the Mesaverde Group. 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 part 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

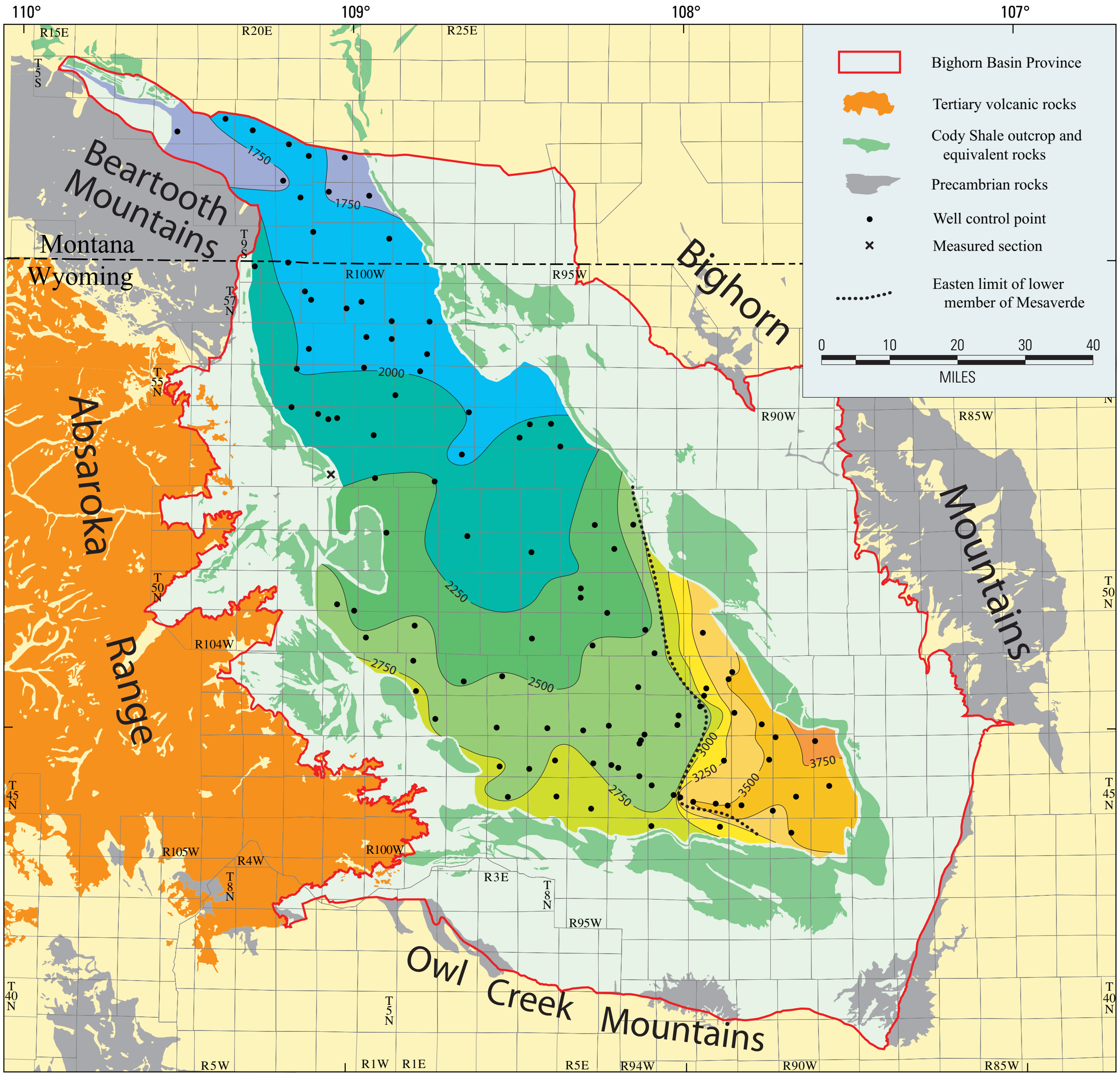

Figure 11. Isopach map of the main body of the Cody Shale excluding the Claggett Member, Bighorn Basin, Wyoming and Montana; thickness interval 250 ft. Outcrop data from Hewett (1912).

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 (fig. 14).

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, Johnson and others (1998) described hummocky cross-bedding in the lower part of the unit, indicating that it is partly marginal marine in origin. The thickness of the Teapot Member is highly variable and ranges from a few tens of feet to more than 300 ft (Keefer and others, 1998; Johnson and others, 1998).

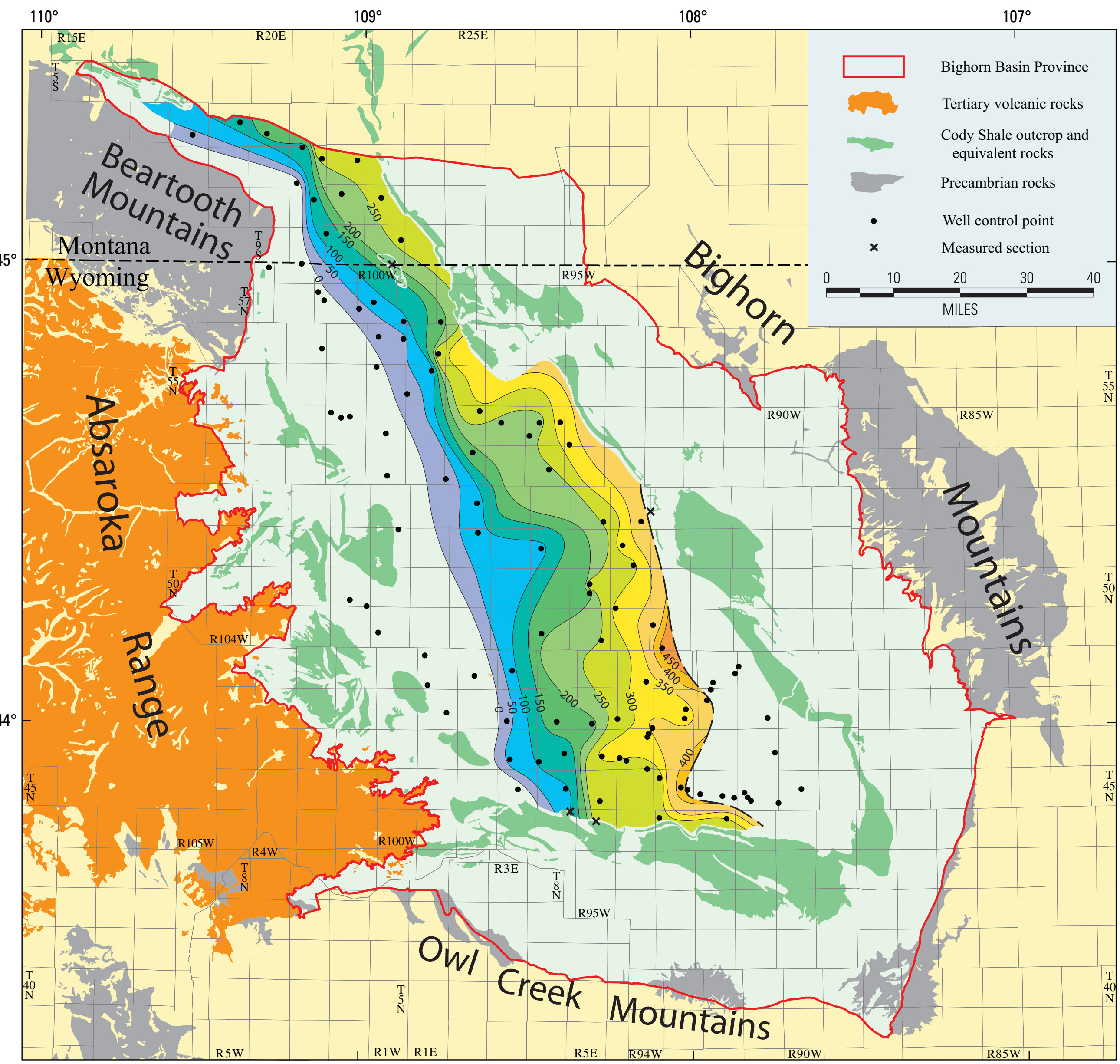

Figure 12. Isopach map of the Claggett Member of the Cody Shale, Bighorn Basin, Wyoming and Montana; thickness interval 50 ft. Outcrop data from Johnson and others (1998).

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 age (Gill and Cobban, 1966; Merewether, 1996) (figs. 6, 7). 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. 6, 7). The marine strata in this interval are included in the Lewis and Bearpaw Shales, and the marginal marine and nonmarine strata in the Meeteetse Formation. The maximum combined thickness for the formations ranges from more than 1,100 ft in the northern and southwestern parts of the basin to about 500 ft in the southeastern part (fig. 15).

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

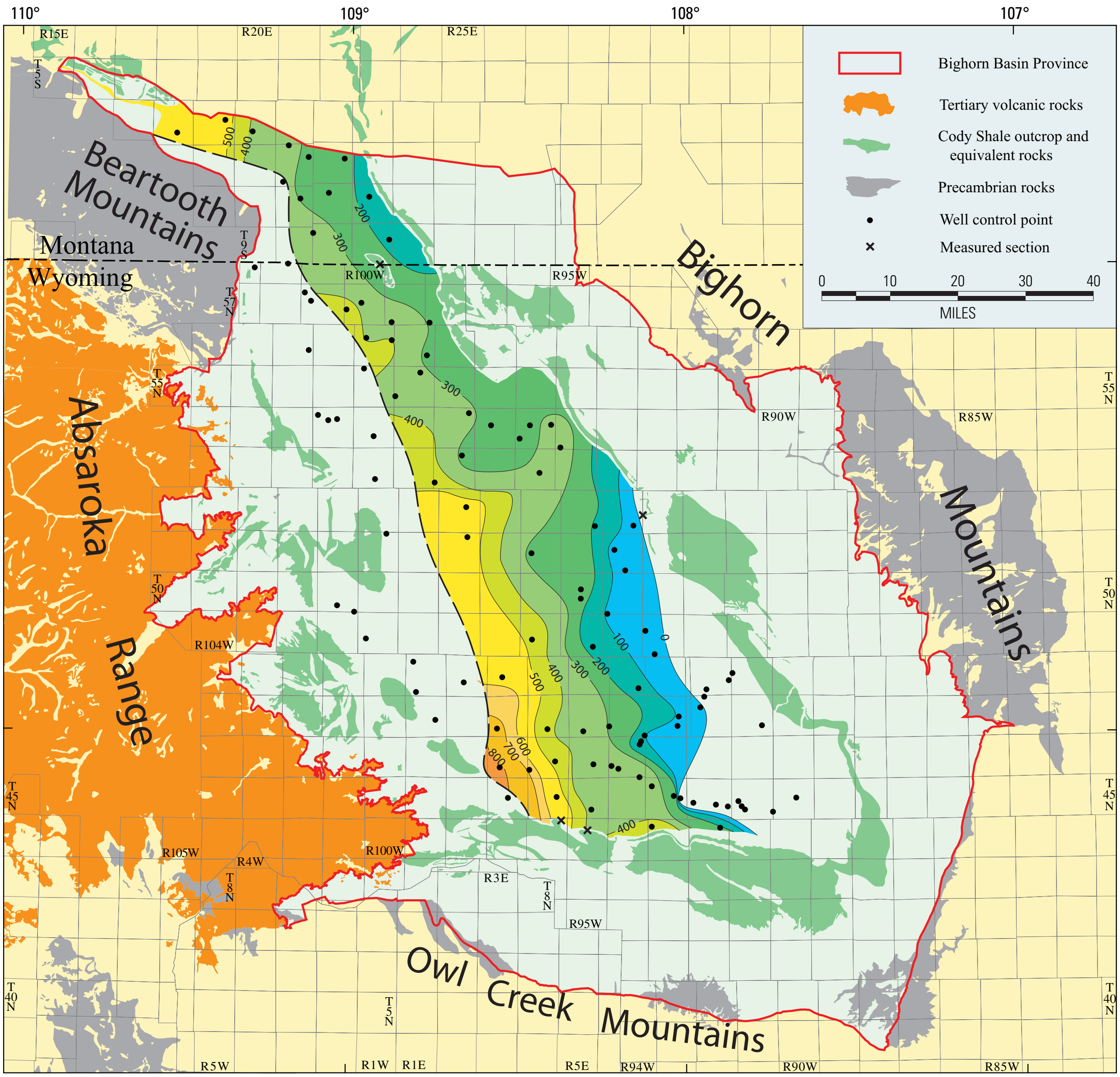

Figure 13. Isopach map of the lower member of the Mesaverde Formation and Eagle Sandstone, Bighorn Basin, Wyoming and Montana; thickness interval 100 ft. Outcrop data from Johnson and others (1998).

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 (fig. 6). Where present, the Bearpaw is about 80 to 200 ft thick (see Finn, Chapter 6, this CD–ROM); according to Johnson and others (1998), it consists 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 minor conglomerate and

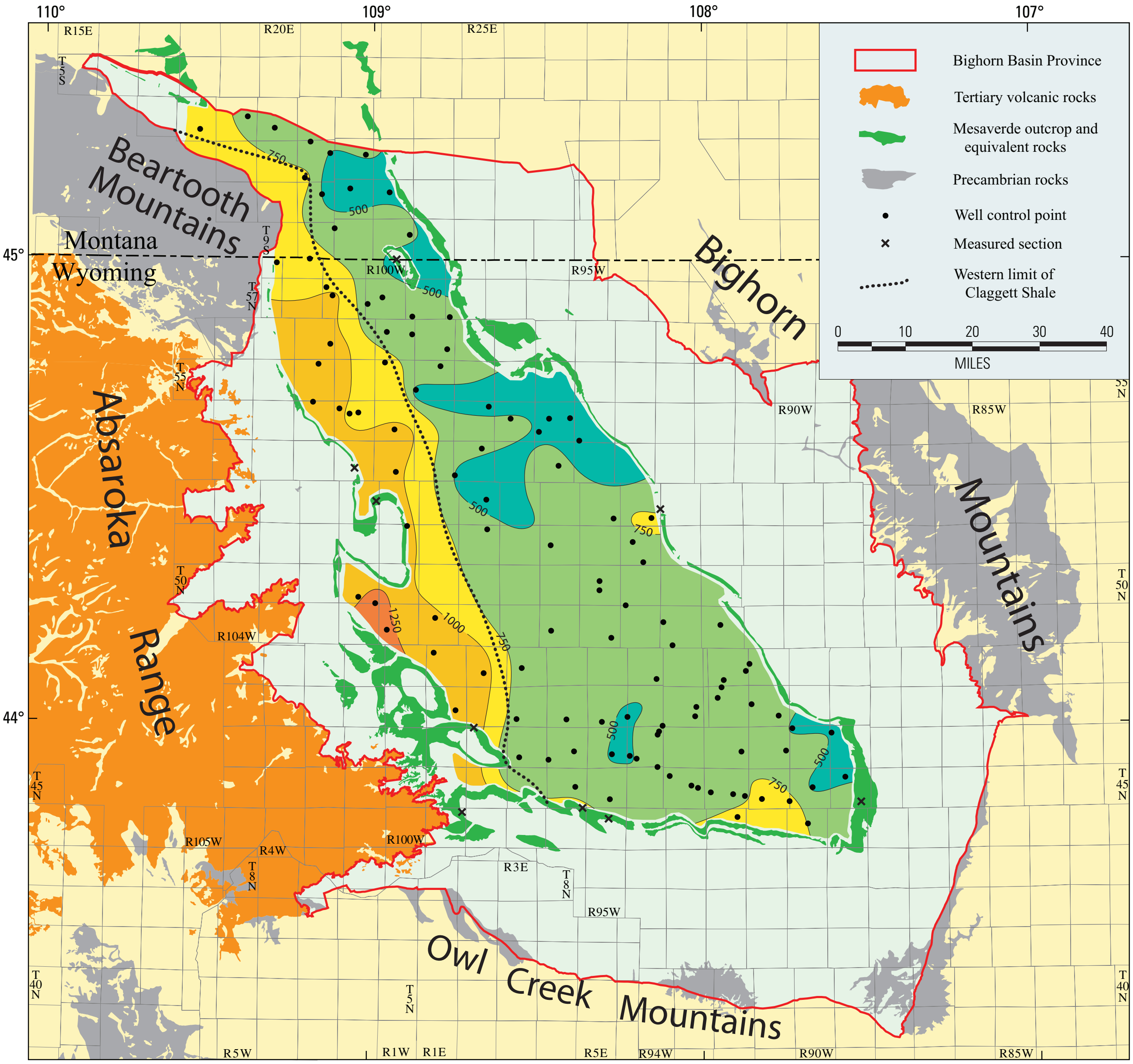

Figure 14. Isopach map of the main body of the Mesaverde Formation excluding the lower member and Eagle Sandstone, Bighorn Basin, Wyoming and Montana; thickness interval 250 ft. Outcrop data from Hewett (1912) and Johnson and others (1998).

represents the uppermost Cretaceous rocks in the Bighorn Basin. Minor amounts of coal are present locally, but Johnson (1998) concluded that it was of minor importance. Sandstone is the predominant lithology throughout much of the basin, particularly in the lower part of the formation, whereas the upper part is largely 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 Upper Cretaceous Fox Hills Sandstone. Johnson and Finn (2004) referred to this marginal marine interval as the Lennep Sandstone in Montana (figs. 6, 7). The Lance is generally considered to be Maastrichtian in age; however, palynogical age determinations by Nichols (1998) indicated 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 smaller

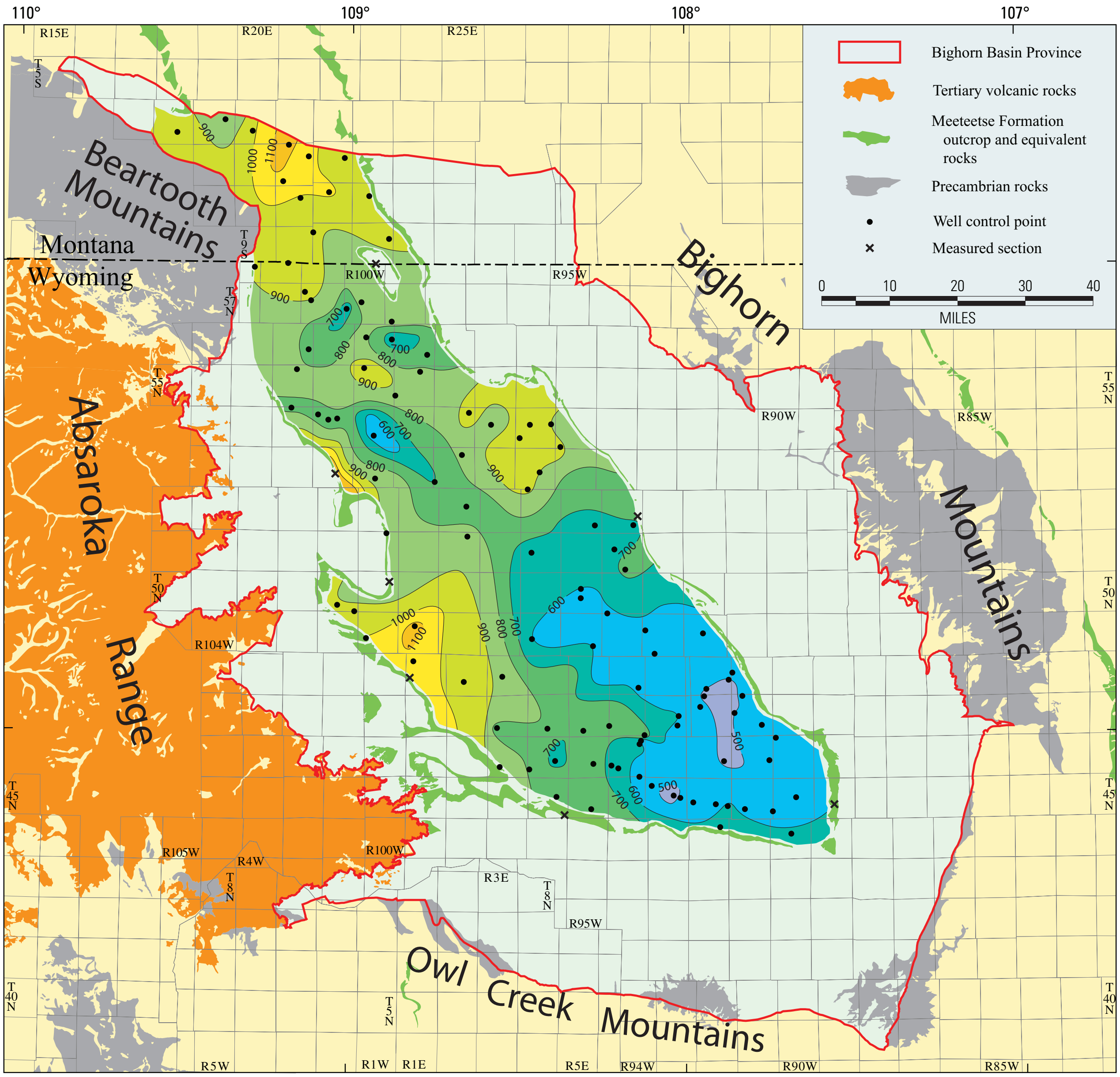

Figure 15. Isopach map of the Meeteetse Formation including the Lewis and Bearpaw Shales, Bighorn Basin, Wyoming and Montana; thickness interval 100 ft. Outcrop data from Hewett (1912) and Johnson and others (1998).

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 more than 1,500–1,800 ft near the basin axis (shown on fig. 3) adjacent to and east of the Oregon Basin thrust fault (figs. 3, 16) (Parker and Jones, 1986; see Finn, Chapter 6, this CD–ROM).

Fort Union Formation

The Fort Union Formation, referred to as the Polecat Bench Formation by Bown (1975) is composed 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 northwest margin of the Bighorn Basin and as fluvial channel deposits where streams flowed into the basin from surrounding highlands (Hickey, 1980; Johnson and Middleton, 1990; Roberts and Stanton, 1994; Roberts, 1998). The sandstones are very fine to coarse-grained and represent a variety of fluvial deposits, while the finer grained and carbonaceous deposits represent lacustrine and swamp deposits (Hickey, 1980; Yuretich and others,

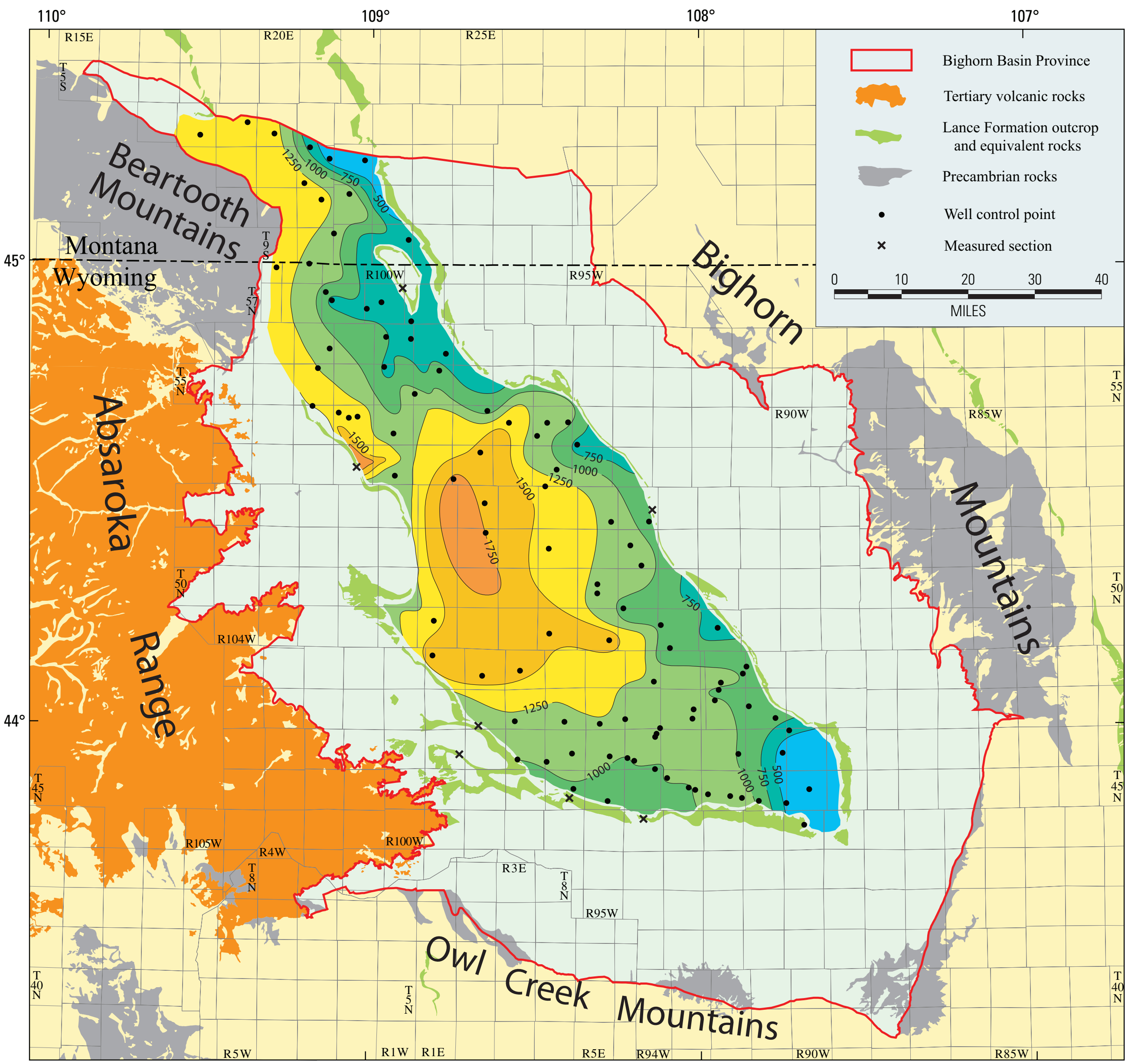

Figure 16. Isopach map of the Lance Formation, Bighorn Basin, Wyoming and Montana; thickness interval 250 ft. Outcrop data from Hewett (1912) and Johnson and others (1998).

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 formation is generally less than 1,000 ft thick around the basin margins, thins locally to about 300 ft in the north, and thickens to more than 7,500 feet in the structurally deepest central part (Moore, 1961; see Finn, Chapter 6, this CD–ROM). In outcrops around the margins it unconformably overlies Lance and locally 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

Strata that represent the lowermost Eocene in the Bighorn Basin are assigned to the Willwood Formation and consist of variegated shales, sandstones, and conglomerates (Van

Houten, 1944; Bown, 1980). The Willwood is nearly flat lying, occupies the central part of the basin, and conceals much of the structure of the underlying rocks (fig. 2). Bown (1980) reported a maximum thickness of nearly 2,400 ft in exposures in the southern part of the basin. The lower Eocene Tatman Formation overlies and in part interfingers with the Willwood. It is present only as isolated erosional remnants in the south-central part of the basin (Love and Christiansen, 1985; Bown, 1980), where it has a maximum thickness of nearly 900 ft, and is comprised of fine-grained sandstone and carbonaceous shale that accumulated in lakes and swamps (Van Houten, 1944). Keefer and others (1998) and Finn (Chapter 6, this CD–ROM) report a combined thickness for the Willwood and Tatman Formations of nearly 5,000 ft in the subsurface along the deep axis of the basin. The combined thickness of all lower Tertiary rocks ranges from less than 1,000 ft around the margins of the basin to greater than 12,000 ft near the basin axis, a pattern that reflects the present-day structure of the basin (figs. 3, 17).

Cretaceous–Tertiary Composite Total Petroleum System (503402)

The Cretaceous–Tertiary Composite Total Petroleum System (TPS 503402) produces oil and natural gas from predominantly sandstone reservoirs in anticlinal traps around the margins of the Bighorn Basin (fig. 18). The TPS covers most of the central part of the basin and encompasses approximately 7,900 mi^2. The south, east, and northeast boundaries are defined generally as the base of Cretaceous outcrops (fig. 18). The north boundary is drawn to include the production along the Nye-Bowler lineament and coincides with the province boundary. The northwest boundary along the Beartooth Mountain front is drawn at the contact between Precambrian crystalline rocks and younger sedimentary rocks. South of the Beartooth Mountains the TPS boundary extends to the eastern limit of the Absaroka volcanics, with the exception of the area in the vicinity of Rattlesnake Mountain where it is defined as the base of exposed Cretaceous rocks (fig.1). Within the TPS some areas were excluded with respect to resource potential (for example, Sheep Mountain and Thermopolis anticlines, fig. 1) because of being eroded deeply enough to have removed all Cretaceous and Tertiary rocks. Stratigraphically, the TPS includes reservoirs that range from Early Cretaceous to Paleocene in age (fig. 7).

Geochemical studies have identified two oil types in addition to those associated with the Permian Phosphoria Formation, both with characteristics of Cretaceous source rocks. One oil type appears to be sourced from the Thermopolis Shale and is produced mainly from Muddy Sandstone reservoirs, whereas the second has characteristics of oils derived from the Mowry Shale and is produced mainly from Frontier Formation reservoirs (P.G. Lillis, written commun., 2007). Geochemical data also show that there has been little or no mixing of the two oil types, indicating that the Cretaceous section could theoretically be divided into two separate TPSs. However, gas isotope studies by Johnson and Keighin (1998) indicate that there has been extensive vertical migration of thermogenic gases from deep mature source rocks into shallow reservoirs that are immature with respect to thermogenic gas generation; in some cases, these gases have mixed with biogenic methane generated at the shallower depths. Therefore, because of the extensive vertical migration and comingling of gases described by Johnson and Keighin (1998), and the difficulty in differentiating gas types and assigning them to specific source rocks, all Cretaceous and Tertiary source rocks, reservoirs, and accumulations have been assigned to one composite TPS for this assessment.

Source Rocks

Source rocks in the Bighorn Basin include organic-rich marine shales in the Thermopolis Shale, Mowry Shale, Frontier Formation, and Cody Shale (fig. 7). The amount and type of organic matter in these marine shales are summarized in figure 19, and was compiled from Schrayer and Zarrella (1963), Nixon (1973), Hagen and Surdam (1984), Burtner and Warner (1984), Hagen (1986), Davis (1986), Yin (1997), and Finn (Chapter 4, this CD–ROM). Guidelines for evaluating kerogen type and organic richness are from Peters and Cassa (1994).

The total organic carbon (TOC) content of the Thermopolis Shale ranges from 0.37 to 1.91 percent and averages 1.23 percent, indicating a fair to good generating potential. The hydrogen index (HI), ranging from 79 to 446 with all but one sample less than about 200, shows the formation to be predominantly gas-prone; however, S_2/S_3 ratios reported by Finn (Chapter 4, this CD–ROM), and associated oil production from the overlying Muddy Sandstone indicates that the Thermopolis generated, or has the potential to generate, oil (P.G. Lillis, written commun., 2007).

The TOC content for the Mowry Shale ranges from 0.08 to 3.6 percent with an average of 1.36 percent, indicating a poor to very good generating potential, with most samples falling in the fair to good range. The HI values range from 10 to 634, with most samples falling between 50 to 360, so the Mowry has the potential to generate both oil and gas.

The TOC content of the marine shales in the Frontier Formation ranges from 0.11 to 4.53 percent and averages around 1.13 percent, with most samples in the fair to good range of generating potential. HI values show the Frontier to be gas-prone, with values ranging from 10 to 201.

The TOC content of the Cody Shale ranges from 0.12 to 5.86 percent, with most samples falling around 1 percent or less; thus, the formation has fair generating potential, with some excellent potential locally. The HI ranges from 88 to 337, with most samples less than 200, indicating that the Cody is predominantly gas-prone but may be oil-prone locally. However, due to a lack of oil production associated with the Cody Shale (for example, from Cody sandstones and interfingering

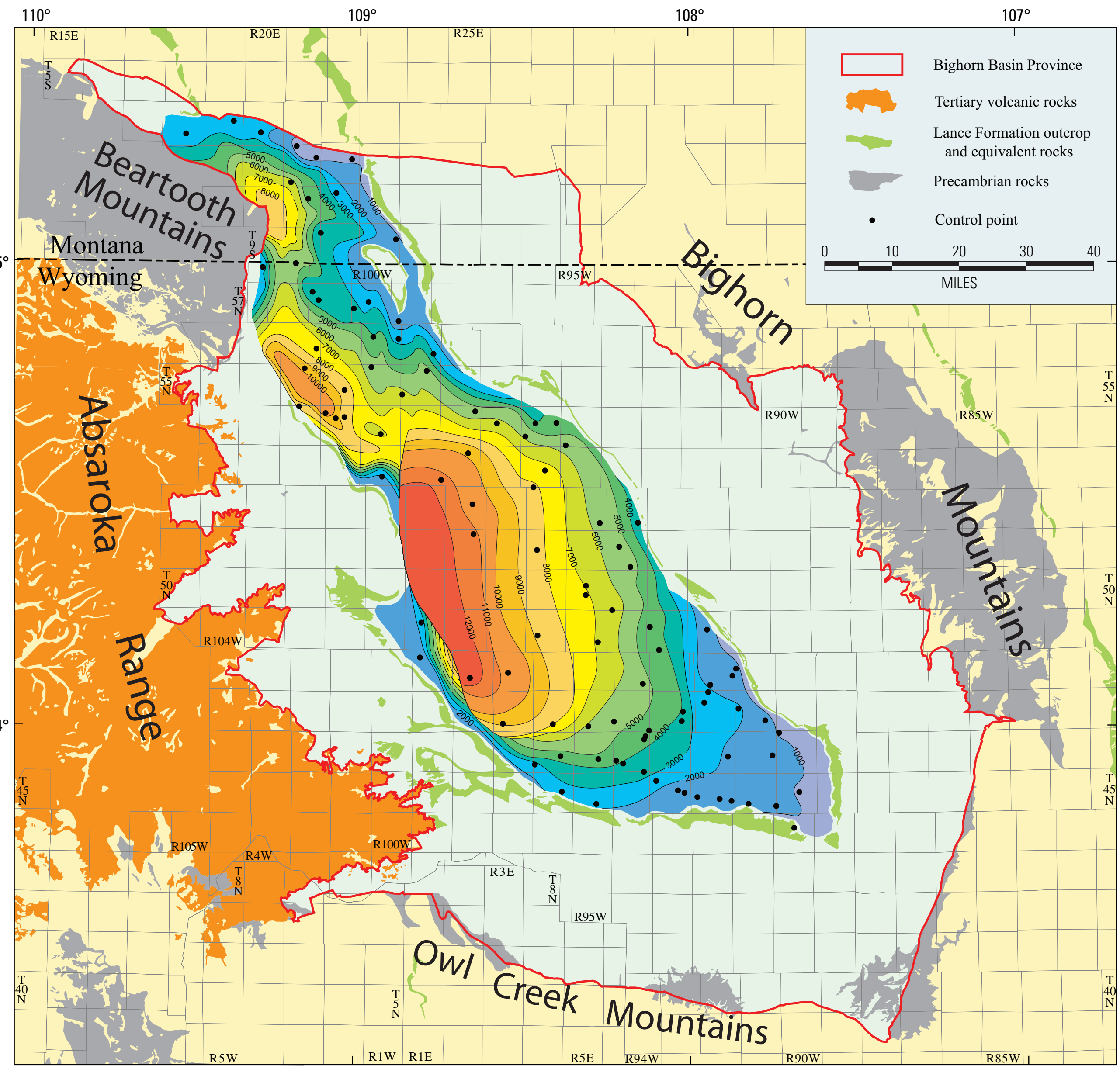

Figure 17. Isopach map of the Fort Union, Willwood, and Tatman Formations combined, Bighorn Basin, Wyoming and Montana; thickness interval 1,000 ft.

Mesaverde sandstones), it is believed to be mainly a gas-prone source rock.

In addition to the marine shales, coal beds and carbonaceous shales in the Mesaverde, Meeteetse, and Fort Union Formations are considered to be sources of gas in the Bighorn Basin (Nuccio and Finn, 1998; Yin, 1997) (fig. 7). However, according to Jones and DeBruin (1990) and Johnson (1998), the total volume of coal in the Bighorn Basin is considerably less than in the Wind River Basin, a basin of similar size where coal is thought to be an important source for gas (Johnson and others, 2007). Also, subsurface mapping by Johnson (1998) shows that the distribution of coal beds in the Bighorn Basin are limited (figs. 20, 21, 22), so are probably not a major source for gas generation.

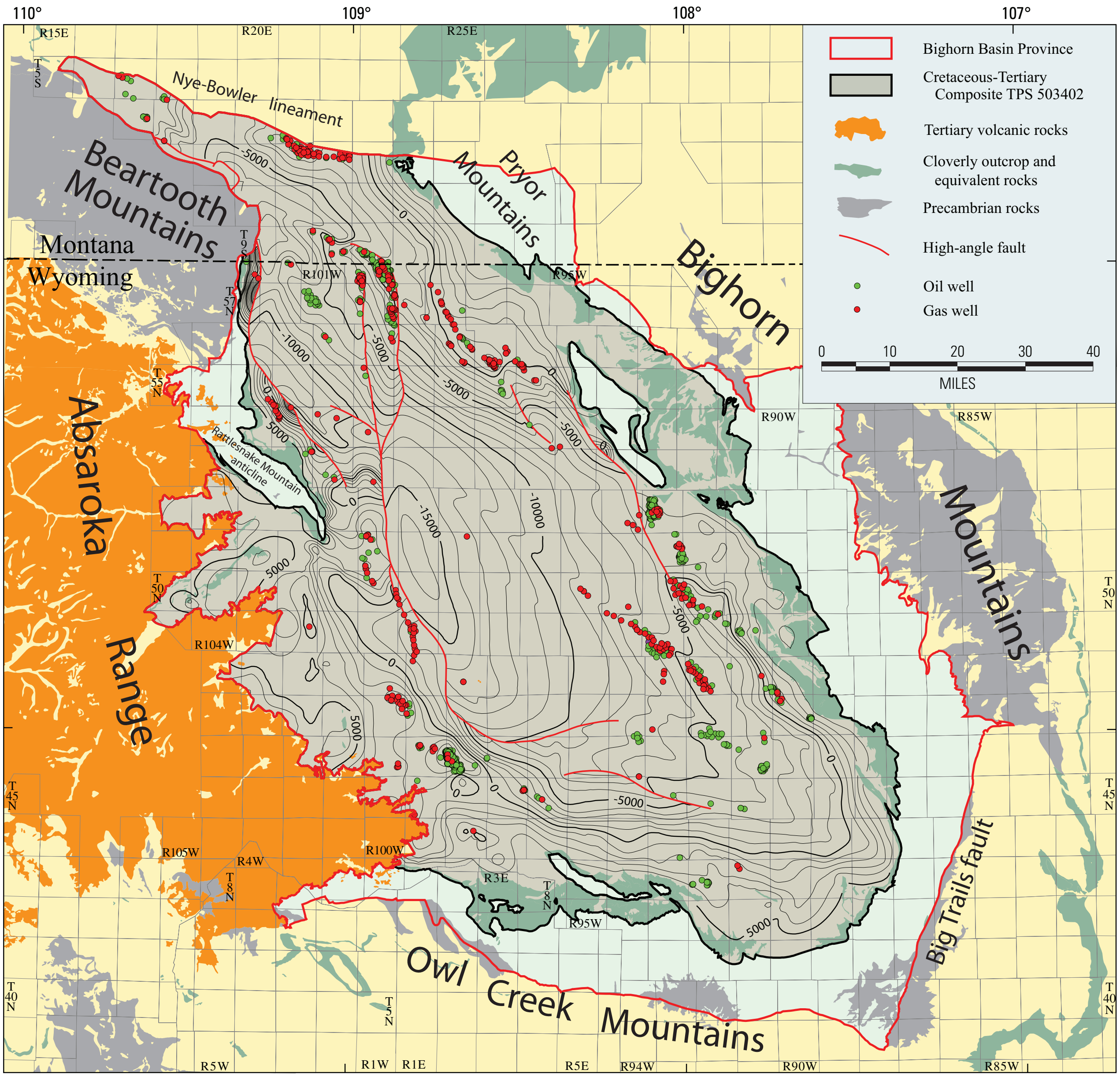

Figure 18. Map of the Bighorn Basin Province showing extent of the Cretaceous–Tertiary Composite Total Petroleum System (503402), major structural elements, and oil and gas wells that produce from Cretaceous and Tertiary reservoirs. Structure contours drawn on top of the Cloverly Formation; contour interval 1,000 ft.

Reservoir Rocks

The most important reservoir in the Cretaceous–Tertiary sequence in the Bighorn Basin is the Frontier Formation; sandstones with a minimum cumulative production of about 90 MMBO and 670 BCFG from some 1,250 wells (IHS Energy Group, 2007). This accounts for about 96 percent of the total oil production and 80 percent of the total gas production from all Cretaceous and Tertiary reservoirs combined, and about 31 percent of the total gas and 3 percent of the total oil production from all reservoirs in the basin. Production is from sandstone reservoirs encased in marine shale that in some cases pinch out across structures (Keefer, 1998). The sandstones are fine- to medium-grained, locally shaly, with porosities ranging from about 4 to 34 percent and permeabilities ranging from .001 to 260 millidarcies (mD) (Shapard, 1975; Tonnsen, 1985; Cardinal and others, 1989).

The Muddy Sandstone and the Cloverly Formation are next in relative importance as reservoirs in the Cretaceous–Tertiary interval. The Muddy Sandstone has produced a

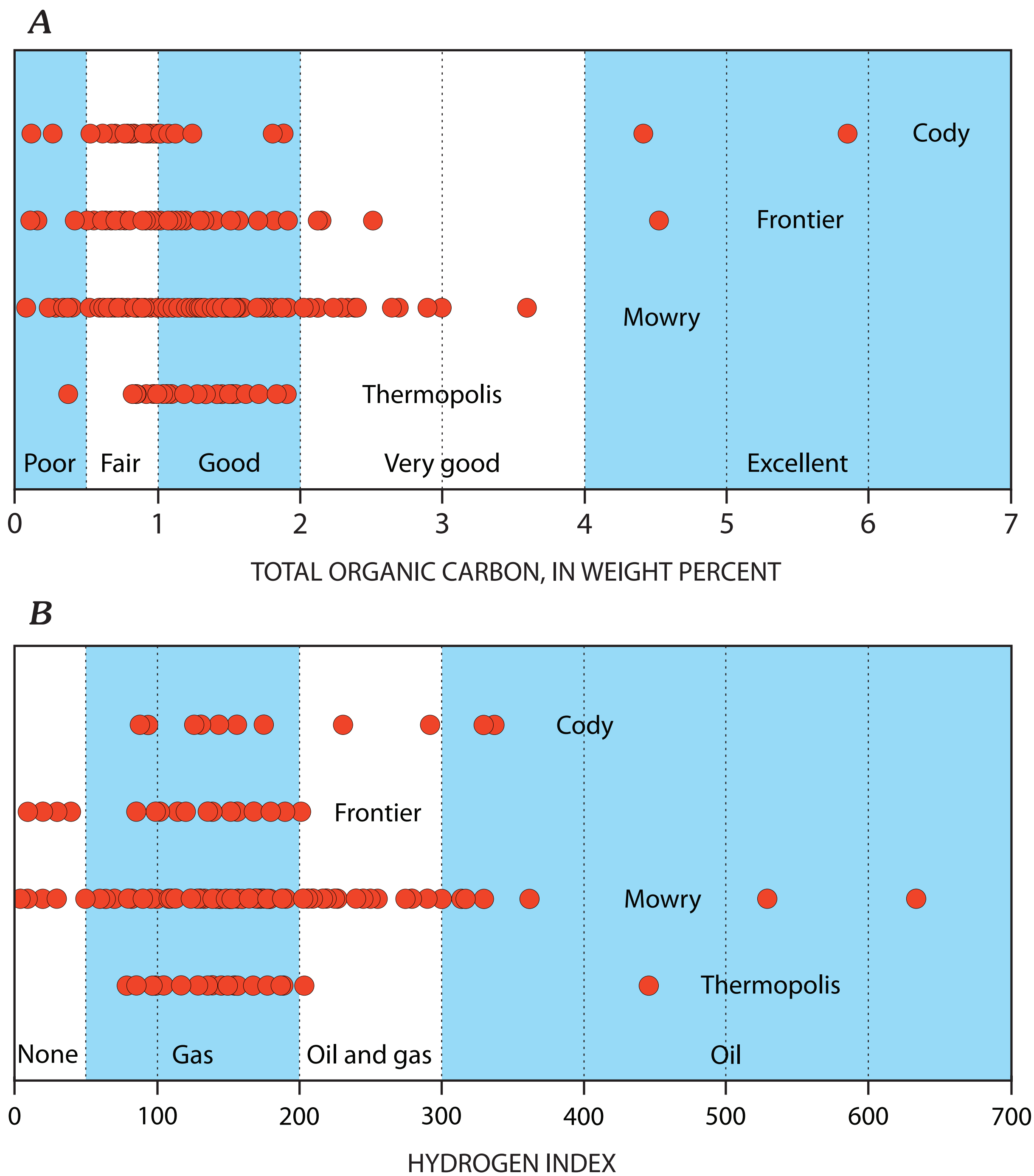

Figure 19. Plots showing (*A*) total organic carbon content and (*B*) hydrogen index of Cretaceous marine shales in the Bighorn Basin, Wyoming and Montana.

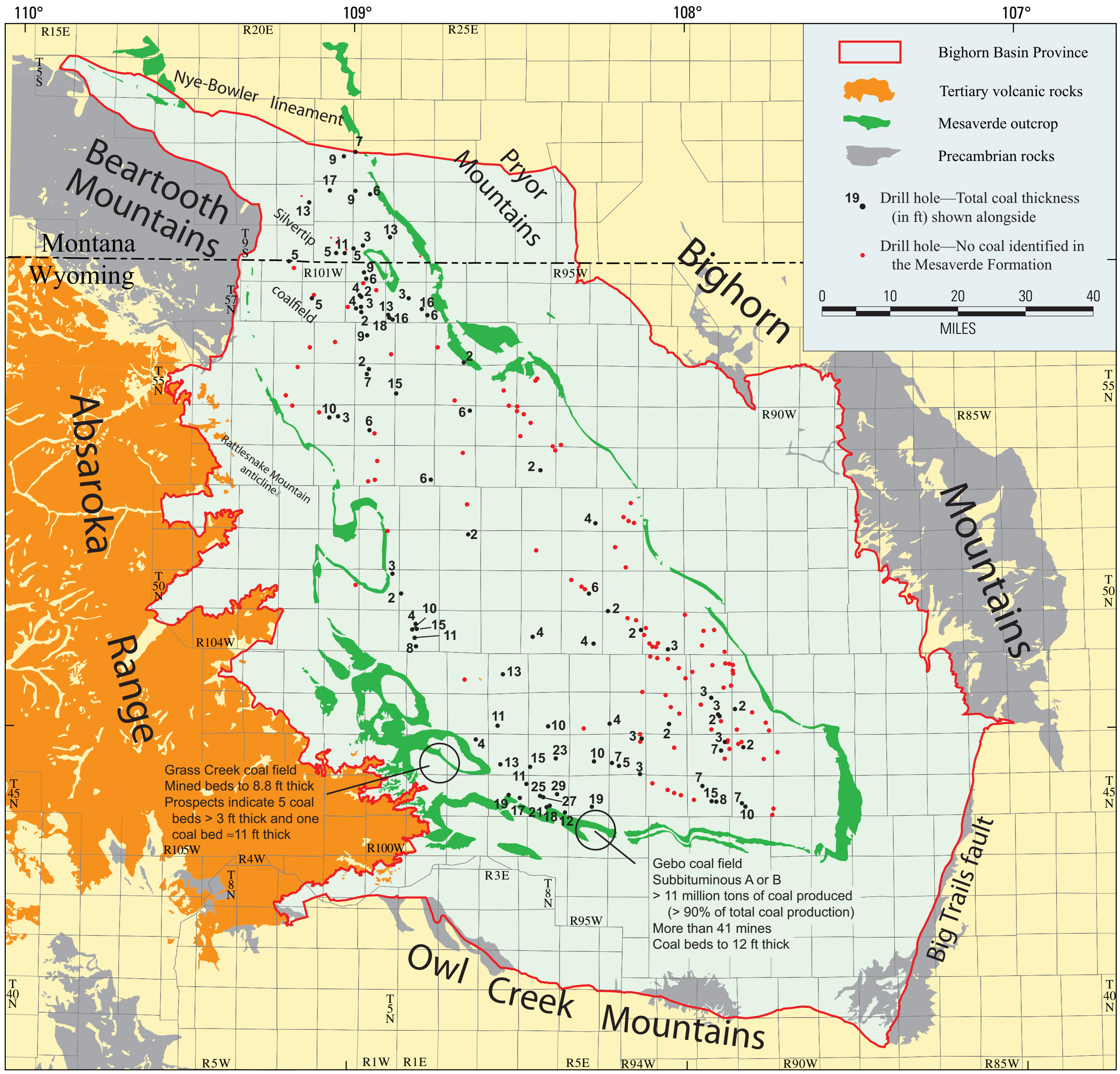

Figure 20. Map showing distribution and thickness (in ft) of coal in the Mesaverde Formation, Bighorn Basin, Wyoming and Montana. Data from Glass and others (1975) and Johnson (1998).

minimum of about 1.5 MMBO, and 117 BCFG from about 105 wells, accounting for about 1.5 percent of the oil and 14 percent of the gas that have been produced (IHS Energy Group, 2007). The reservoirs are generally very fine to medium-grained sandstones, with core porosities and permeabilities ranging from 1.6 to about 23 percent, and 0.01 to 8 mD, respectively (Cardinal and others, 1989). The Cloverly Formation has produced about 2 MMBO and 41 BCFG from about 240 wells, which accounts for about 2 percent of the oil and 5 percent of the gas produced from the Cretaceous–Tertiary section (IHS Energy Group, 2007). The main reservoir in the Cloverly is the Greybull Sandstone Member, a fine- to medium-grained sandstone with porosities generally ranging from 5 to 20 percent (max up to 30 percent) and permeabilities ranging from 0.41 to 50 mD (max 150 mD) (Hafenbrack and others, 1958; Tonnsen, 1985; Bartow-Campen, 1986; Cardinal and others, 1989). Additional production from the Cloverly is from the basal Pryor Conglomerate Member consisting of fine- to coarse-grained conglomeratic sandstone, and chert-pebble conglomerate, with

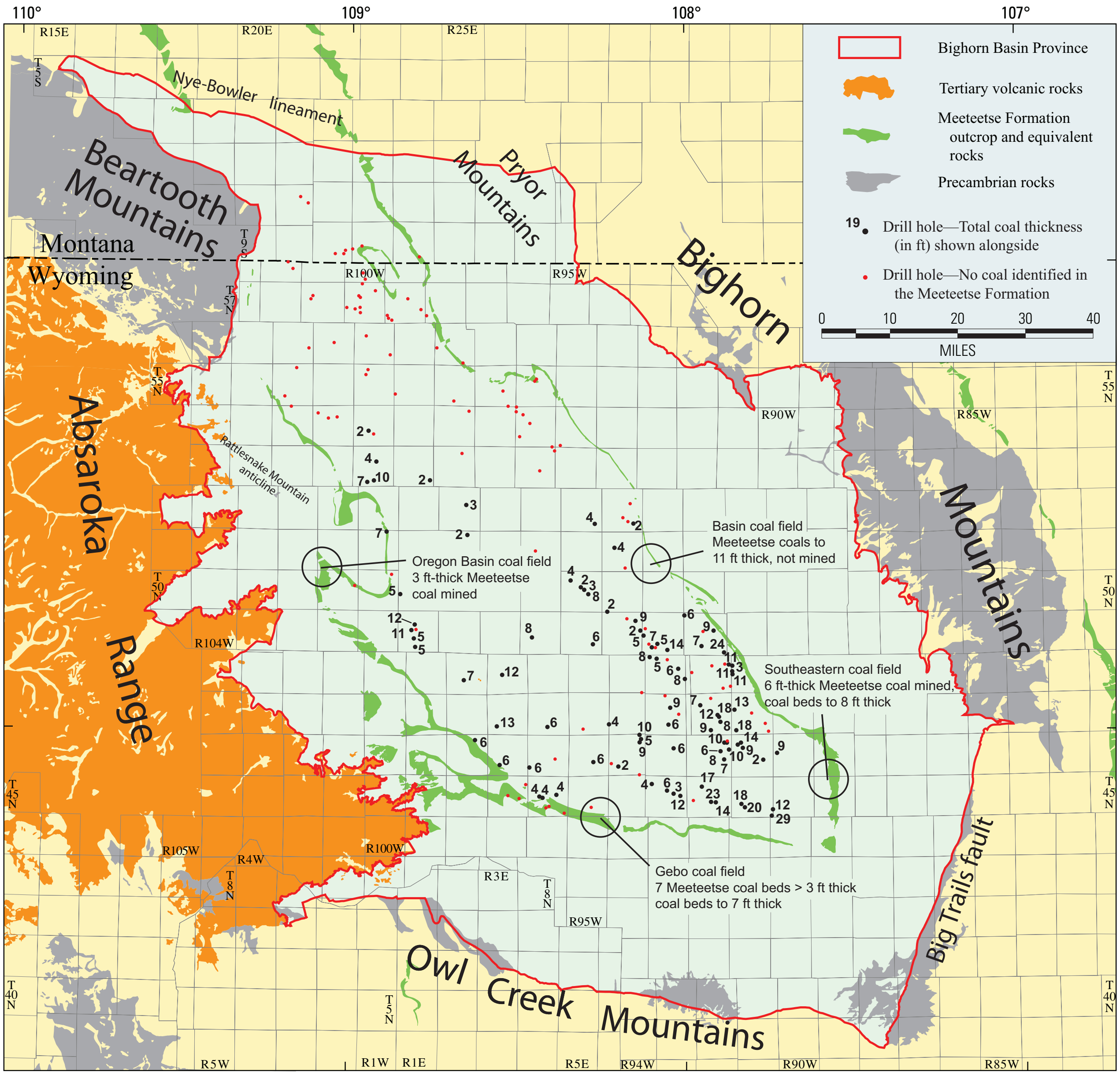

Figure 21. Map showing distribution and thickness (in ft) of coal in the Meeteetse Formation, Bighorn Basin, Wyoming and Montana. Data from Glass and others (1975) and Johnson (1998).

porosities ranging from 8 to 15 percent, and permeabilities ranging to as much as 75 mD (Hafenbrack and others, 1958; Tonnsen, 1985; Cardinal and others, 1989).

Minor reservoirs include the Mowry and Cody Shales and the Mesaverde (including the Eagle Sandstone and Judith River Formation), Meeteetse, Lance, and Fort Union Formations. Combined cumulative production from these units is about 410 thousand barrels of oil (MBO) and 7 BCFG, which accounts for less than one percent of the oil and gas produced from all Cretaceous–Tertiary reservoirs in the basin (IHS Energy Group, 2007). Reservoirs in the Mowry Shale are thin, fine-grained sandstones, referred to as the “Kimball” and “Octh Louie” sands, with reported log porosities of 13–16 percent (Cardinal and others, 1989); future potential from the Mowry might include production from fractured shale. Reservoirs in the Cody Shale are isolated shallow marine sandstones encased in marine shale. These beds are very fine to medium-grained, commonly blanket-like, can be traced for several miles, and appear to pinch out in marine shale in several directions. No porosities or permeabilities have been

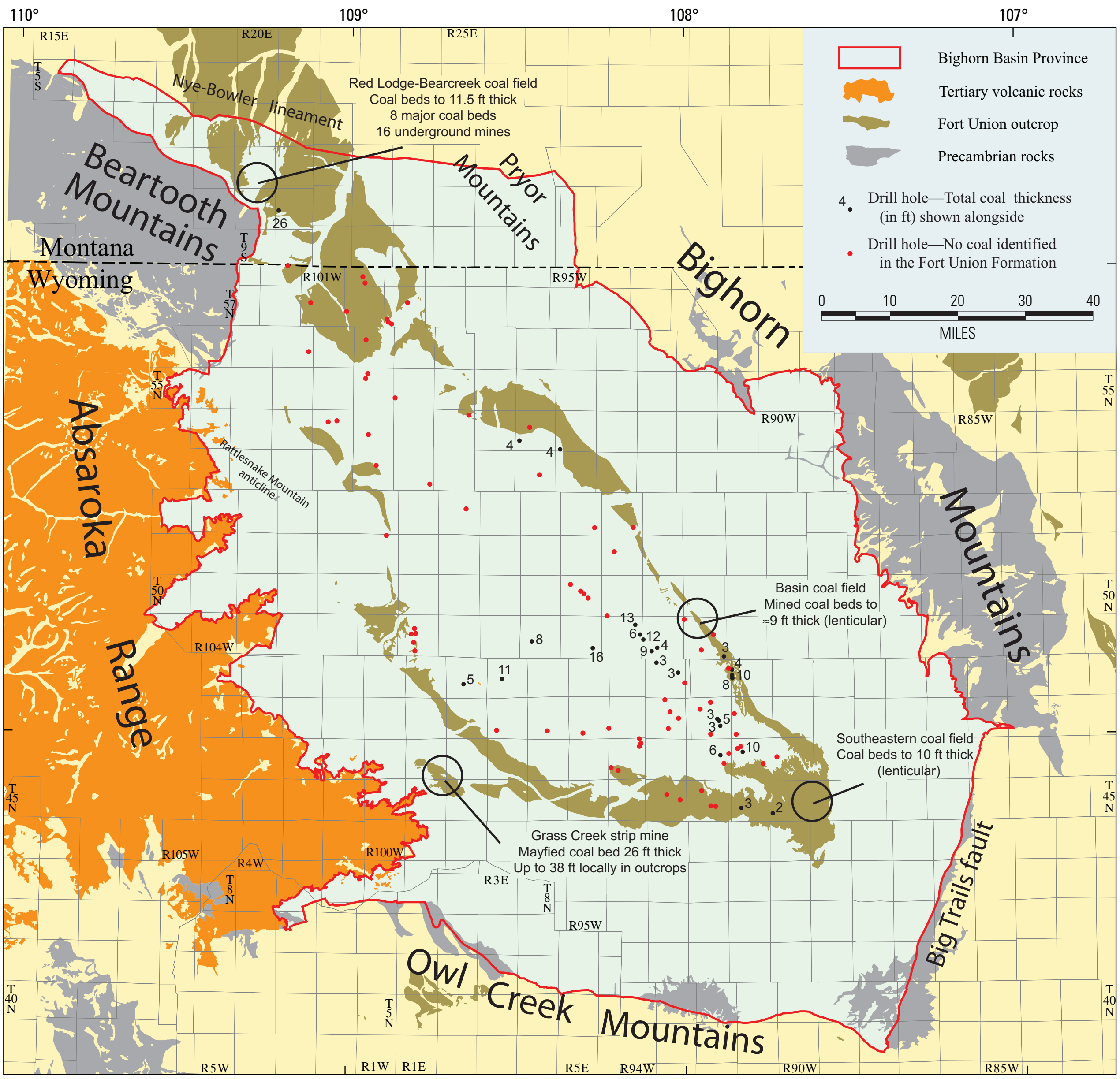

Figure 22. Map showing distribution and thickness (in ft) of coal in the Fort Union Formation, Bighorn Basin, Wyoming and Montana. Data from Woodruff (1907), Glass and others (1975), and Johnson (1998).

reported. Production from the Mesaverde and Meeteetse Formations (including the Judith River Formation) is from lenticular fluvial sandstones that have limited areal extent. In addition, some production in the Mesaverde (including the Eagle Sandstone) is from blanket-like, marginal marine sandstones. The sandstones are generally very fine grained, with porosities ranging from 10 to 26 percent (Shapard, 1975; Cardinal and others, 1989; Tonnsen, 1985). Potential future production from both formations might include coal beds in the coastal plain facies of each unit. However, as reported by Johnson (1998), coal beds have a limited distribution in the basin. Limited production from the Lance and Fort Union Formations is from fluvial sandstone reservoirs. Cardinal and others (1989) reported log porosities of 20–24 percent for the Lance, and 38 percent for the Fort Union, with no permeabilities reported. Potential future production from the Fort Union might be coal beds.

Traps and Seals

Production from conventional oil and gas accumulations from Cretaceous and Tertiary reservoirs is from anticlines and combination stratigraphic structural traps. To date most of the production is from anticlinal traps that formed during the Laramide orogeny (Fox and Dolton, 1996). These traps are mainly around the margins of the Bighorn Basin, the Nye-Bowler lineament (fig. 1), and along the Five Mile trend (fig. 3) (Fox and Dolton, 1989). The anticlines are typically asymmetric, thrust-fault-bounded along their steep flanks, and in many cases produce from more than one reservoir horizon (Hafenbrack and others, 1958; Tonnsen, 1985; Cardinal and others, 1989). Many of these traps have a stratigraphic component where lenticular or channel sandstones—such as those in the Frontier Formation, the Greybull Sandstone Member of the Cloverly Formation, and possibly the Muddy Sandstone—pinch out or are draped across structures (Anonymous, 1958; Stone, 1975; Cully, 1985; Mohl, 1989; Keefer, 1998; Talbot, 1996).

Limited drillstem test and mud log data from wells drilled in the structurally deep part of the basin indicate the presence of an overpressured basin-centered gas accumulation (BCGA) of limited extent in Cretaceous rocks and has been discussed in detail by Johnson and Finn (1998b) and Johnson and others (1999). Surdam and others (1997) also suggested the presence of an overpressured gas compartment in the Bighorn Basin based on sonic velocity anomalies. According to Johnson and Finn (1998b), the top of overpressuring in the main part of the basin generally is at depths between 13,000 and 17,000 ft, and in the deepest part of the basin extends from near the base of the Meeteetse Formation down to the base of the Cretaceous section (figs. 23, 24, 25). In the Clarks Fork sub-basin, the top of overpressuring starts at around 14,000 ft in the basal part of the Cody Shale and extends to near the base of the Cretaceous section (fig. 24*E*).

Thick sections of marine shale, ranging to as much as several thousand feet of strata in the Thermopolis, Mowry, Cody, Lewis, and Bearpaw Shales and the Frontier Formation, provide good quality regional seals throughout most of the Bighorn Basin (see cross sections by Finn, Chapter 6, this CD–ROM; and Johnson, Chapter 7, this CD–ROM). The thick marine shales are also important where they isolate marine sandstone reservoirs such as those in the Frontier Formation and the Cody Shale. In addition, nonmarine sandstone reservoirs are interbedded with shale and mudrock deposited in coastal or alluvial plain settings that provide local seals. The trap and sealing mechanism for BCGAs is generally believed to be formed where high water saturations are updip of gas-bearing low-permeability reservoir rocks thereby reducing the relative permeability of gas to near zero (Masters, 1979; Law and Dickinson, 1985; Spencer, 1989; Law, 2002). Masters (1979) referred to this type of trapping mechanism as a water block, whereas Law (2002) used the term capillary pressure seal. Fine-grained rocks in the Cloverly-Morrison interval act as a barrier to downward migration of gas out of the BCGA which helps to maintain pressure (Nelson, Chapter 5, this CD–ROM).

Thermal Maturity

In outcrop areas of the Bighorn Basin, thermal maturity based on vitrinite reflectance (R_o) values for coal-bearing strata range from 0.27 to 0.96 percent around the basin margins, but generally fall in the range of 0.3 to 0.5 percent (Nuccio and Finn, 1998; Finn and Pawlewicz, 2007). In the subsurface, Nuccio and Finn (1998) presented maps showing the levels of thermal maturity for the top of the Cody Shale and the top of the Mesaverde Formation (figs. 26, 27). These maps were constructed from data collected from coal-bearing strata (outcrop and wells) in the Mesaverde, Meeteetse, Lance, and Fort Union Formations (fig. 7). Thermal maturity maps for the Cody and Mesaverde show that R_o values are less than 0.73 percent around the margins of the basin and increase basinward to greater than 1.10 percent in the deeper areas (figs. 26, 27). In the Clarks Fork sub-basin, both the Mesaverde and the Cody reach a level of thermal maturity of around 0.80 percent, and only the Cody reaches a level exceeding 1.10 percent in the northern part of the basin adjacent to the Beartooth Mountains. The thermal maturity trends generally reflect the structural configuration of the basin, indicating thermal maturity is related to the structural development and burial history of the basin. These levels of thermal maturity are much lower than equivalent strata in the Wind River Basin and Southwestern Wyoming Province to the south. In the central deep part of the Wind River Basin both the Cody and the Mesaverde reach R_o levels greater than 2.0 percent and in one smaller area in the northeastern part, the R_o exceeds 3.0 percent (Johnson and others, 2007; Finn, 2007b). In the Southwestern Wyoming Province, Johnson and others (2005) show R_o levels for strata equivalent to the Cody Shale and Mesaverde Formation exceeding 2.2 percent. By comparison, R_o data collected by Finn and Pawlewicz (2007) in the deepest parts of the Bighorn Basin for Cretaceous strata older than the Cody Shale show values ranging to only around 1.8 percent at depths generally greater than 15,000 ft. Petroleum generation modeling by Roberts and others (2008) indicated that the Frontier Formation and older Cretaceous rocks may have reached an R_o level of 2.0 percent only at the Emblem Bench location in the deep part of the basin, whereas, equivalent rocks reached or exceeded this level over large parts of the Wind River Basin and Southwest Wyoming Province (Nuccio and others, 1996; Roberts and others, 2004; Roberts and others, 2007).

Hydrocarbon Generation

Roberts and others (2008) modeled the burial history, thermal maturity, and timing of petroleum generation for

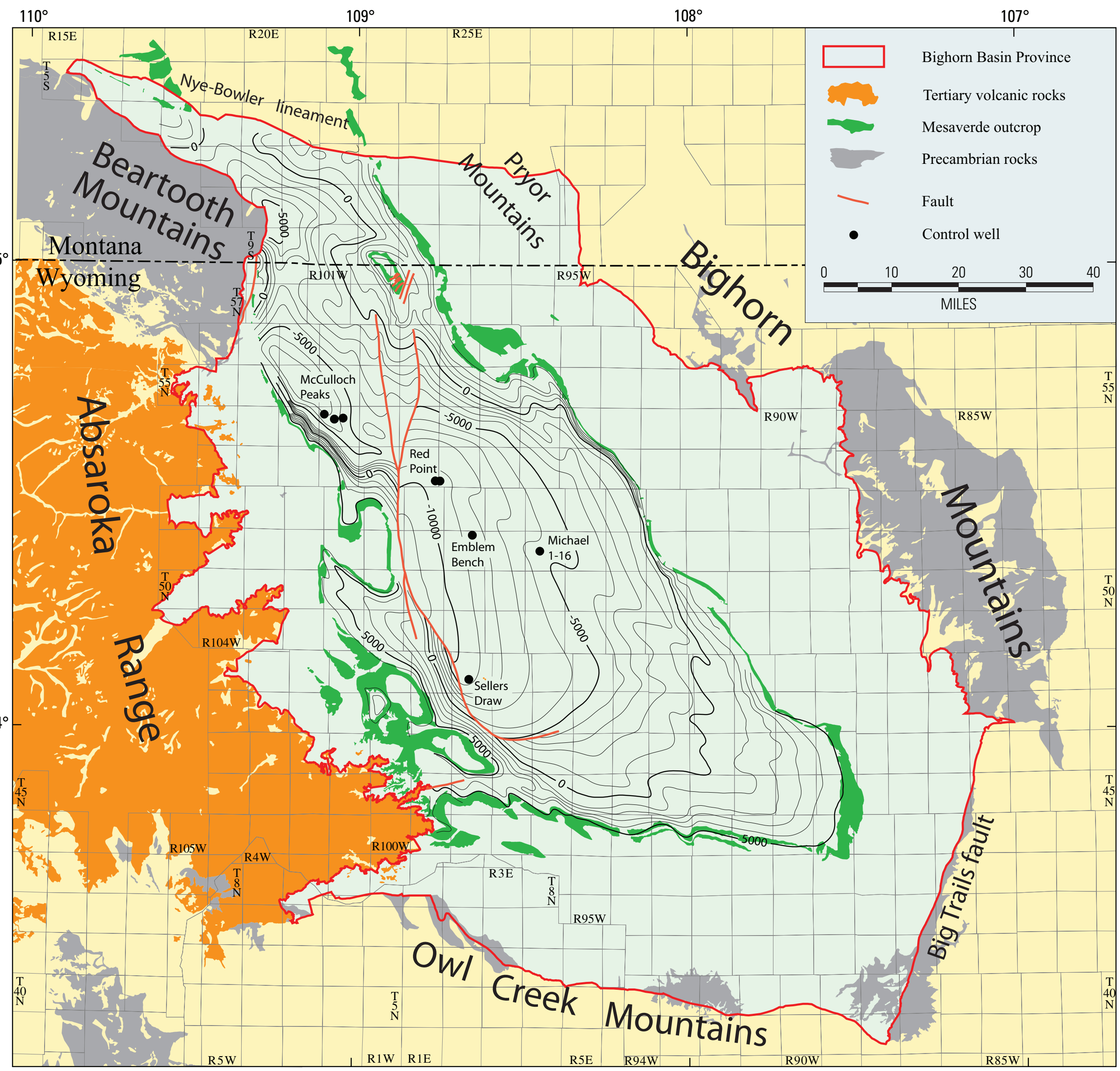

Figure 23. Map showing locations of wells with mud-weight and drillstem test data that indicate the presence of an overpressured basin-centered gas accumulation in the Bighorn Basin, Wyoming and Montana. Structure contours drawn on top of the Teapot Sandstone Member of the Mesaverde Formation are modified from Johnson and Finn (1998a); contour interval 1,000 ft.

Cretaceous and Tertiary source rocks at eight locations in the Bighorn Basin that differ in structural settings and represent deep, intermediate, and shallow burial depths. Two types of modeling were performed at each location to predict the timing and type of hydrocarbon generation from Type-III gas-prone source rocks, and from Type-II oil-prone source rocks. They are (1) time-temperature modeling based on vitrinite reflectance, and (2) kinetic modeling based on time-temperature integrated with the results of hydrous-pyrolysis experiments.

Time-temperature modeling predicts critical levels of thermal maturity based on vitrinite reflectance by integrating burial and thermal history and time to model gas generation from Type-III gas-prone source rocks. The results, summarized from Roberts and others (2008) in figure 28, indicate that in areas where source rocks were buried the deepest, gas generation from Type-III source rocks started in the early Paleocene (about 63 Ma for Cretaceous source rocks) to early Eocene (52 Ma for Fort Union source rocks), reached peak generation by early to middle Eocene (44 Ma for Cretaceous

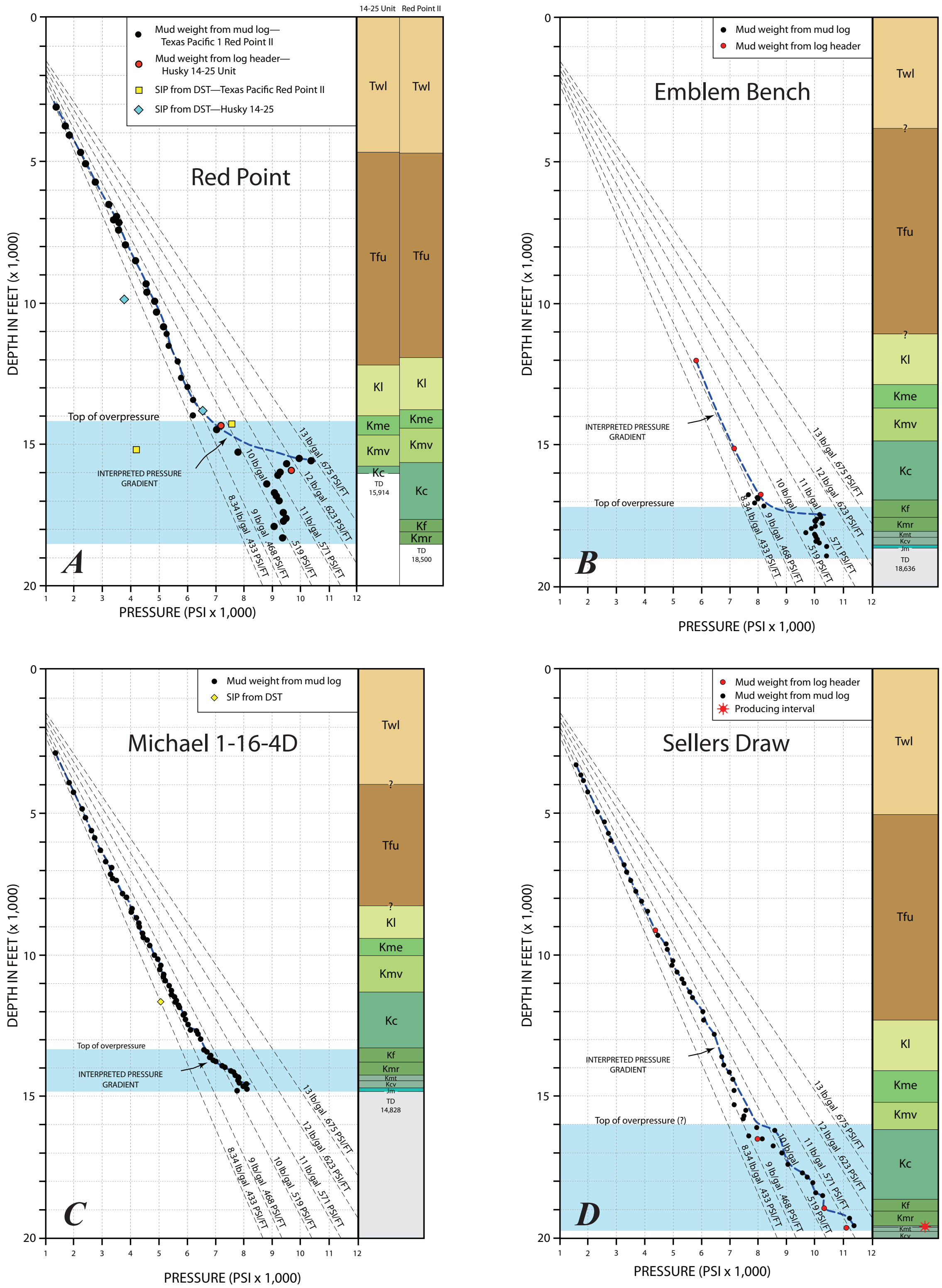

Figure 24 (above and next page). Pressure-depth plots for five locations in the deep part of the Bighorn Basin, Wyoming and Montana. Abbreviations: DST, drillstem test; lb/gal, pounds per gallon; PSI, pounds per square inch; SIP, shut-in pressure; TD, total depth; Jm, Morrison Formation; Kcv, Cloverly Formation; Kmt, Thermopolis Shale, Muddy Sandstone, undivided; Kmr, Mowry Shale; Kf, Frontier Sandstone; Kc, Cody Shale; Kmv, Mesaverde Formation; Kme, Meeteetse Formation; Kl, Lance Formation; Tfu, Fort Union Formation; Twl, Willwood Formation. Well locations shown in figure 23.

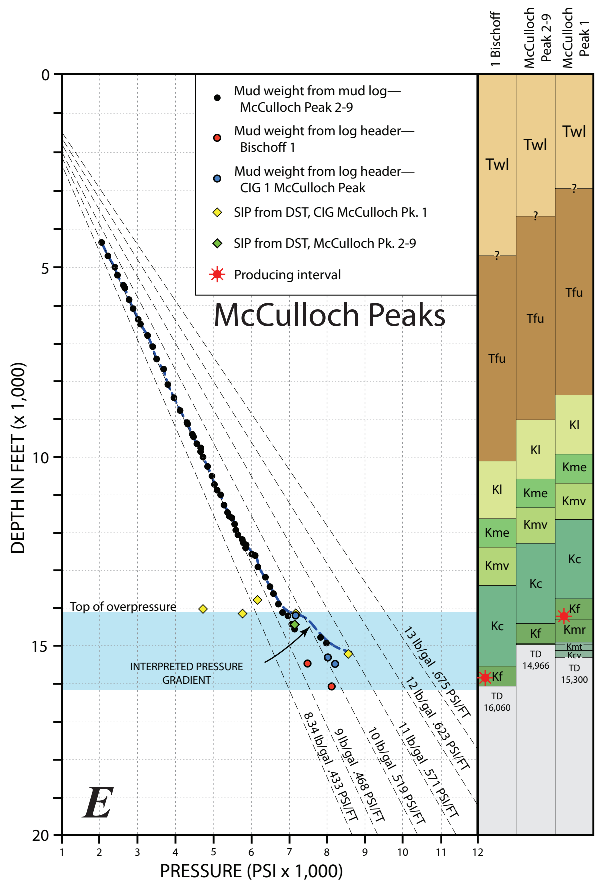

Figure 24.—Continued

source rocks), and ended only at the Emblem Bench location by the late Miocene (12 Ma for Frontier source rocks). The results are similar for source rocks buried at intermediate depths, except that Mesaverde and Meeteetse did not reach peak generation until later in the Eocene to early Miocene (47 to 15 Ma) and Fort Union source rocks did not reach peak generation. Timing of gas generation from source rocks buried at shallower depths, ranges from onset of gas from the middle Paleocene (60 Ma for the Thermopolis) to early Oligocene (33 Ma for the Fort Union) and peak generation was reached only in the Thermopolis, Mowry, Frontier, and Cody source rocks from middle Eocene (47 Ma) to early Miocene (23 Ma). Sometime after middle Miocene time (about 10 Ma), the region was uplifted (including the Bighorn Basin), resulting in the exhumation of the basin-bounding mountain ranges and removal of large volumes of the basin's sedimentary fill (Love, 1988). Subsequently, the basin cooled significantly reducing the rates of gas generation during the last 10 Ma (Roberts and others, 2008).

Kinetic models were generated for these same well locations to model oil generation from Type-II oil-prone kerogen. Kinetic modeling by Roberts and others (2008) used time and temperature integrated with results from laboratory hydrous-pyrolysis experiments by Lewan and Ruble (2002) and Tsuzuki and others (1999) to predict the timing and type of hydrocarbon generation. The results of this modeling, using hydrous-pyrolysis kinetic parameters, are summarized in figure 29. The results indicate that in areas where oil-prone source rocks of the Thermopolis and Mowry Shales were (1) buried the deepest, oil generation occurred from late Paleocene to middle Eocene (58 to 47 Ma); (2) buried at intermediate depths, oil generation occurred from late Paleocene to late Eocene (58 to 35 Ma); and (3) buried to shallowest depths, oil generation occurred in early Eocene (52 Ma) and ended only at Dobie Creek by early Miocene (19 Ma). Continued burial in the deeper part of the basin elevated maturities to a level sufficient to initiate cracking of oil to gas between about 37 Ma and 16 Ma; however, transformation ratios are only between 2 and 9 percent, indicating that the cracking of oil to gas does not contribute significantly to the gas potential of the basin (Roberts and others, 2008). As with gas generation rates of oil generation during the last 10 Ma have slowed due to post-middle Miocene regional uplift and exhumation of the basin (Roberts and others, 2008).

Events Chart

The events chart in figure 30 summarizes the essential elements of source rock, reservoir rock, seal rock, and overburden rock, and the processes of generation, migration, accumulation, and trap formation that are essential to form petroleum accumulations. Source rocks include marine shales deposited from Early to Late Cretaceous time (≈105–80 Ma) and include the Lower Cretaceous Thermopolis Shale, and the Upper Cretaceous Mowry and Cody Shales, along with marine shales in the Frontier Formation. Coal beds in the Upper Cretaceous Mesaverde and Meeteetse Formations and Paleocene Fort Union Formation (≈82–55 Ma) are also believed to be gas-source rocks. Reservoir rocks range in age from Early Cretaceous to Paleocene (≈134–55 Ma) and include (1) fluvial sandstones and conglomerate in the Cloverly Formation, (2) fluvial and estuarine sandstones in the Muddy Sandstone, (3) sandstone and possibly fractured shale in the Mowry Shale, (4) marine sandstones in the Frontier Formation and upper part of the Cody Shale, (5) marginal marine and fluvial sandstones and coal beds in the Mesaverde and Meeteetse Formations, (6) nonmarine sandstones in the Lance Formation, and (7) nonmarine sandstones and coal beds in the Fort Union Formation. The Thermopolis, Mowry, Cody, Lewis, and Bearpaw Shales provide thick regional seals. In addition, shales interbedded with sandstone reservoirs provide local seals.

Important structural traps formed during the Laramide orogeny where compressional tectonics formed numerous anticlines along the margins of the basin. Permeability in tight basin-centered accumulations is thought to be enhanced by fractures that resulted from Laramide deformation. Based on burial history and petroleum-generation modeling, the amount of overburden rock required to reach thermal maturation levels

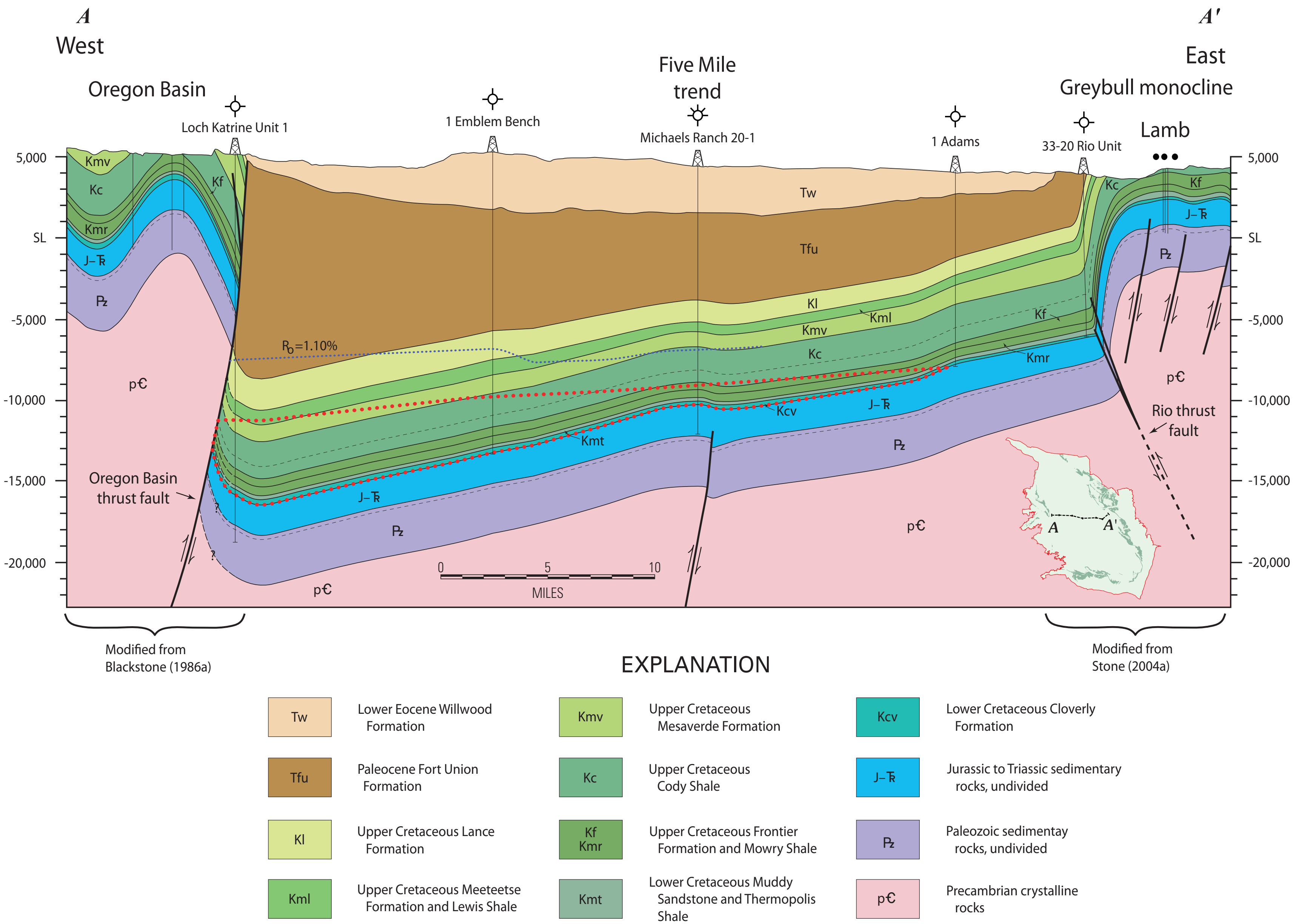

Figure 25. Diagrammatic east-west cross section of the central part of the Bighorn Basin, Wyoming and Montana, showing the extent of the overpressured basin-centered gas accumulation (shown within the dotted red line). Line of section shown in figure 2. SL, sea level. Modified in part from Blackstone (1986a) and Stone (2004a).

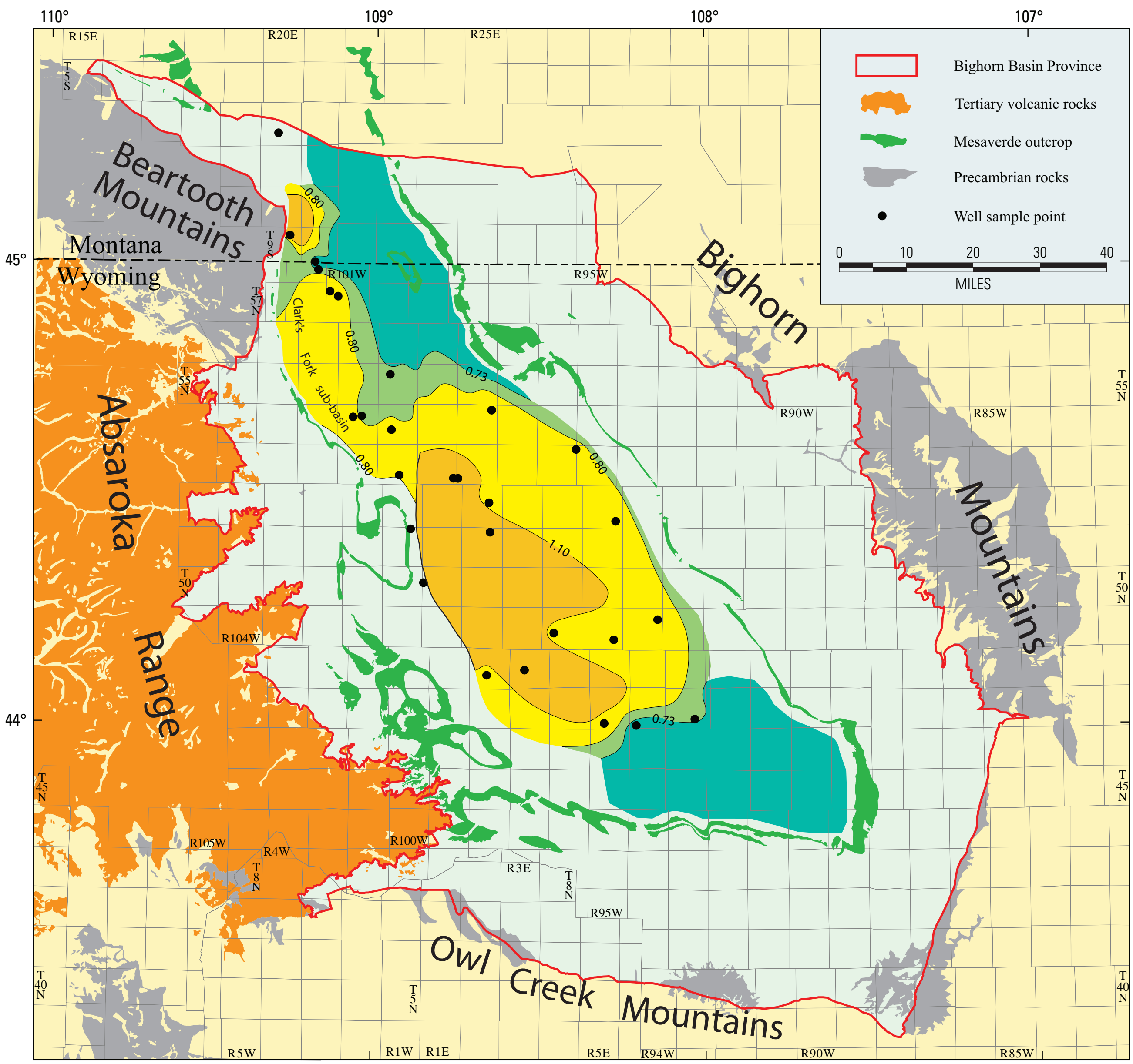

Figure 26. Map showing levels of thermal maturity based on vitrinite reflectance (in percent) for the top of the Cody Shale in the Bighorn Basin, Wyoming and Montana. Modified from Nuccio and Finn (1998).

sufficient to generate hydrocarbons (gas) from the oldest source rocks—Mowry and Thermopolis Shales—accumulated by about 63 Ma in the deeper parts of the basin (fig. 28). Continued subsidence and deposition progressively buried the younger source rocks until they achieved levels of thermal maturity sufficient to generate hydrocarbons. Locally in some of the deeper parts of the basin, generated oil reached thermal maturities sufficient to initiate thermal cracking of oil to gas. Gas generated in the deeper parts of the basin migrated vertically, in some cases many thousands of feet into younger, less mature reservoirs. Around 10 Ma the Rocky Mountain region, including the Bighorn Basin, was uplifted, initiating erosion and rapid basin excavation. Subsequent cooling significantly reduced the rates of hydrocarbon generation. However, computer modeling indicates that in some parts of the basin minor generation may continue to the present day.

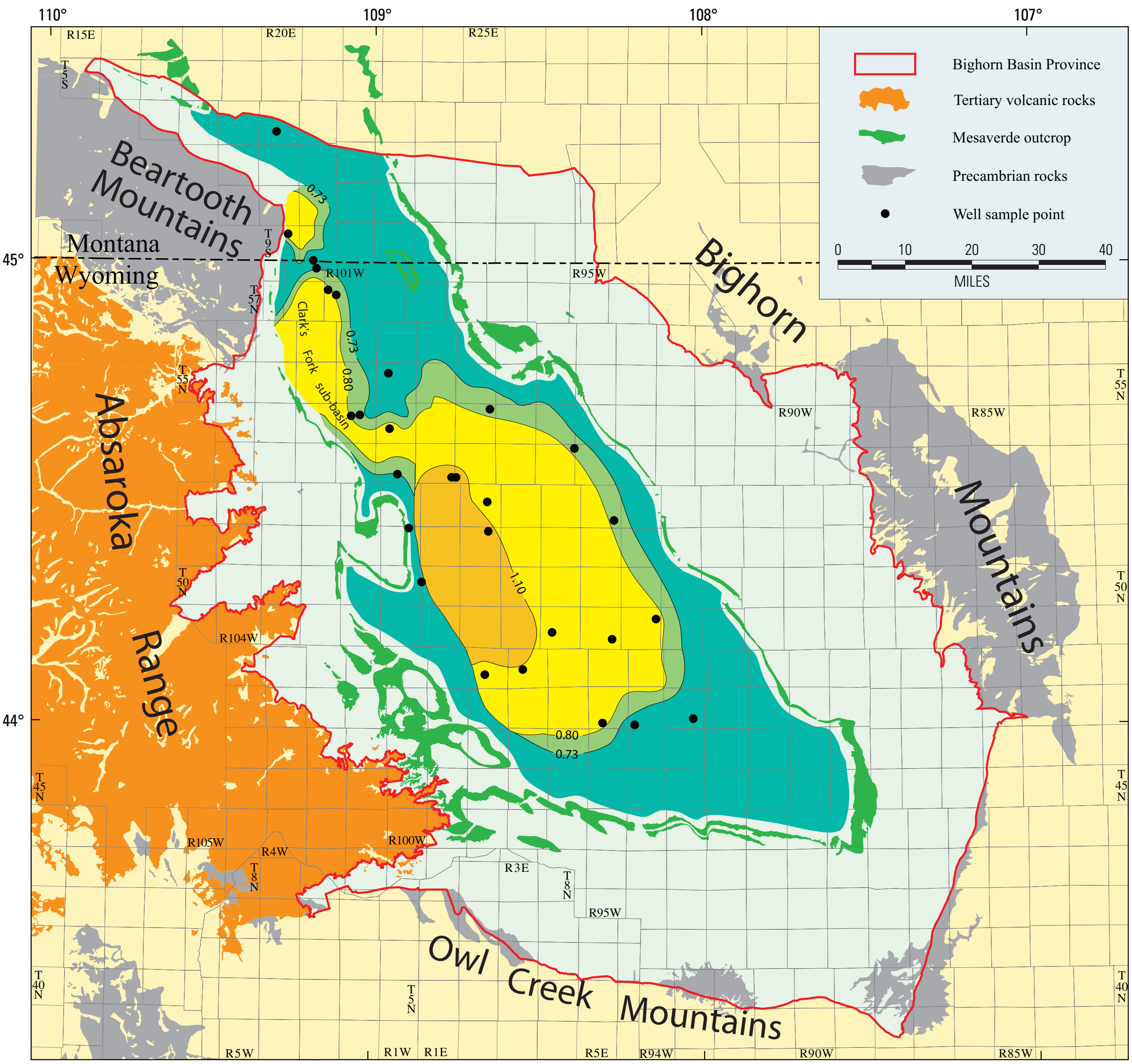

Figure 27. Map showing levels of thermal maturity based on vitrinite reflectance (in percent) for the top of the Mesaverde Formation in the Bighorn Basin, Wyoming and Montana. Modified from Nuccio and Finn (1998).

Assessment Units and Results

An assessment unit (AU) is a mappable volume of rock within a Total Petroleum System (TPS) that contains known or postulated oil and gas accumulations that share similar geologic characteristics (Klett and others, 2000). The Cretaceous–Tertiary Composite TPS (503402) is subdivided into seven AUs. Three are identified as basin-centered gas accumulations (BCGA): the Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas AU (50340261), the Cody Sandstone Continuous Gas AU (50340263), and the Mesaverde Continuous Gas AU (50340264). One fractured shale oil accumulation, the Mowry Fractured Shale Continuous Oil AU (50340262), and two coalbed gas accumulations: the Mesaverde-Meeteetse Coalbed Gas AU (50340281), and the Fort Union Coalbed Gas AU (50340282) were defined. One conventional AU was defined, the Cretaceous–Tertiary Conventional Oil and Gas AU (50340201). The Cretaceous–Tertiary Conventional Oil and Gas AU (50340201) and the Muddy-Frontier Sandstone and

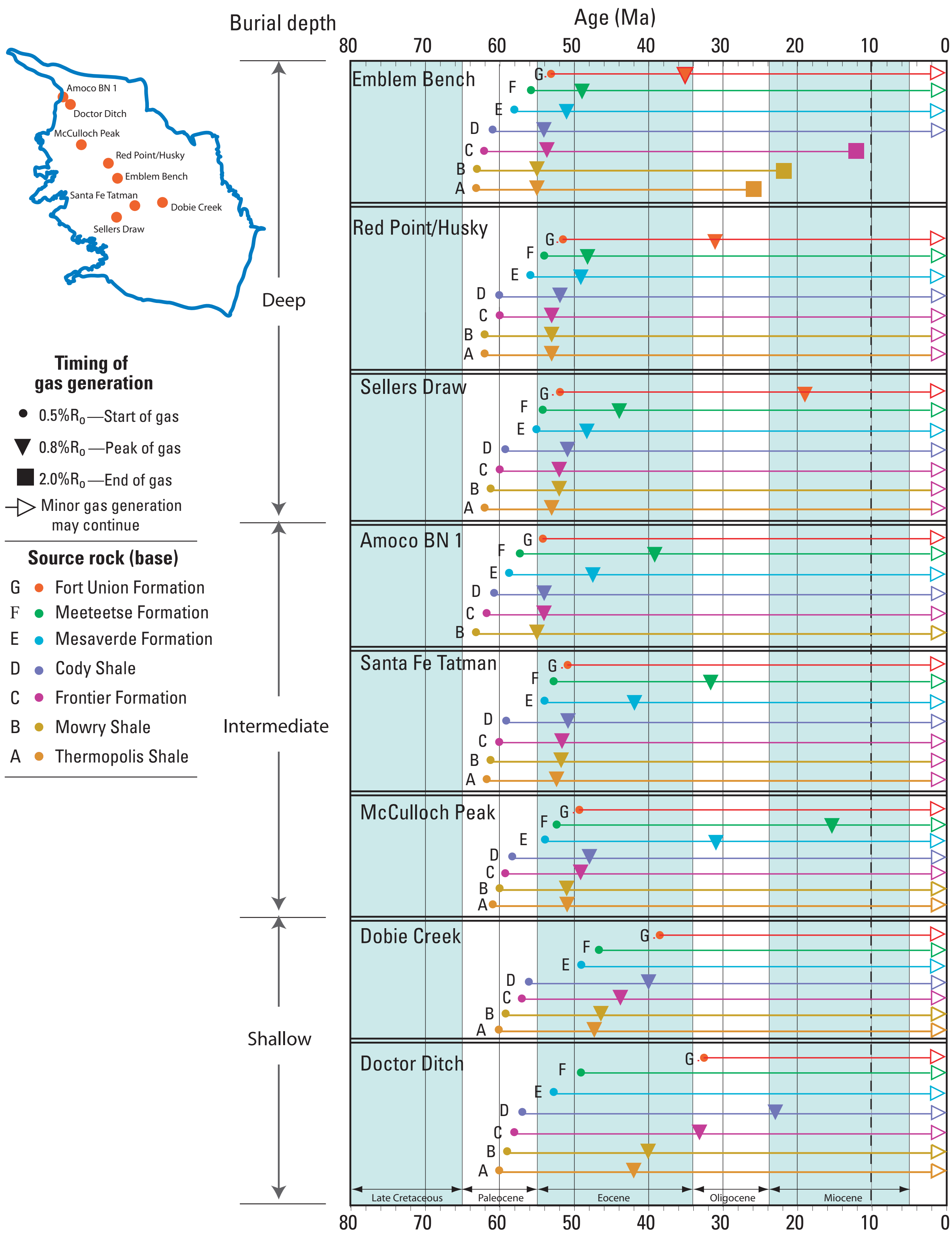

Figure 28. Timing of gas generation from Type-III gas-prone source rocks in the Bighorn Basin, Wyoming and Montana. From Roberts and others (2008). R_o, vitrinite reflectance.

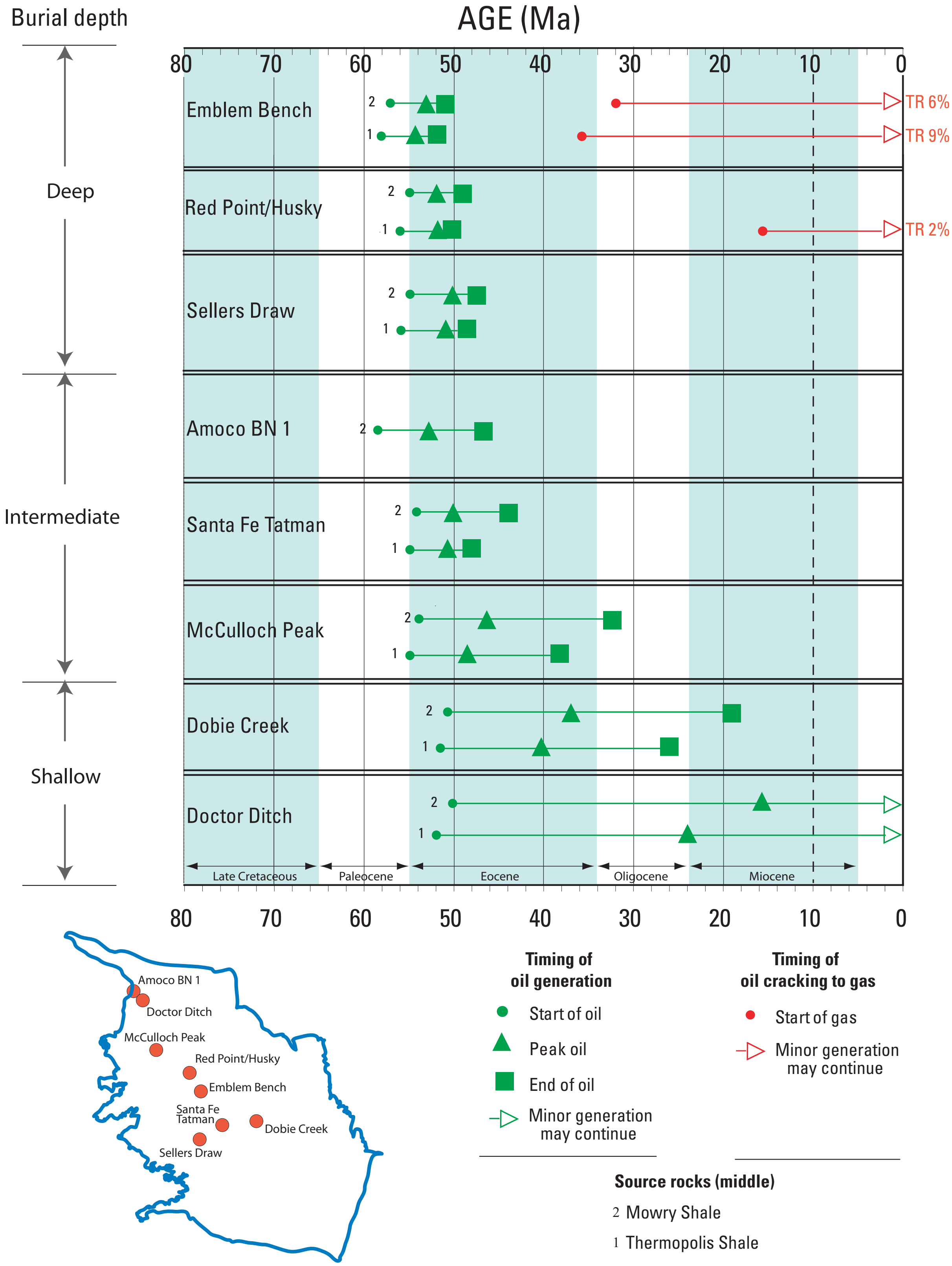

Figure 29. Timing of oil and gas generation from Type-II oil-prone source rocks in the Bighorn Basin, Wyoming and Montana. From Roberts and others (2008). TR, transformation ratio.

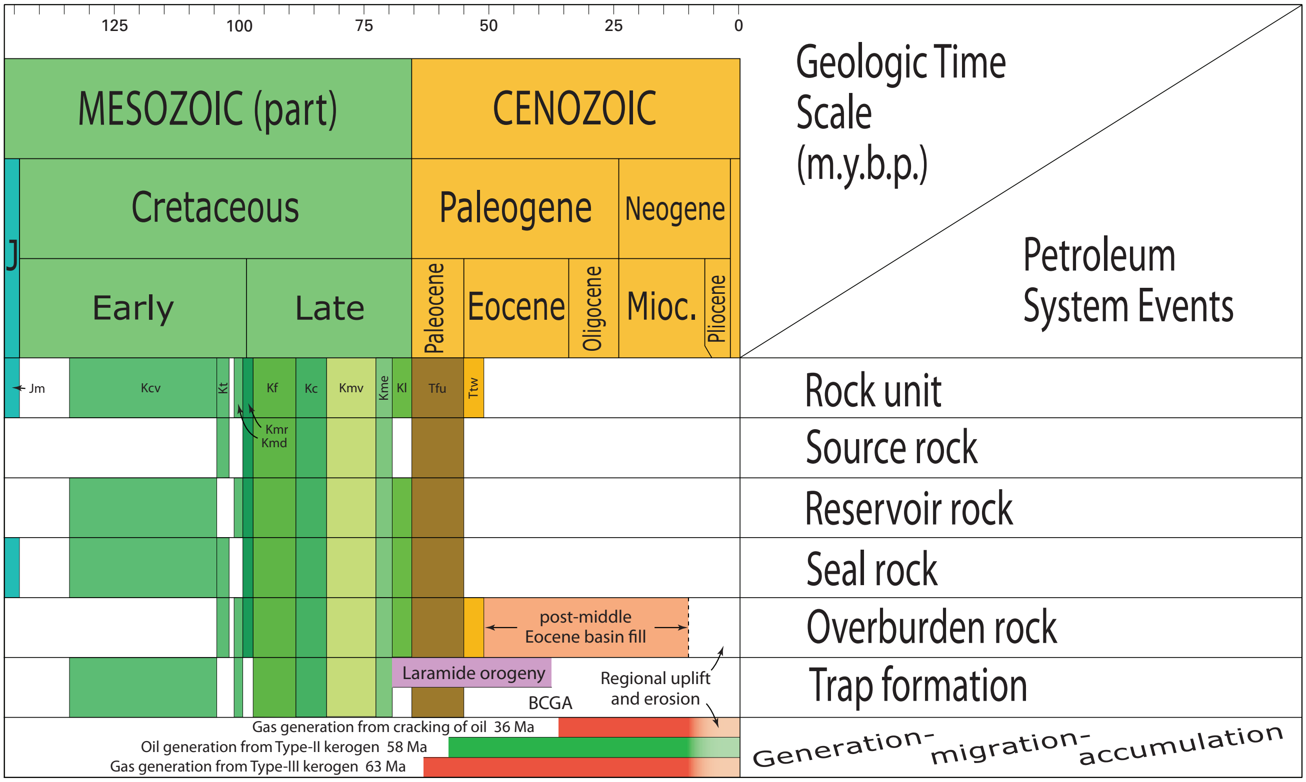

Figure 30. Events chart summarizing the essential elements and processes of the Cretaceous–Tertiary Composite Total Petroleum System. Jm, Morrison Formation; Kcv, Cloverly Formation; Kt, Thermopolis Shale; Kmd, Muddy Sandstone; Kmr, Mowry Shale; Kf, Frontier Sandstone; Kc, Cody Shale; Kmv, Mesaverde Formation; Kme, Meeteetse Formation; Kl, Lance Formation; Tfu, Fort Union Formation; Ttw, Tatman and Willwood Formations undivided. BCGA, basin-centered gas accumulation.

Mowry Fractured Shale Continuous Gas AU (50340261) both have established production; the remaining five AUs have no production and are considered hypothetical. (Note: the coding numbers follow the worldwide coding system used by the USGS).

Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas Assessment Unit (AU 50340261)

The Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas Assessment Unit (AU 50340261) is an established AU that is thought to have additional potential to produce gas from low permeability fluvial and estuarine sandstone reservoirs, marine deltaic and shoreface sandstone reservoirs, and fractured marine shale reservoirs. The AU consists of two areas totaling approximately 1,500 mi^2 in the center of the Bighorn Basin and in the deepest part of Clark's Fork subbasin (fig. 31). The AU boundary is defined as that part of the petroleum system where the conditions favorable for continuous gas accumulations are met using the criteria established by Spencer (1987): (1) greater than normal pressures, (2) present-day temperatures greater that 200° F, (3) vitrinite reflectance greater than 0.8 percent, (4) presence of low permeability sandstone or fractured shale, and (5) no reported gas/water contacts. Based on relatively sparse data, these conditions are generally met at a depth of around 12,000 ft, except in the Clark's Fork sub-basin where the boundary is placed at a deeper level. These contour lines have been modified where information was obtained from (1) drillstem test results and (or) mud weights that indicate greater than normal pressure gradients, (2) wells with mud logs that have gas shows in reservoir units, and (3) vitrinite reflectance data for rocks of the AU that show the area is mature for gas generation. The south edge of the AU corresponds to a fault described by Stone (1999) and also shown by Ver Ploeg (1985), which Stone interprets to be a continuation of the Tensleep fault (fig. 3). The west boundary of the main assessment area is placed at the projected footwall cutoff of the top of the Frontier Formation, which is slightly west of the surface trace of the Oregon Basin thrust fault (see fig. 25).

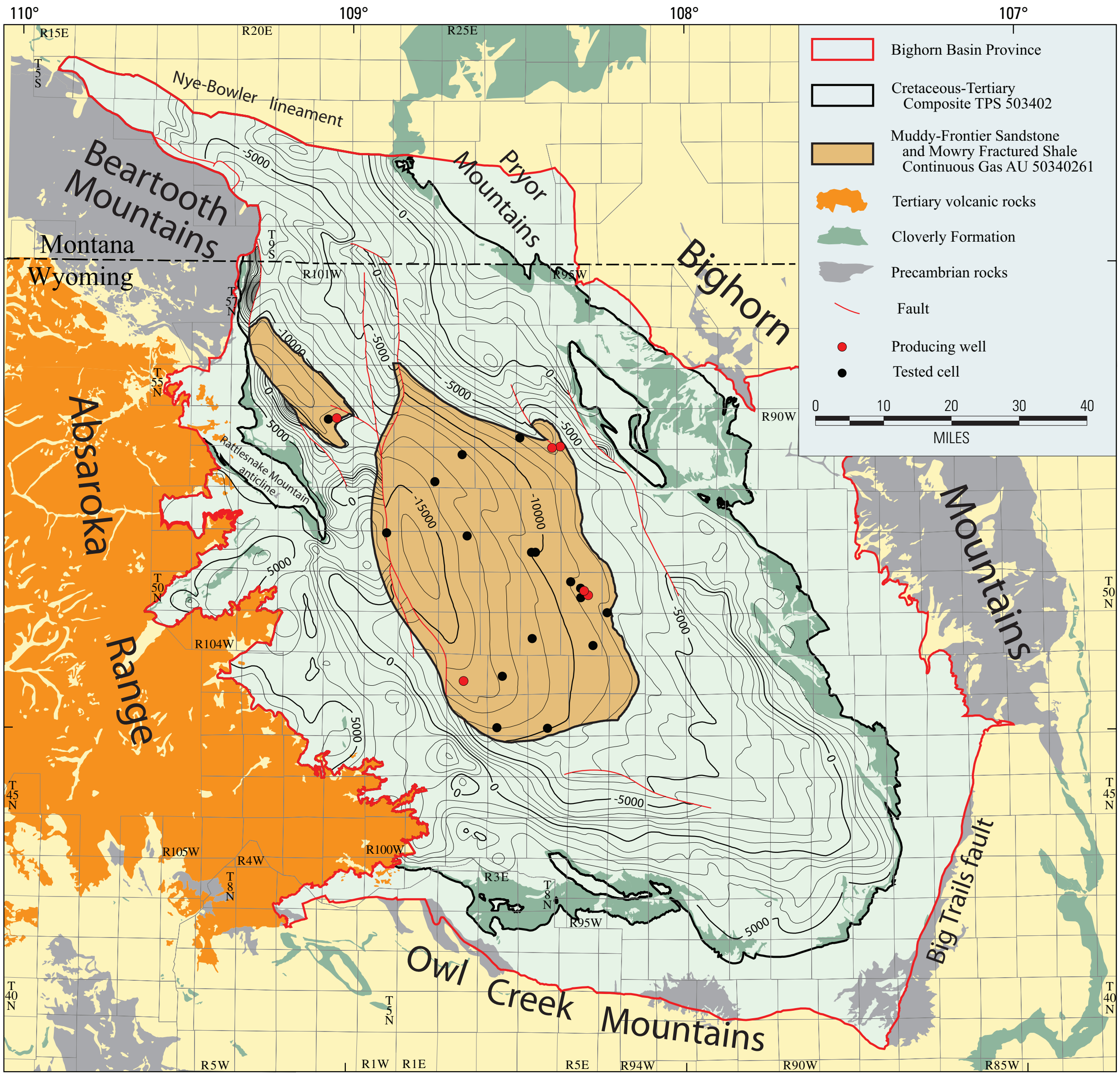

Figure 31. Map showing the areal extent of the Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas Assessment Unit (50340261) in the Cretaceous–Tertiary Composite Total Petroleum System, Bighorn Basin, Wyoming and Montana. Structure contours drawn on top of the Cloverly Formation; contour interval 1,000 ft. TPS, Total Petroleum System; AU, Assessment Unit.

Potential additions to reserves would come from drilling depths ranging from about 10,500 to 21,000 ft. There are about 144 wells within the AU boundary, of which 23 are interpreted to be wells tested in the formation. Some of the test wells had minor production, gas shows and (or) production, and drillstem tests; others reached their total depth in the AU indicating a test. Five wells had production above the minimum cutoff of 20 MMCFG; however, only the Sellers Draw well (see fig. 23 for location) had production exceeding one BCFG. The remaining 121 wells were either drilled in the hanging wall of the Oregon Basin thrust fault, and therefore did not test the basin center, or did not show sufficient evidence that the operator tested the units for gas; for example, in one well the Cretaceous rocks defining the AU were cased off and the obvious target was deeper in the Paleozoic strata. The paucity of data unit makes most of the area of the AU untested and gives rise to considerable uncertainty in the evaluation of potential additions to reserves. Analogs are drawn from similar assessment units in the Wind River and Green River Basins (Kirschbaum and Roberts, 2005; Johnson and others, 2007).

Input data for assessment of the Muddy-Frontier Sandstones and Mowry Fractured Shale Continuous Gas AU is shown on the FORSPAN ASSESSMENT MODEL FORM in Appendix A. The minimum and maximum areas for the AU are 872,000 acres and 1,066,000 acres, respectively, with a calculated mean of 969,000 acres. This range in area size reflects the uncertainty of the location of structures in the subsurface and the lack of data available to constrain key parameters such as the zone of overpressure. The untested area within the AU that has potential for additions to reserves is 0.6 and 22.5 percent, respectively, with a calculated mean of 8.4 percent (Appendix A). The range in the percentages is based on the uncertainty in the amount of area that is interpreted to have enhanced permeability due to fracturing, and on a range of success ratios that can be applied to these areas based on analog data.

The total recovery per cell or estimated ultimate recovery (EUR) for untested cells having potential for additions to reserves is 0.02 BCFG at the minimum, 0.35 BCFG at the median, and 7.5 BCFG at the maximum, with a calculated mean of 0.57 BCFG (Appendix A). The EUR distribution is typically based on historical production, but because of the lack of data in the Bighorn Basin, analogs from the Southwestern Wyoming Province and Wind River Basin Province were used to help estimate a range of production (fig. 32). The median and maximum values are conservatively estimated to be half the values of the Southwestern Wyoming Province, such values being from the largest data set available for rocks of similar reservoirs properties but where, it should be noted, that the thermal maturities of the source rocks are higher overall than in the Bighorn Basin.

The minimum and maximum area per cell of untested cells having the potential for additions to reserves is 40 and 300 acres, respectively, with a calculated mean of 130 acres. This is the most difficult parameter to determine, so these estimates are derived directly from the Mowry TPS in the Southwestern Wyoming Province (Kirschbaum and Roberts, 2005), which was based on current and anticipated well-spacing information for that area.

The mean estimate for undiscovered gas resources that have potential for additions to reserves in the Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas Assessment Unit (50340261) is 348 billion cubic feet of gas (BCFG); tabulated assessment results are summarized in table 1.

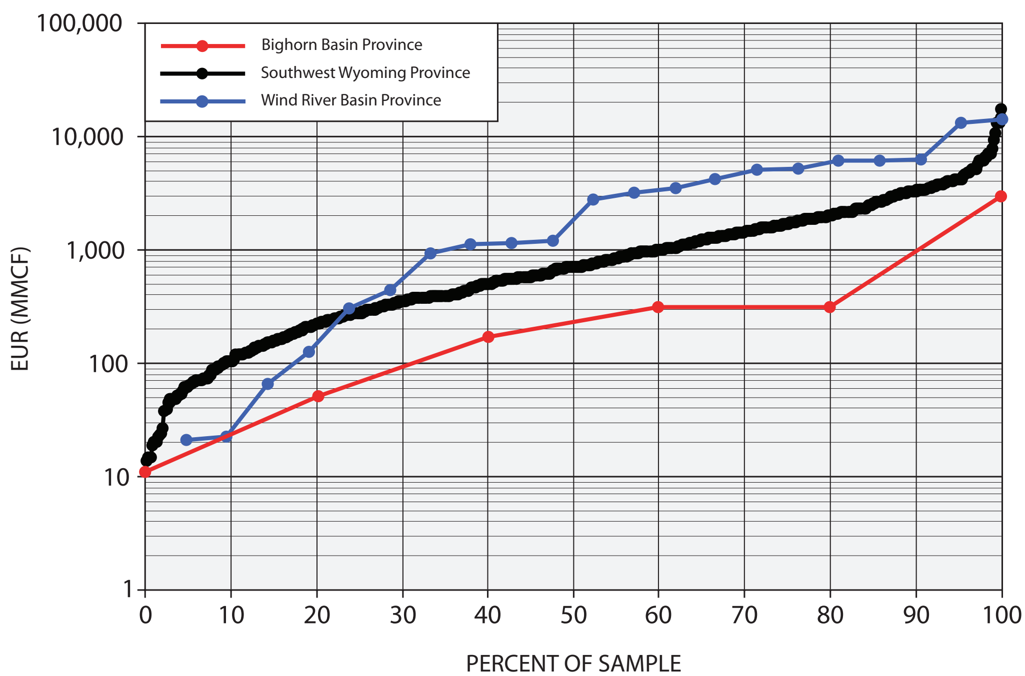

Figure 32. Estimated ultimate recovery (EUR) distributions for wells in the Frontier Formation, Muddy Sandstone, and Cloverly Formation and equivalents in the Southwestern Wyoming, Wind River Basin, and Bighorn Basin Provinces. The EURs are truncated to remove wells below 10 million cubic ft of gas. MMCF, million cubic ft.

Table 1. Cretaceous–Tertiary Composite Total Petroleum System assessment results.

[MMBO, million barrels of oil. BCFG, billion cubic feet of gas. MMBNGL, million barrels of natural gas liquids. Results shown are fully risked estimates. For gas accumulations, all liquids are included as NGL (natural gas liquids). F95 represents a 95 percent chance of at least the amount tabulated; other fractiles are defined similarly. TPS, total petroleum system; AU, assessment unit. Gray shading indicates not applicable]

	Total Petroleum System and Assessment Unit	Field Type	*Total Undiscovered Resources*											
			Oil (MMBO)				*Gas (BCFG)*				*NGL (MMBNGL)*			
			F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean
Continuous Resources	**Cretaceous-Tertiary Composite TPS**													
	Muddy-Frontier Sandstone and Mowry Fractured Shale Gas AU	***Gas***					119	298	743	348	0	0	1	0
	Mowry Fractured Shale Oil AU	***Oil***	2	4	11	5	1	2	6	2	0	0	0	0
	Cody Sandstone Gas AU	***Gas***					14	33	80	38	0	0	0	0
	Mesaverde Sandstone Gas AU	***Gas***					13	28	63	32	0	0	0	0
	Mesaverde-Meeteetse Formation Coalbed Gas AU	***CBG***					38	87	196	98	0	0	1	0
	Fort Union Formation Coalbed Gas AU	***Gas***					14	29	59	32	0	0	0	0
	Total Continuous Resources		**2**	**4**	**11**	**5**	**199**	**477**	**1,147**	**550**	**0**	**0**	**2**	**0**
Conventional Resources	**Cretaceous-Tertiary Composite TPS**													
	Cretaceous-Tertiary Oil and Gas AU	***Oil***	4	12	24	13	9	29	66	32	1	2	4	2
		Gas					53	176	370	189	1	3	6	3
	Total Conventional Resources		**4**	**12**	**24**	**13**	**62**	**205**	**436**	**221**	**2**	**5**	**10**	**5**
	Total Undiscovered Oil Resources		**6**	**16**	**35**	**18**	**261**	**682**	**1,583**	**771**	**2**	**5**	**12**	**5**

Mowry Fractured Shale Continuous Oil Assessment Unit (AU 50340262)

The Mowry Fractured Shale Continuous Oil Assessment Unit (AU 50340262) is thought to have potential to produce oil from fractured marine siliceous shale and interbedded siltstones and thin sandstones of the Mowry Shale. It is, however, classed as hypothetical in that there have been no wells producing oil from fractured reservoirs nor any wells known to have been tested for fractured oil. The AU is approximately 1,000 mi^2 in the eastern and southern parts of the Bighorn Basin (fig. 33). The AU boundaries encompass the area between the depths of 8,000–12,000 ft to the top of the Mowry Shale, such depths approximately matching the oil window for Type-II kerogen present in the formation. The Mowry contains both Type-II and -III kerogen, and the measured hydrogen indices show some oil-prone source rock are present. The transition from oil to gas generation at about the 12,000 ft depth in the Mowry was based loosely on the transition to peak gas development (0.8 percent R_o) from Type-III organic matter.

Input data for the assessment of AU 50340262 is shown on the FORSPAN ASSESSMENT MODEL FORM in Appendix B. The minimum and maximum areas in which are the Mowry is considered to have thermal maturity values in the oil window are 581,000 and 710,000 acres, respectively, with a calculated mean of 646,000 acres. This range-in-sizes area reflects high uncertainty in determining the extent of the pod of mature source rock, which may, in large part, be due to the lack of vitrinite reflectance data available for the Mowry in the Bighorn Basin. The area interpreted to have potential for additions to reserves ranges from 0.1 to 17 percent of the AU. The highest percentage area represents those areas where major structures are present in the AU and assumes fractures are present in the Mowry. This range in values also reflects the uncertainty of this hypothetical AU. The low end of values is a worst case scenario.

The closest analog for the Mowry Fractured Shale hypothetical AU 50340262 is from the Mowry AU in the Powder River Basin (Anna and Cook, 2008); however, the Mowry source rock there has higher TOC and Type-II kerogen

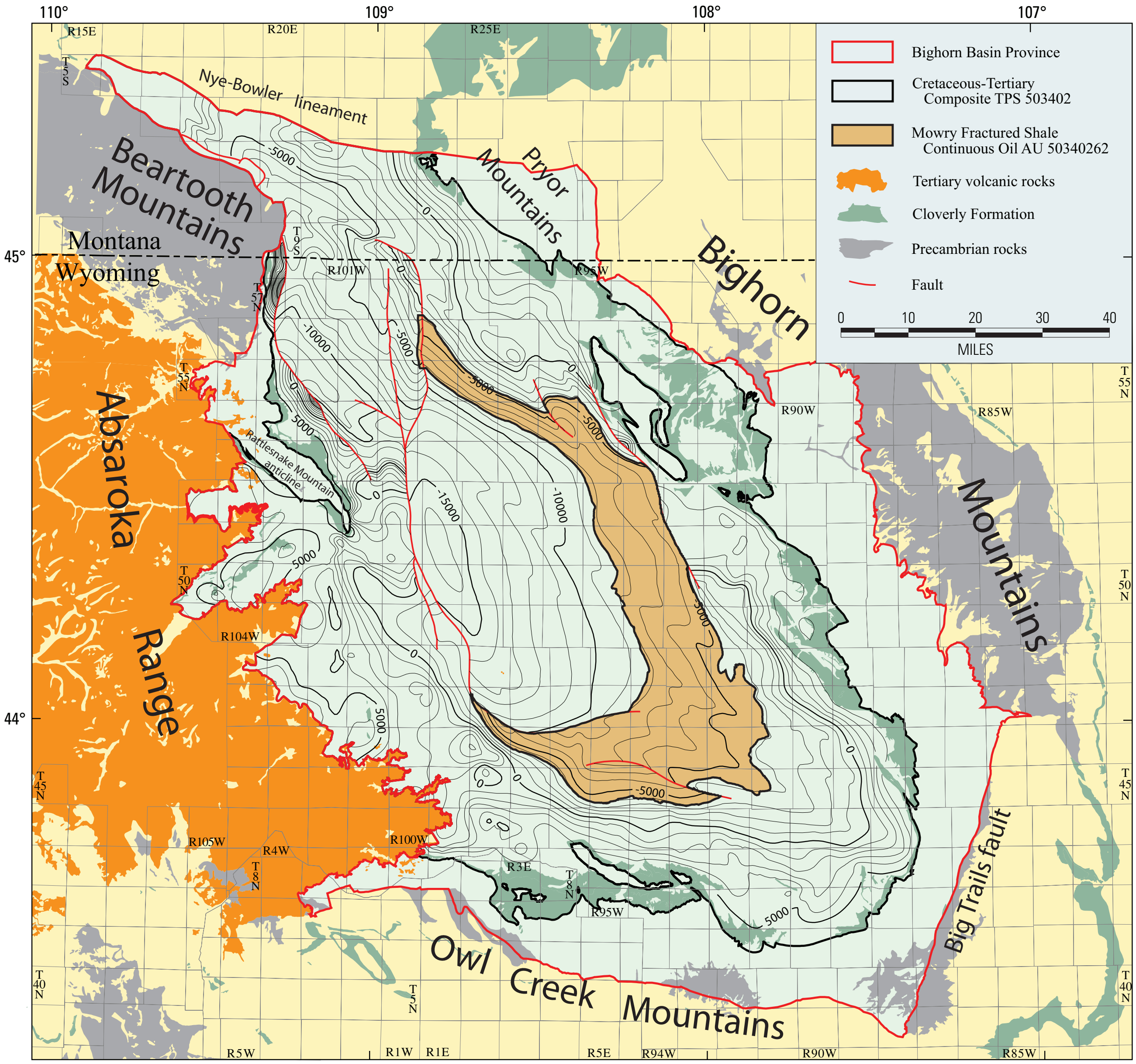

Figure 33. Map showing areal extent of the Mowry Fractured Shale Continuous Oil Assessment Unit (50340262), Bighorn Basin, Wyoming and Montana. Structure contours drawn on top of the Cloverly Formation; contour interval 1,000 ft. TPS, Total Petroleum System; AU, Assessment Unit.

contents (Burtner and Warner, 1984). The estimated ultimate recoveries for 17 Mowry wells in the Powder River Basin range from 2 to 170 thousand barrels of oil (MBO) (fig. 34). The Mowry EURs in the Powder River Basin are also similar to the Niobrara EURs in that basin (fig. 34). A larger dataset is available from the Permian Spraberry Formation in the Midland Basin where there are about 7,000 producing wells. Although the depositional environment is different, the Mowry and Spraberry have similarities—that is, low permeability fractured siltstones and sandstones and similar TOC content (Spraberry: 1.1–2.8 weight percent, Handford, 1981; Mowry: 0.8 to 3.6 weight percent, fig. 19).

For the Mowry Fractured Shale AU 50340262, the minimum recovery is set at 0.002 million barrels of oil (MMBO). The maximum is estimated at 0.35 MMBO to reflect a slightly lower maximum EUR than in the Powder River Basin (fig. 34). Additionally, most of the high end production from the maturely explored Spraberry Formation in the Midland Basin is also within this range of values. The median EUR is estimated at 0.025 MMBO, which is close to the median in

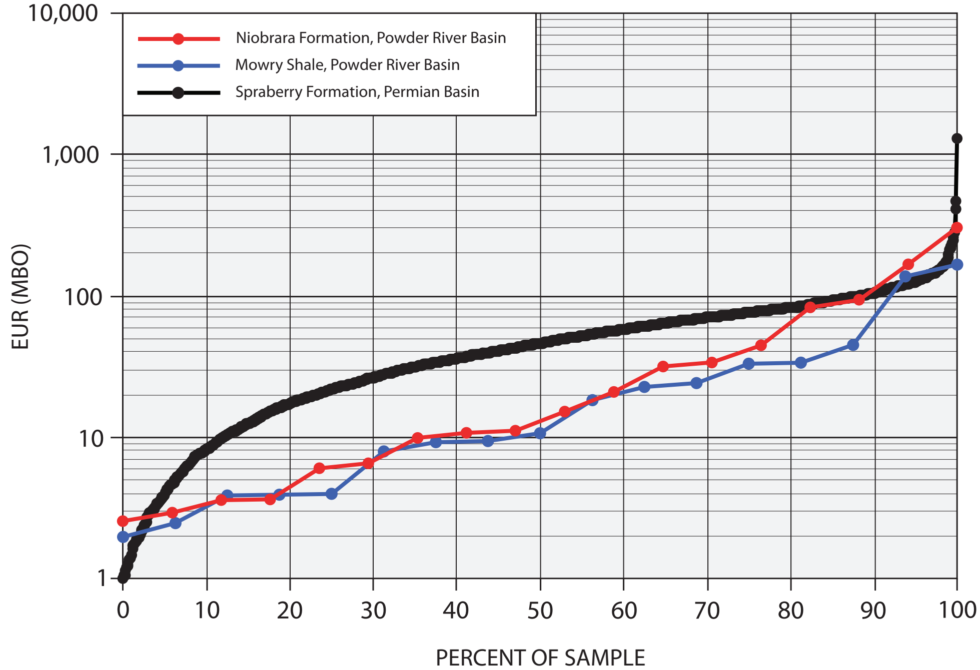

Figure 34. Estimated ultimate recovery (EUR) distributions for wells producing from the Mowry Shale and Niobrara Formation in the Powder River Basin, Wyoming and Montana, and the Spraberry Formation in the Midland Basin, Texas. The EURs are truncated to remove wells below one thousand barrels of oil (MBO). The cutoff in the Bighorn Basin is 2 MBO. MBO, thousand barrels of oil.

the Powder River Basin. Drainage areas are taken from the Powder River Basin analog, with a minimum of 40 acres, a mean of 290 acres and a maximum of 640 acres (Larry Anna, written commun., 2007).

The mean estimate for undiscovered oil resources in the Mowry Fractured Shale Continuous Oil AU (50340262) that have potential for additions to reserves is 5 MMBO; tabulated assessment results are summarized in table 1.

Cody Sandstone Continuous Gas Assessment Unit (AU 50340263)

The Cody Sandstone Continuous Gas Assessment Unit (AU 50340263) is a hypothetical AU that is believed to have the potential to produce gas from low permeability marine sandstone reservoirs in the upper part of the Cody Shale (fig. 7). It encompasses approximately 660 mi^2 in the central part of the Bighorn Basin (fig. 35). The north, east, and south boundaries of the AU were drawn, using sparse well data to generally outline areas where (1) drillstem test results and (or) mud weights indicate greater than normal pressure gradients, and (2) mud logs record continuous gas shows in downdip areas along the deep trough of the basin (Johnson and Finn, 1998b). The west boundary is projected beneath the Oregon Basin thrust fault and is drawn approximately at the cutoff of the Cody Shale in the footwall of the fault (Stone 1993; Taylor, 1998). Drilling depths range from about 12,000 to 19,000 ft. The AU is essentially unexplored, with only nine wells penetrating the Cody Shale section (fig. 35). Of these wells, none have reported any production from the Cody Shale; therefore, the AU is considered 100 percent untested and classified as hypothetical. Because of this, the Cody Sandstone Continuous Gas AU (50350262) from the Wind River Basin assessment was used as an analog because of similar geologic characteristics (Johnson and others, 2007).

Input data for the assessment is shown on the FORSPAN ASSESSMENT MODEL FORM in Appendix C. The minimum and maximum areas for the AU are 378,000 and 462,000 acres, respectively, with a calculated mean of 420,000 acres. The reason for the wide range is because of the structural complexity along the Oregon Basin thrust fault at the west side and the small amount of well data used to determine the other boundaries. The minimum and maximum percentages of the untested AU area that have potential for additions to reserves are 0.3 and 19.6 percent, respectively, with a calculated mean of 7.6 percent (see Appendix C). These percentages represent well success-ratios (from the Wind River Basin analog) applied to possible “sweet spots,” where reservoir permeability may be enhanced by fracture development associated with Laramide compression (anticlinal trends and thrust faults) and post-Laramide extension (normal faulting).

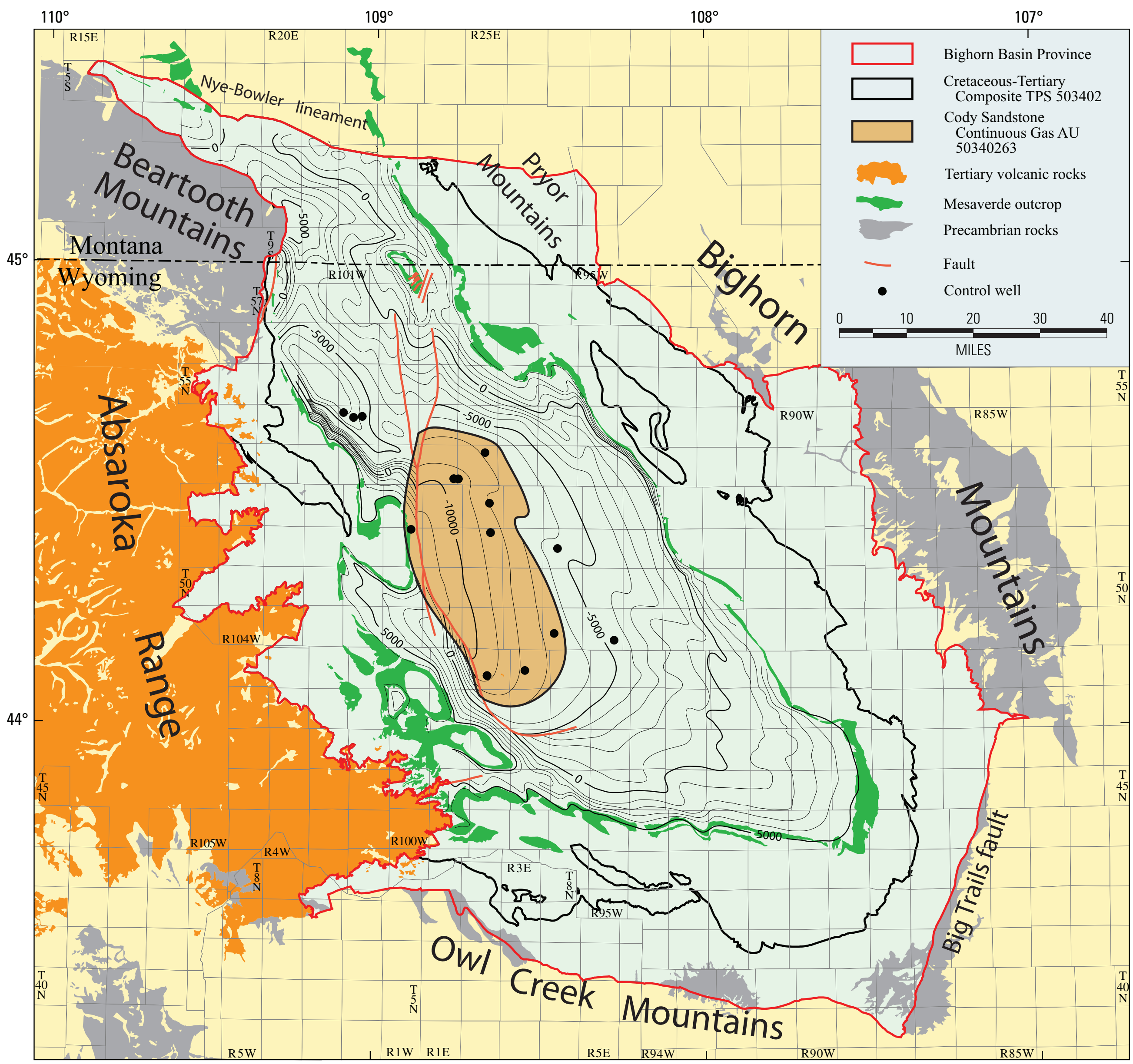

Figure 35. Map showing areal extent of the Cody Sandstone Continuous Gas Assessment Unit (50340263), Bighorn Basin, Wyoming and Montana. Structure contours drawn on top of the Teapot Sandstone Member of the Mesaverde Formation; contour interval 1,000 ft. TPS, Total Petroleum System; AU, Assessment Unit.

The minimum, median, and maximum total recovery per cell for untested cells having potential for additions to reserves is 0.02, 0.2, and 5 BCFG, respectively, with a calculated mean of 0.34 BCFG (Appendix C). These values are based on the low end of the EUR distribution of the analog AU in the Wind River Basin (Johnson and others, 2007) because of the general lack of reservoir rock in the upper part of the Cody Shale in the Bighorn Basin (figs. 36, 37), and overall lower thermal maturities in the Bighorn Basin as compared to the Wind River Basin (Nuccio and Finn, 1998). Also, most of the wells that make up the EUR distribution for the analog Cody Shale AU in the Wind River Basin are located on the Madden anticline, a large and highly fractured “sweet spot” (fig. 36). Based on the extensive seismic data that are available, it is unlikely that a similar “sweet spot” is present in the Bighorn Basin (fig. 38).

The minimum and maximum area per cell of untested cells having the potential for additions to reserves is 40 and 640 acres, respectively, with a calculated mean of 280 acres.

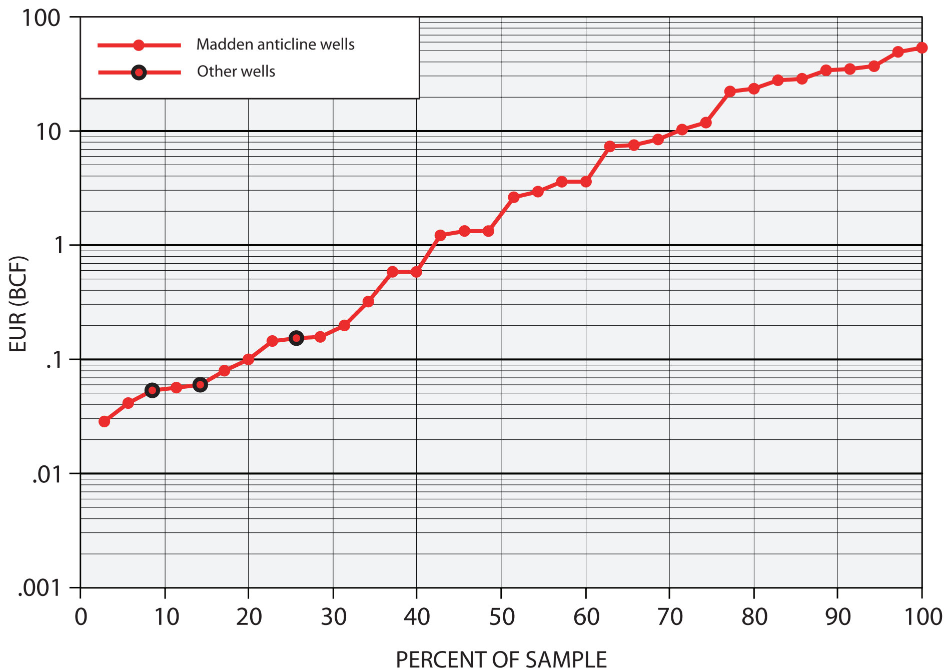

Figure 36. Estimated ultimate recovery (EUR) distribution for wells greater than 0.02 billion cubic feet of gas in the Cody Sandstone Continuous Gas Assessment Unit in the Wind River Basin Province, Wyoming, used as an analog for Assessment Unit 50340263. BCF, billion cubic feet.

These values are from the Wind River Basin analog and, according to Dunleavy and Gilbertson (1986), reflect the variability that is typical of many fractured reservoirs.

The mean estimate for undiscovered gas resources in the Cody Sandstones Continuous Gas Assessment Unit (50340263) that have potential for additions to reserves is 38 BCFG; tabulated assessment results are summarized in table 1.

Mesaverde Sandstone Continuous Gas Assessment Unit (AU 50340264)

The Mesaverde Sandstone Continuous Gas Assessment Unit (AU 50340264) is a hypothetical AU that is believed to have the potential to produce gas from low permeability fluvial and marginal marine sandstone reservoirs in the Mesaverde Formation. The AU encompasses approximately 345 mi^2 in the central part of the Bighorn Basin (fig. 39). The north, east, and south boundaries were drawn using sparse well data that generally outlines areas where drillstem tests indicate greater than normal pressure gradients and (or) mud logs record continuous gas shows in the downdip areas along the deep trough of the basin (Johnson and Finn, 1998b). The west boundary is projected beneath the Oregon Basin thrust fault and is drawn approximately at the cutoff of the Mesaverde Formation in the footwall of the fault (Stone, 1993; Taylor, 1998). Drilling depths range from about 12,500 to 17,500 ft (fig. 40). Because it is classed as hypothetical, analogs were used in the assessment of this AU, including Mesaverde production at Muddy Ridge (Johnson and others, 2007), and Lance/Fort Union production at Sand Mesa from the Wind River Basin, Wyoming (Troy Cook, written commun., 2008). These areas were chosen because they represent production from lenticular fluvial sandstones in areas with lower thermal maturities similar to levels in the Bighorn Basin, and because they are not associated with major anticlinal structures.

The Mesaverde Sandstone Continuous Gas AU is essentially unexplored, with only four wells penetrating the Mesaverde section, only one of which reported gas production from the formation (fig. 39). According to Cardinal and others (1989), the Sellers Draw Unit 1(see fig. 39 for location) was initially completed in the Muddy Sandstone in 1978 at a depth of about 19,500 ft. According to the Wyoming Oil and Gas Conservation Commission (WOGCC), the well was shut-in in 1997, then was recently recompleted in the Mesaverde at a depth of about 16,100 ft. At the time of this assessment there was not enough production history of the well to determine if the well will ultimately make the minimum of 0.02 BCFG

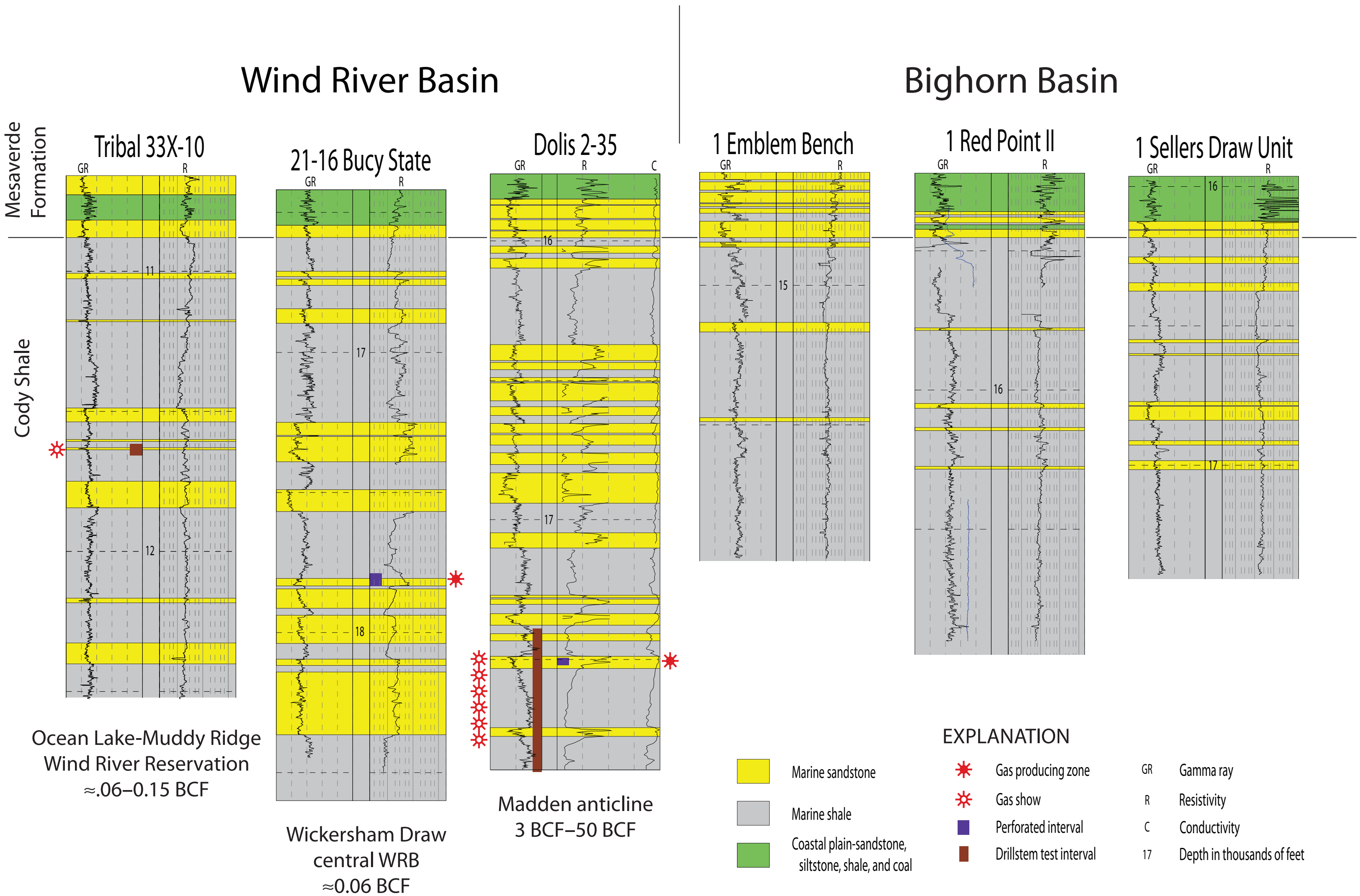

Figure 37. Comparison of well log responses between the sandy interval in the upper part of the Cody Shale in the Bighorn Basin, Wyoming and Montana, and the upper sandy member of the Cody Shale in the Wind River Basin.

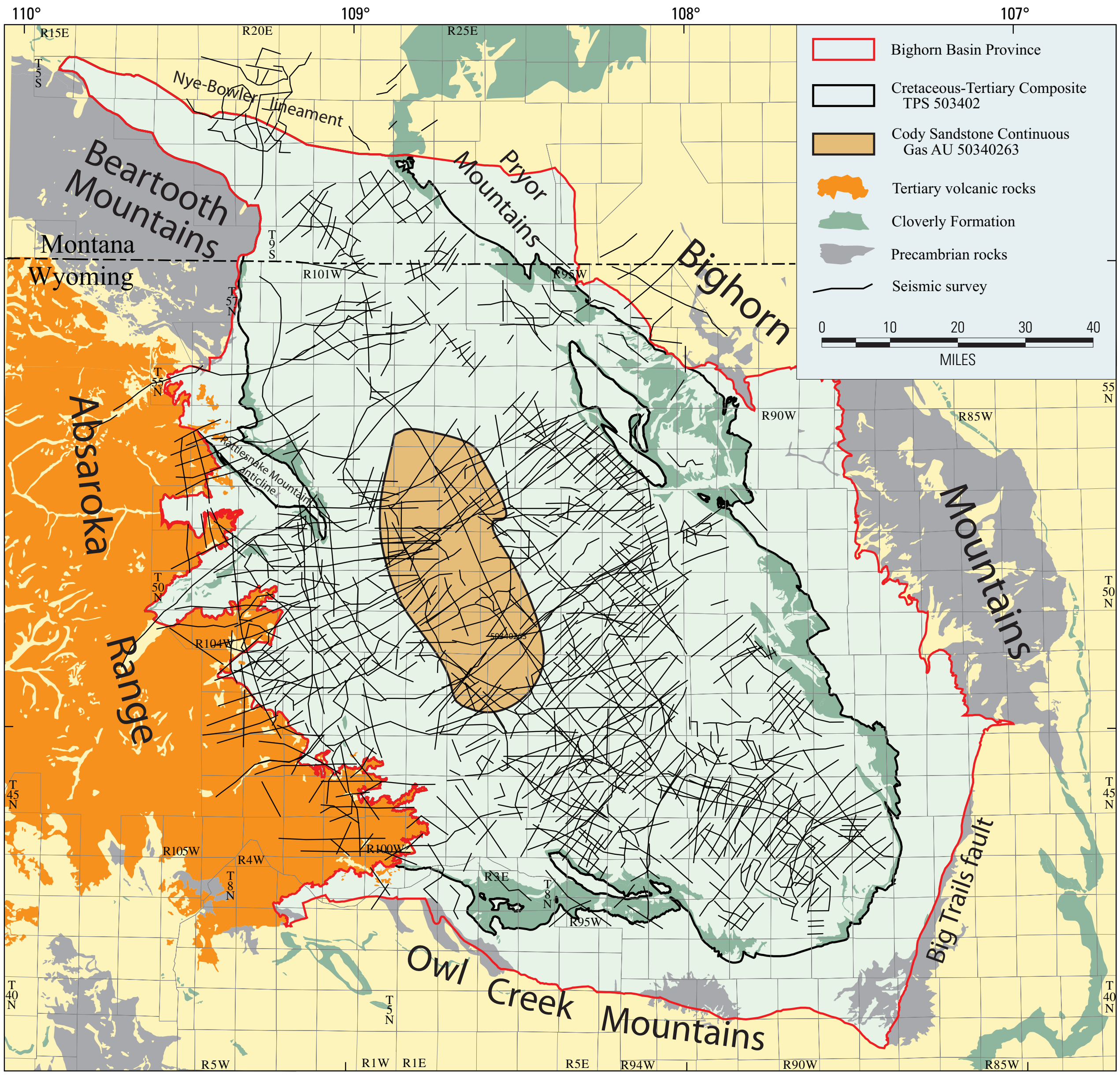

Figure 38. Map showing coverage (in part) of commercially available seismic surveys in the Bighorn Basin, Wyoming and Montana. TPS, Total Petroleum System; AU, Assessment Unit.

to qualify as a producer, therefore the AU is considered hypothetical and essentially 100 percent untested.

Input data for the assessment are shown on the FORSPAN ASSESSMENT MODEL FORM in Appendix D. The minimum and maximum areas assigned to the AU are 199,000 and 243,000 acres, respectively, with a calculated mean of 221,000 acres; this wide range is because little is known about subsurface structure along the west boundary and because of the uncertainty over the other boundaries owing to the lack of well data. The minimum and maximum percentages of the untested AU area that has potential for additions to reserves are 0.2 and 8.5 percent, respectively, with a calculated mean of 3.6 percent (Appendix D). These percentages represent well success-ratios (from the Wind River Basin analogs) applied to possible "sweet spots," where reservoir permeability may be enhanced by fracture development associated with Laramide compressional features (anticlinal trends and thrust faults) and normal faulting associated with post-Laramide extension.

The minimum, median, and maximum total recovery per cell for untested cells having potential for additions to reserves

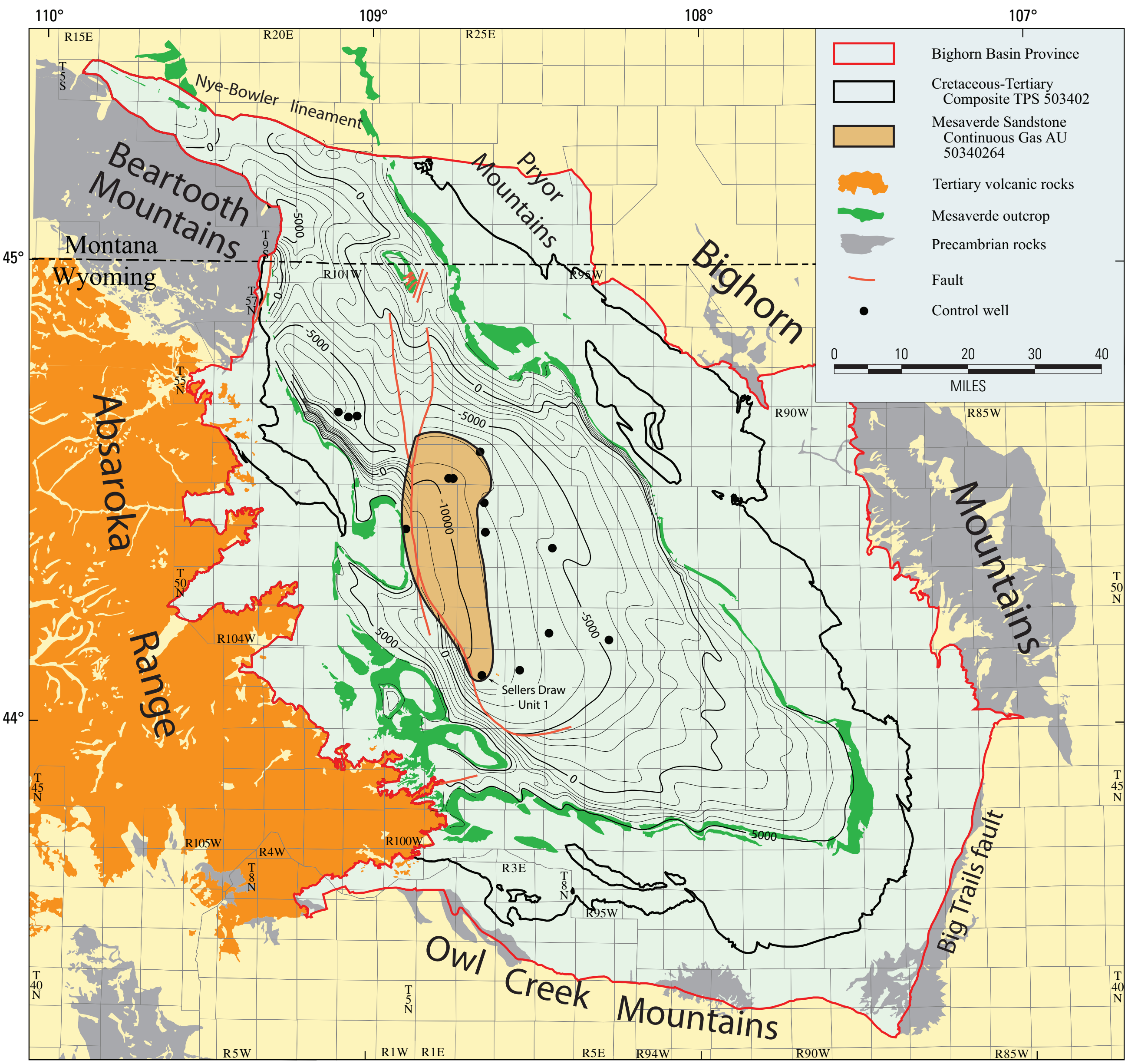

Figure 39. Map showing areal extent of the Mesaverde Sandstone Continuous Gas Assessment Unit (50340264), Bighorn Basin, Wyoming and Montana. Structure contours drawn on top of the Teapot Sandstone Member of the Mesaverde Formation; contour interval 1,000 ft. TPS, Total Petroleum System; AU, Assessment Unit.

is 0.02, 0.2, and 5 BCFG, respectively, with a calculated mean of 0.34 BCFG (Appendix D). These values are based on the EUR distribution from the analog areas in the Wind River Basin, but are lower because of the overall lower volume of potential sandstone reservoir rock in the Mesaverde section in the Bighorn Basin as compared to the Wind River Basin (fig. 41).

The minimum and maximum area per cell of untested cells having the potential for additions to reserves is 20 and 180 acres, respectively, with a calculated mean of 83.3 acres and a mode of 50 acres. These values are also from the Mesaverde analogs in the Wind River Basin, the smaller values reflecting potential future production from lenticular fluvial sandstone bodies and the larger values reflecting potential future production from blanket-like marginal marine sandstones (Johnson and others, 2007).

The mean estimate for undiscovered gas resources that have potential for additions to reserves in the Mesaverde Sandstone Continuous Gas AU (50340264) is 32 BCFG; tabulated assessment results are summarized in table 1.

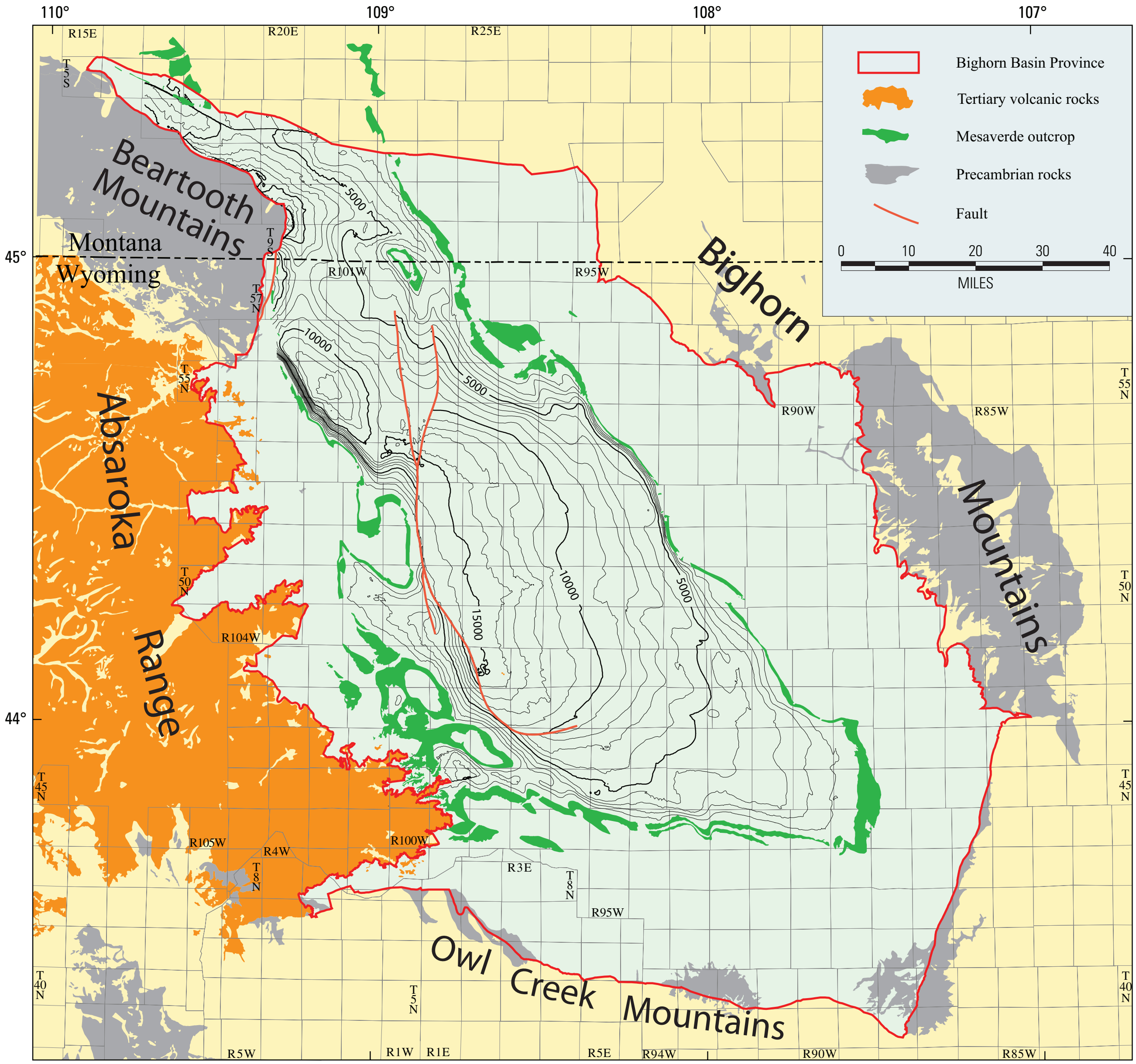

Figure 40. Map showing approximate depth to top of the Teapot Sandstone Member of the Mesaverde Formation, Bighorn Basin, Wyoming and Montana; contour interval 1,000 ft.

Mesaverde-Meeteetse Formation Coalbed Gas Assessment Unit (AU 50340281)

The Mesaverde-Meeteetse Formation Coalbed Gas Assessment Unit (AU 50340281) is a hypothetical AU that is believed to have the potential to produce gas from coal beds in the Mesaverde and Meeteetse Formations (Judith River Formation and Eagle Sandstone in Montana). These formations were assessed jointly because of general continuity of the coal-bearing section extending from the Mesaverde Formation upward into the Meeteetse Formation. The AU encompasses approximately 2,500 mi^2 around the periphery of the Bighorn Basin (fig. 42). The upper limit is defined as the base of the Mesaverde Formation outcrop or equivalent rocks, and the lower limit is defined as the area where coal beds are interpreted to be present at depths of 6,000 ft or less (fig. 40). Coal beds at greater depths were not considered due to the potential decrease in permeability with increasing depth (Rice and others, 1996).

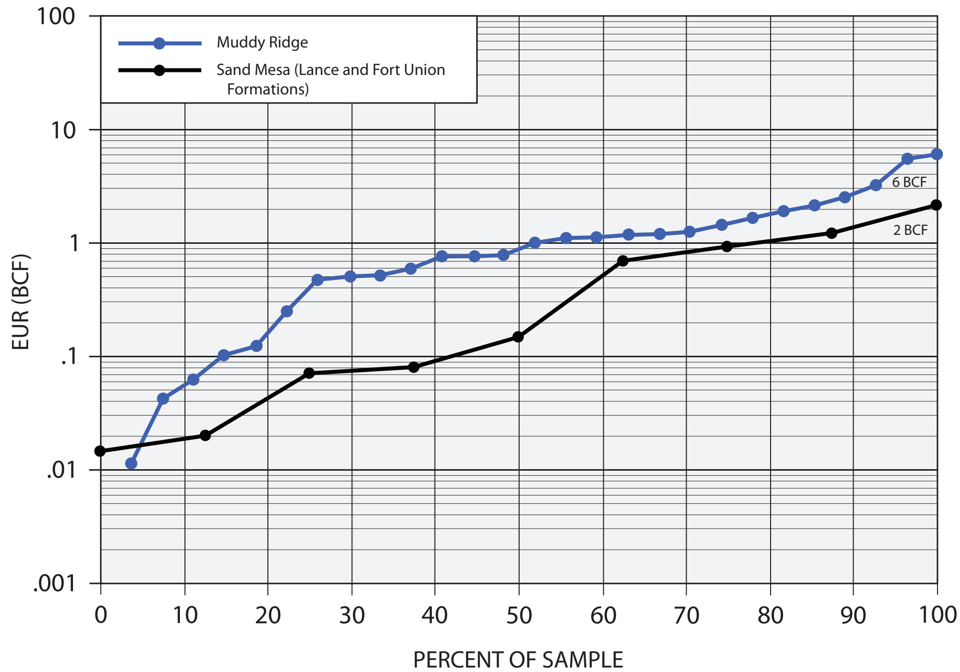

Figure 41. Estimated ultimate recovery (EUR) distributions for wells producing from the Mesaverde, Lance, and Fort Union Formations in the Wind River Basin, Wyoming. BCF, billion cubic feet.

Estimates of the total in-place coal resources in Upper Cretaceous and Tertiary strata of the Bighorn Basin are on the order of 1.8 billion short tons (R.W. Jones, written commun., as reported in Love, 1988). Coal mining in the basin began in the late 1800s, and more than 12,000,000 tons were produced from Cretaceous coal deposits in the Wyoming part of the basin. About 90 percent of the total came from some thirteen mines producing coal in the Upper Cretaceous Mesaverde Formation near Gebo (Glass and others, 1975); currently there are no mines.

Upper Cretaceous coal beds are concentrated in the lower and middle parts of the Mesaverde Formation and in the upper part of the Meeteetse Formation (Johnson, 1998). Individual coal beds are as thick as 12 ft, but typically range from 4 to 6 ft or less (Glass and others, 1975; Johnson, 1998). In the subsurface, the maximum, combined coal thickness for both formations is 38 ft, with the thicker coal accumulations primarily in the southern part of the basin. The apparent rank of coal beds in the Mesaverde Formation ranges from high volatile C bituminous to subbituminous A or B; the bituminous coal is restricted to one coalfield (Silvertip field) near the Wyoming-Montana state line (fig. 20). Meeteetse coals are subbituminous in rank (Glass and others, 1975). Reported thermal maturity (R_0) values for coal in the Mesaverde Formation range from a low of 0.27 percent in outcrops in the western part of the basin to more than 1.10 percent in the deep basin adjacent to the Oregon Basin thrust fault; Meeteetse coal thermal maturities range from 0.35 percent in outcrops to more than 0.90 percent in the deep basin (Nuccio and Finn, 1998; Finn and Pawlewicz, 2007).

Test wells for coalbed gas in the Mesaverde Formation have been drilled in Wyoming, adjacent to the Wyoming-Montana state line, and at one location in the southwestern part of the basin near Grass Creek (WOGCC, 2007). However, there have been no published results from this drilling and the AU is essentially 100 percent untested. The AU is classed as hypothetical because there is currently no production of coal-bed gas from the Mesaverde, Meeteetse, or equivalent strata in the basin (WOGCC, 2007), so analogs from the Powder River Basin and Piceance Basin (in Colorado) (Flores, 2004; Johnson and Roberts, 2003) were used in this assessment on the basis that they produce coal of similar rank (primarily subbituminous).

Input data for the assessment of AU 50340281 is shown on the FORSPAN ASSESSMENT MODEL FORM in Appendix E. The minimum and maximum areas for the AU are 1,457,000, and 1,781,000 acres, respectively, with a calculated mean of 1,619,000 acres. The reason for the wide range in acreages is because drill data are lacking for determining the depth to or even the presence of coal beds in the lower part of the Mesaverde Formation in many areas. The minimum and maximum percentages of the untested AU area that has potential for additions to reserves are 0.5 and 14 percent, respectively, with a calculated mean of 5.7 percent

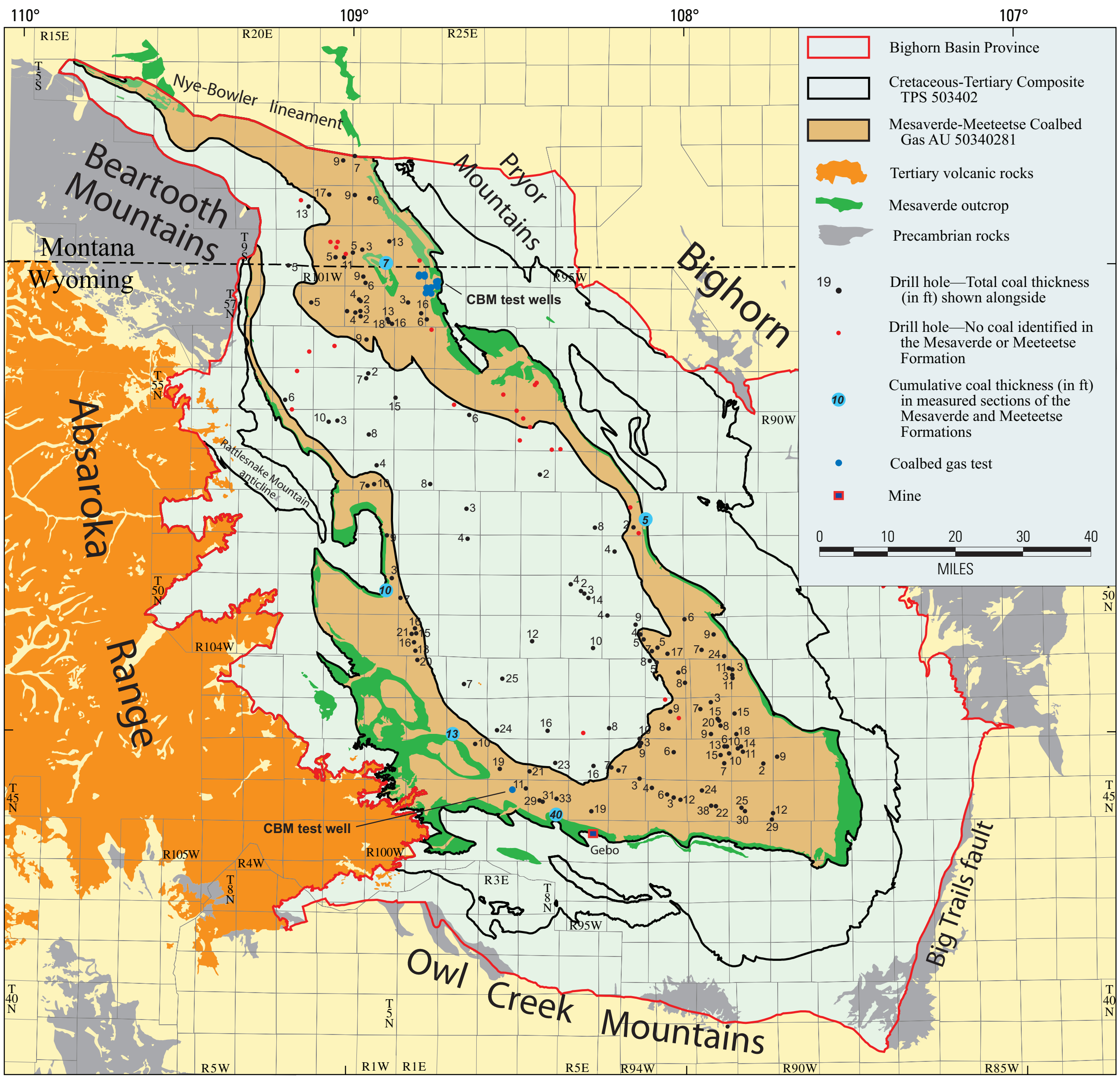

Figure 42. Map showing areal extent of the Mesaverde-Meeteetse Formation Coalbed Gas Assessment Unit (50340281), Bighorn Basin, Wyoming and Montana. Coal thicknesses (in ft) are a composite of Mesaverde and Meeteetse thicknesses reported by Johnson (1998). CBM, coalbed methane. TPS, Total Petroleum System; AU, Assessment Unit.

and a mode of 2.5 percent (see Appendix E). The minimum area restricts coalbed gas potential to areas in the southern part of the basin where total coal thicknesses exceed 30 ft. The mode area includes the minimum area, coupled with areas where the total coal thickness exceeds 20 ft and additional areas where coal beds coincide with subtle anticlinal folds at the top of the Mesaverde Formation. The maximum area includes the minimum and mode areas plus all remaining areas where the total coal thickness exceeds 10 ft.

The estimated minimum, median, and maximum total recovery per cell for untested cells having potential for additions to reserves is 0.02, 0.1, and 1.2 BCFG, respectively, with a calculated mean of 0.14 BCFG (Appendix E). These estimates are based primarily on comparisons to estimated ultimate recoveries (EURs) of coalbed gas from wells producing from subbituminous coal in the Powder River Basin in Wyoming (Anderson and Canyon coal beds). A minimum EUR of 0.02 billion cubic feet of gas (BCFG) was applied to untested cells in AU 50340281; this value is generally considered representative of the minimum gas recovery required for a successful well. Median EURs for wells producing from the Anderson and Canyon coal beds in the Powder River Basin range from about 0.13 to 0.17 BCFG (Troy Cook, written commun., 2007). However, a lower median EUR was applied to untested cells in this assessment unit because Mesaverde and Meeteetse coal beds in the Bighorn Basin are less continuous and significantly thinner than the Anderson and Canyon coal beds, which range from 20 to 30 ft in thickness. The maximum recovery estimate is essentially equal to maximum EURs for the analog Powder River Basin coals (EUR range 1.2 to 1.3 BCFG).

The minimum and maximum area per cell of untested cells having the potential for additions to reserves is 40 and 240 acres, respectively with a calculated mean of about 127 acres and a mode of 100 acres. Coalbed gas wells producing from coal in the Fort Union Formation (Tongue River Member) in the Powder River Basin, Wyoming, and from coal in the Mesaverde Formation in the Piceance Basin, Colorado, were used as analogs (Flores, 2004; Johnson and Roberts, 2003) for estimating cell size (drainage area) because of general similarities in coal rank (primarily subbituminous coal). A 40-acre cell size was used at the minimum because of the potential for interference between wells producing at a closer spacing. A 100-acre cell size (mode) is considered optimal in regard to gas volume and recovery, dewatering considerations, and reduction (or omission) of interference between adjacent wells. The maximum of 240 acres considers the potential for increased drainage areas in exceptionally continuous and permeable coal reservoirs. Estimated mode and maximum cell sizes used in this assessment are slightly larger than estimated cell sizes for untested cells in the Powder River Basin (Fort Union Formation; Flores, 2004) because the higher thermal maturities of Mesaverde and Meeteetse coal in the Bighorn Basin coals might enhance their permeability due to better cleat development. Conversely, these values are slightly less than drainage-area estimates for coalbed gas wells in the Piceance Basin (Mesaverde Formation; Johnson and Roberts, 2003) where Upper Cretaceous coals are more mature, generally thicker, and more continuous than coal beds in the Bighorn Basin.

The mean estimate for undiscovered gas resources that have potential for additions to reserves in the Mesaverde-Meeteetse Formation Coalbed Gas Assessment Unit (50340281) is 98 BCFG; tabulated assessment results are summarized in table 1.

Fort Union Formation Coalbed Gas Assessment Unit (AU 50340282)

The Fort Union Formation Coalbed Gas Assessment Unit (AU 50340282) is a hypothetical AU that is believed to have the potential to produce gas from coal beds in the Fort Union Formation. The AU encompasses approximately 3,800 mi^2 in the central part of the Bighorn Basin (fig. 43). The lower limit of the AU is defined as the area where coal beds are interpreted to be present at depths of 6,000 ft or less; coal beds at greater depths were not considered due to the potential decrease in permeability with increasing depth. The upper limit of the AU is defined as the base of the outcrop of the Fort Union Formation.

Fort Union coals have been mined since the late 1800s, and an estimated 30–40 million tons of coal were produced from the Red Lodge area (fig. 43) until the 1950s (Rawlins, 1986). More recent mining has taken place in the Grass Creek area (fig. 43), where some 300,000–400,000 tons of Fort Union coal were mined between 1989 and 1993 (Resource Data International, 1998). Coal and carbonaceous shale beds are common in Fort Union Formation outcrops; the 36-ft-thick Mayfield coal bed in the Grass Creek area is the thickest coal bed identified in the Bighorn Basin (Hewitt, 1926). Near Manderson and in the southeastern part of the basin, isolated coal beds in outcrops range from 10 to 15 ft thick, although most are lenticular. In the Red Lodge area, coal beds range from less than 4 ft to 12 ft in thickness (Woodruff, 1907; Rawlins, 1986). In most other areas, exposed coal beds are generally thin (< 5 ft thick) (Roberts, 1998). Based on limited data from oil and gas exploration wells, cumulative (total) coal thicknesses in the Fort Union Formation in the subsurface range from 3 to 26 ft; the maximum individual coal bed thickness measured in well logs is 11 ft (fig. 43) (Johnson, 1998). In many wells throughout the basin, no coal beds were identified. The apparent rank of Fort Union coal is subbituminous (Glass and others, 1975), and thermal maturity (R_0) values for coal in the AU range from about 0.36 percent to about 0.87 percent in the deep basin adjacent to the Oregon Basin thrust fault (Nuccio and Finn, 1998; Finn and Pawlewicz, 2007). The AU is considered hypothetical because there is currently no production of coalbed gas from the Fort Union Formation in the basin (WOGCC, 2007). To date, there have been no published reports of coalbed gas tests, although indirect evidence of gas (methane?) in Fort Union coals may be represented by the 1943 gas explosion in the Smith Mine in the Red Lodge-Bear Creek coal field, Montana (Rawlins, 1986).

Input data for the assessment of AU 50340282 is shown on the FORSPAN ASSESSMENT MODEL FORM in Appendix F. The minimum and maximum areas for the AU are 2,177,000 and 2,661,000 acres, respectively, with a calculated mean of 2,419,000 acres. This wide range in acreages reflects uncertainty in determining the depth to and (or) the presence of Fort Union coal beds in many areas, due to the lack of definitive drill-hole data. The estimated minimum and maximum percentages of the untested AU area that has potential for additions to reserves are 0.1 and 3 percent, respectively, with a calculated mean of 1.4 percent, and a mode of 1.0 percent (Appendix F). The minimum area restricts coalbed gas potential to the Red Lodge-Bearcreek area (fig. 43), where there are as many as 8 mapped coal beds in a 32-mi^2 area; total coal reserves have been estimated in excess of 600 million tons (Woodruff, 1907; Rawlins, 1986). The median estimate

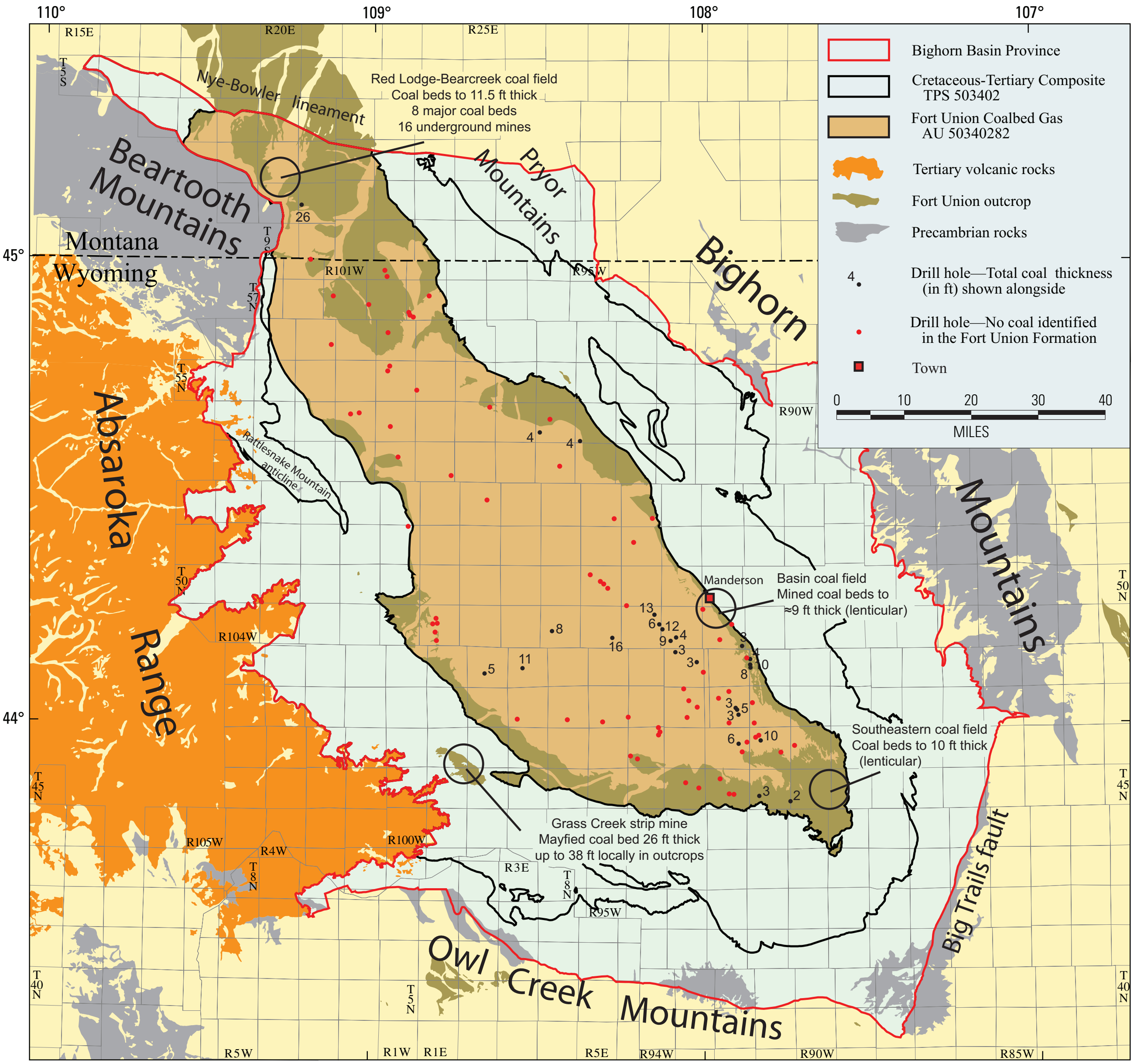

Figure 43. Map showing areal extent of the Fort Union Formation Coalbed Gas Assessment Unit (50340282), Bighorn Basin, Wyoming and Montana. Coal thickness data (in ft) from Woodruff (1907), Glass and others (1975), and Johnson (1998). TPS, Total Petroleum System; AU, Assessment Unit.

includes the Red Lodge-Bearcreek area coupled with an area downdip from coal outcrops near Manderson, where individual coal beds in Fort Union outcrops are locally as thick as 10 ft. The maximum estimate includes the minimum and median areas, and additional untested areas in the east-central part of the basin northwest and southwest of Manderson (fig. 43).

Coalbed gas wells producing from coal in the Fort Union Formation (Tongue River Member) in the Powder River Basin, Wyoming, were used as analogs (Flores, 2004) for estimating cell size (drainage area) and total recovery per cell for untested cells (EURs) because of general similarities in coal rank (subbituminous coal) and thermal maturity; however, coal maturities in some areas of the Bighorn Basin exceed the thermal maturity of Powder River Basin coals. The minimum, median, and maximum total recoveries per cell for untested cells having potential for additions to reserves are estimated at 0.02, 0.08, and 1.0 BCFG, respectively, with a calculated mean of 0.1 BCFG (Appendix F). These estimates are based on EURs for coalbed gas wells producing from the 20- to 30-ft-thick Anderson and Canyon coal beds in the Powder

River Basin. Only the Mayfield coal bed in the Grass Creek area is comparable in thickness (fig. 43), but is limited in areal extent and not buried deep enough (overburden < 200 ft; Stewart, 1975) to be prospective for coalbed gas. Elsewhere in the Bighorn Basin, Fort Union coal beds generally range from less than 5 ft to 12 ft in thickness. Although no direct correlation has been made between coal thickness, gas content, and enhanced production, greater coal volumes associated with thicker coal beds should result in a greater volume of coalbed gas per unit area of land (for example, see Choate and others, 1984). Based on this concept, we interpret EURs for untested cells in AU 50340282 should be somewhat less than those of Fort Union coalbed gas wells in the Powder River Basin. A minimum EUR of 0.02 BCFG was applied to untested cells in AU 50340282, a value generally considered as representative of the minimum gas recovery required for a successful well. A median EUR of 0.08 BCFG and a maximum EUR of 1.0 BCFG were also applied to untested cells. Because of the differences in coal bed thicknesses as discussed previously, these EURs are less than EURs from Powder River Basin coalbed gas wells, which have median recoveries ranging from 0.13 to 0.17 BCFG and maximum recoveries ranging from 1.2 to 1.3 BCFG (Troy Cook, written commun., 2007).

The estimated minimum and maximum areas per cell of untested cells having the potential for additions to reserves are 40 and 200 acres, respectively, with a calculated mean of about 113 acres, and a mode of 100 acres. A 40-acre cell size was used at the minimum because of the potential for interference between wells producing at a closer spacing. A 100-acre cell size (median estimate) is considered optimal in regard to gas volume and recovery, dewatering considerations, and reduction (or omission) of interference between adjacent wells. The maximum of 200 acres considers the potential for increased drainage areas in exceptionally continuous and permeable coal reservoirs. The estimated mode and maximum cell sizes used in this assessment are slightly larger than estimated cell sizes for untested cells in the Powder River Basin (Flores, 2004), because the slightly higher thermal maturity of Fort Union coal in the Bighorn Basin might enhance the permeability due to better cleat development in the more mature coal.

The mean estimate for undiscovered gas resources that have potential for additions to reserves in the Fort Union Formation Coalbed Gas Assessment Unit (50340282) is 32 BCFG; tabulated assessment results are summarized in table 1.

Cretaceous–Tertiary Conventional Oil and Gas Assessment Unit (AU 50340201)

The Cretaceous–Tertiary Conventional Oil and Gas Assessment Unit (AU 50340201) is an established AU that produces oil and gas mainly from sandstone reservoirs associated with anticlinal traps around the margins of the Bighorn Basin and along the Five Mile trend (fig. 44); however, many of these accumulations have a stratigraphic component where sandstone reservoirs pinch out across structure (Hafenbrack and others, 1958; Stone, 1975; Tonnsen, 1985; Cardinal and others, 1989; Bartow-Campen, 1986; Keefer, 1998; Talbot, 1996). The AU encompasses approximately 7,900 mi^2, occupies the entire areal extent of the Cretaceous–Tertiary Composite TPS, and includes reservoirs ranging from the Lower Cretaceous Cloverly Formation through the Paleocene Fort Union Formation (figs. 7, 44). The first discovery was from the Frontier Formation in 1906 at Garland field (Cardinal and others, 1989). The AU is heavily explored and since the initial discovery at Garland field nearly 12,000 wells have been drilled, including about 1,700 wells producing from Cretaceous or Tertiary reservoirs. To date, nine oil fields and 15 gas fields (NRG Associates, 2007) greater than the minimum grown field size of 0.5 million barrels of oil equivalent (MMBOE) have been discovered, with a minimum cumulative production of 94 MMBO and 833 BCFG gas (fig. 45) (IHS Energy Group, 2007).

Input data for the assessment is shown on the Seventh Approximation form in Appendix G. The minimum and maximum number of oil accumulations greater than the minimum field size of 0.5 MMBO expected to be discovered are one and 15, respectively, with five most likely (mode). The estimated size of the oil accumulations ranges from 0.5 to 12 MMBO with a median value expected to be 1.5 MMBO. The minimum and maximum number of gas accumulations greater than 3 BCFG expected to be discovered are 1 and 40, respectively, with a mode of 10. The estimated size of these gas accumulations ranges from 3 to 72 BCFG, with a median value expected to be 9 BCFG. Few of these new discoveries are likely to be from structural accumulations, as most anticlinal features in the basin have been explored with only one accumulation greater than the minimum field size being discovered in the last 50 years despite an increase in exploration activity (figs. 45, 46). Some new fields may be discovered in subthrust areas where petroleum could be trapped beneath the overhang of major thrust faults that flank parts of the basin (Gries, 1981, 1983b). However, future discoveries will more likely be from stratigraphic traps in the Frontier Formation and Cody Shale, where sandstone reservoirs pinch out updip on anticlinal noses (Keefer, 1998) or into marine shales along the basin flanks, or are draped over structures (Fox and Dolton, 1996). These accumulations are expected to be small in size because larger traps likely would have been discovered by the high drilling density that has occurred around the margins of the basin (fig. 47). Additional accumulations may also be from stratigraphic traps from valley-fill sandstones in the Muddy Sandstone and the Greybull Sandstone Member of the Cloverly Formation (Dolson and others, 1991; Fox and Dolton, 1996).

The mean estimates for undiscovered oil and gas resources that have potential for additions to reserves in the Cretaceous–Tertiary Conventional Oil and Gas AU (50340201) are 13 MMBO and 221 BCFG; tabulated assessment results are summarized in table 1.

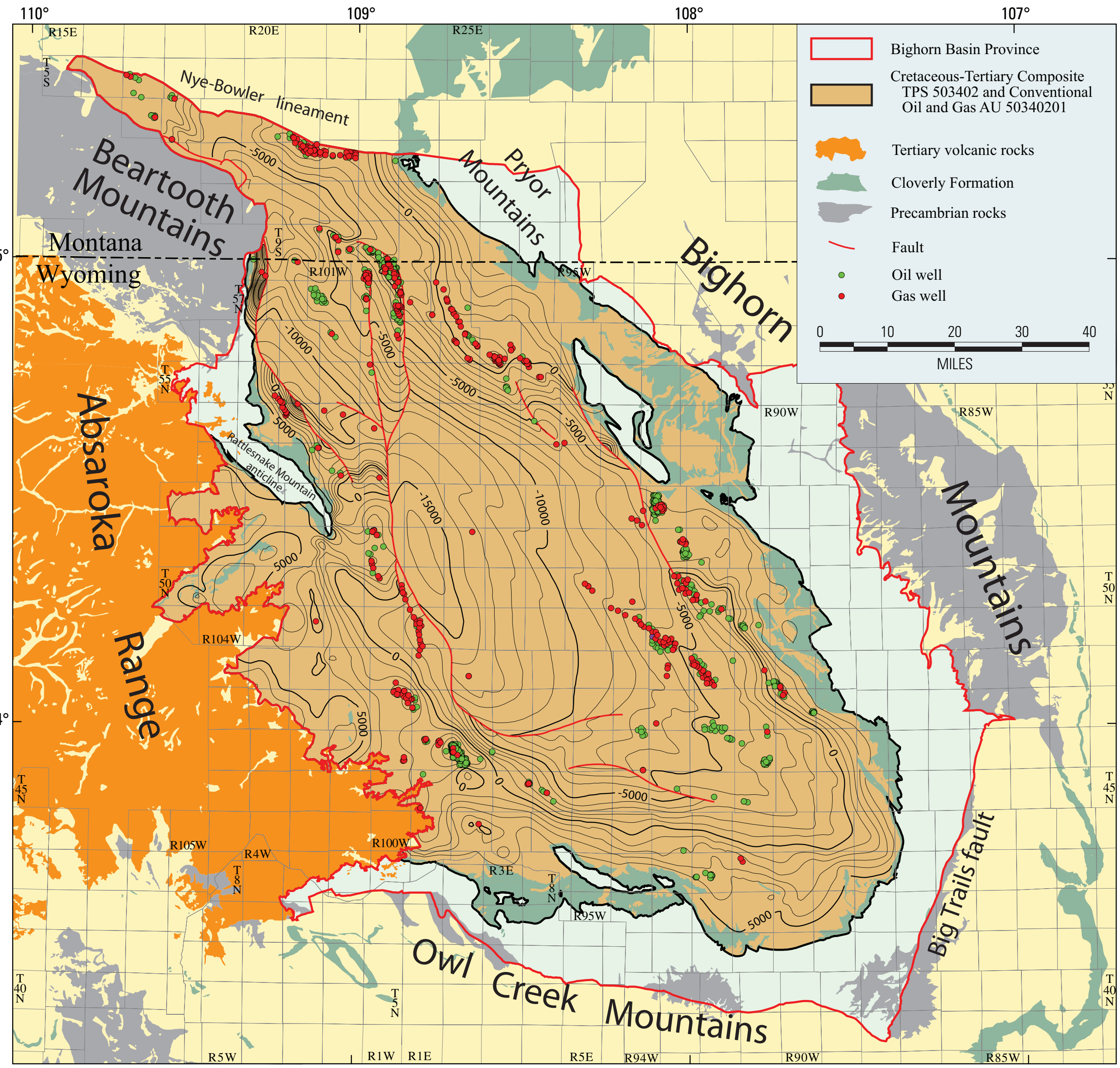

Figure 44. Map showing areal extent of the Cretaceous–Tertiary Composite Conventional Oil and Gas Assessment Unit (50340201), Bighorn Basin, Wyoming and Montana, and location of wells producing from Cretaceous and Tertiary reservoirs. Structure contours drawn on top of the Cloverly Formation; contour interval 1,000 ft. TPS, Total Petroleum System; AU, Assessment Unit.

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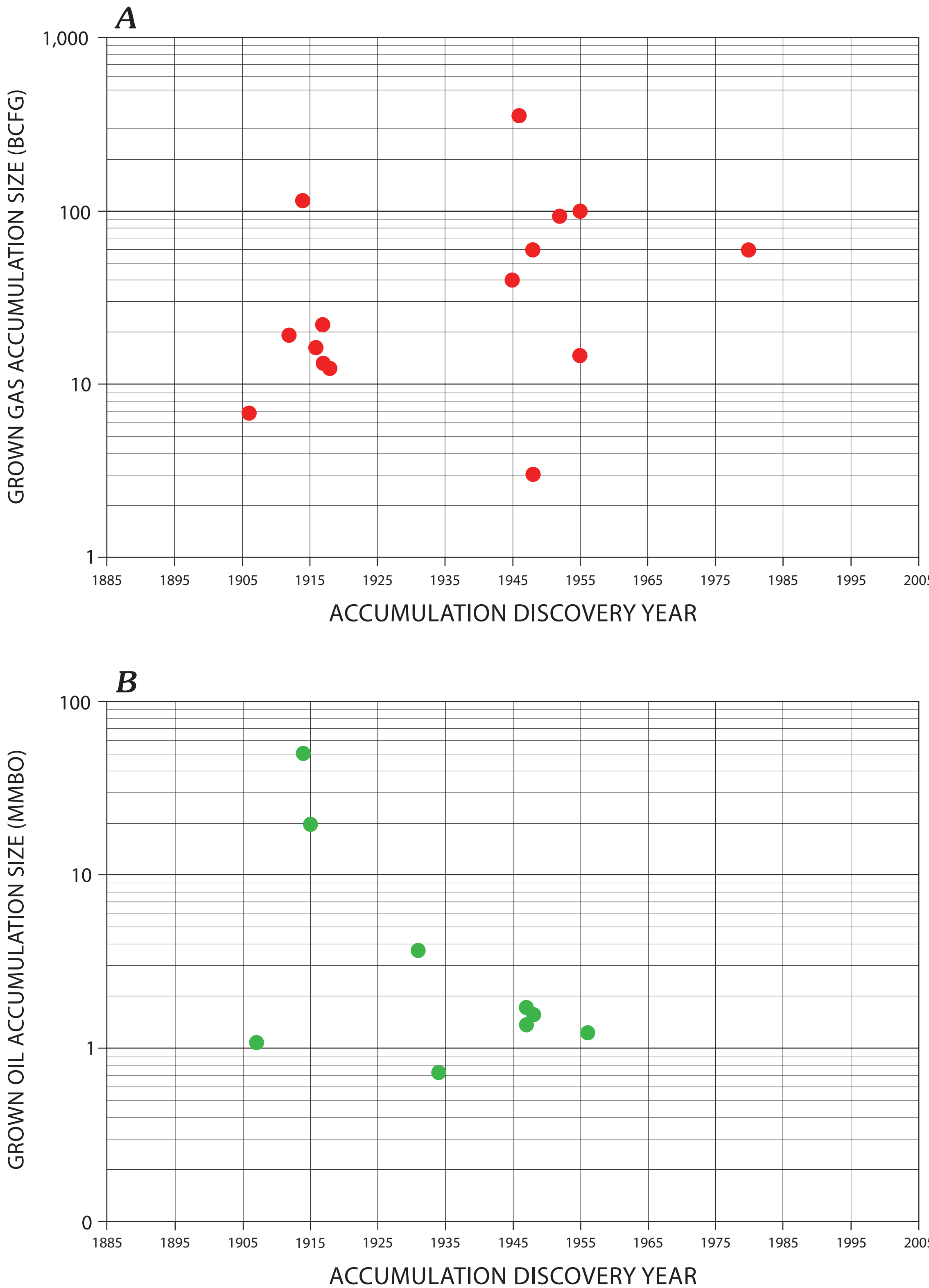

Figure 45. Graphs showing grown field size versus discovery year for (*A*) gas fields and (*B*) oil fields for Cretaceous and Tertiary accumulations in the Bighorn Basin, Wyoming and Montana. BCFG, billion of cubic feet of gas; MMBO, million barrels of oil.

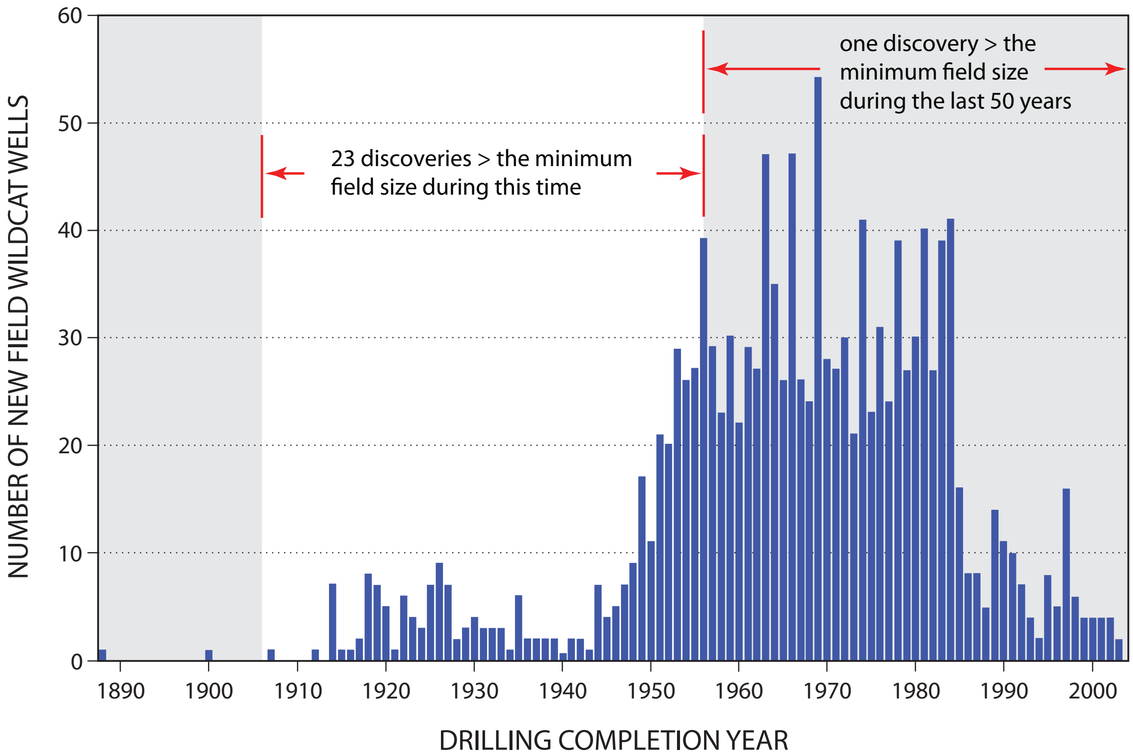

Figure 46. Number of new field wildcats by drilling completion year in the Bighorn Basin, Wyoming and Montana.

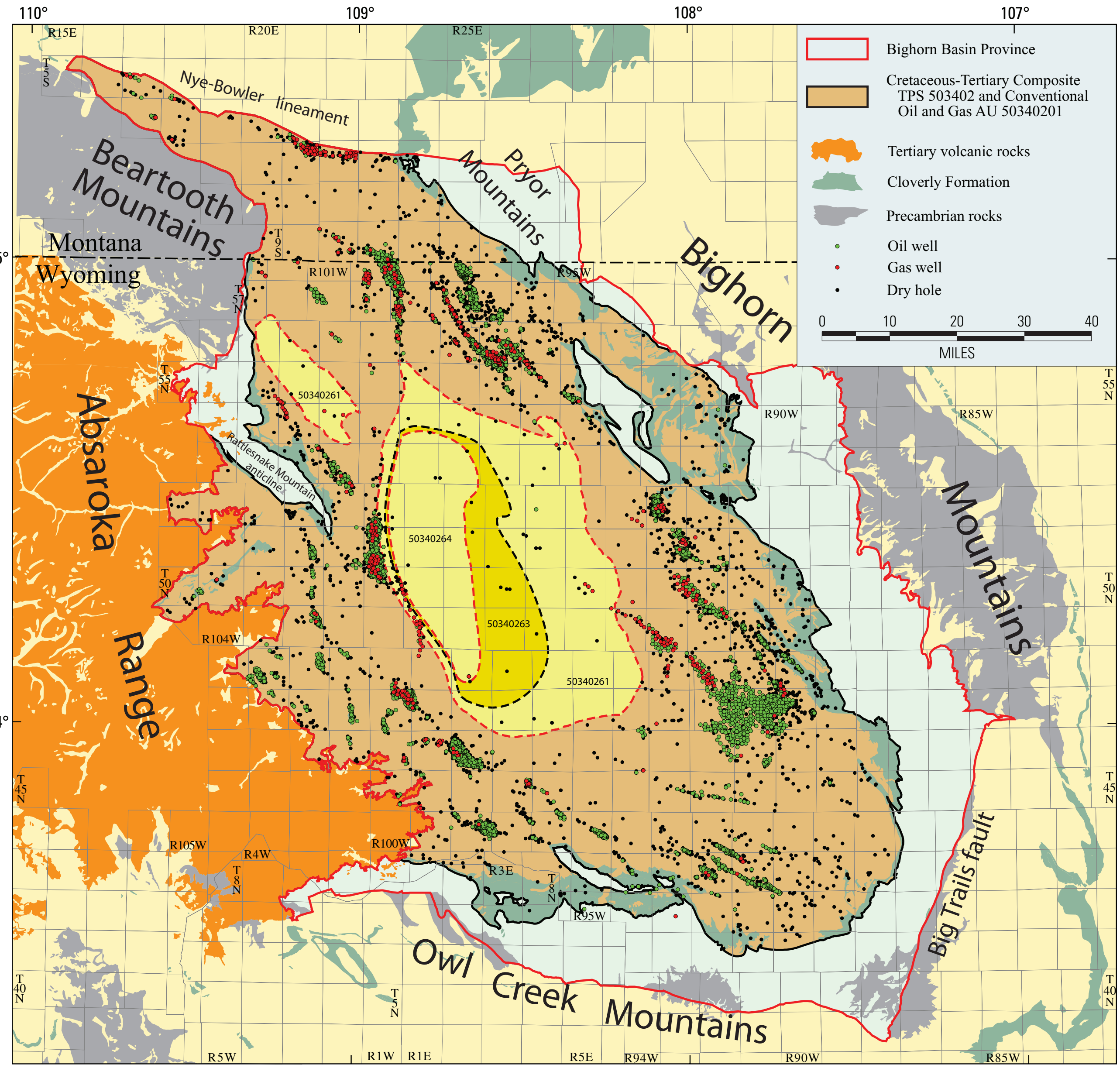

Figure 47. Map showing areal extent of the Cretaceous–Tertiary Composite Conventional Oil and Gas Assessment Unit (50340201) and locations of all wells, including dry holes, within the AU boundary to illustrate the drilling density around the margins of the Bighorn Basin, Wyoming and Montana. The boundaries of the three continuous gas AUs that occupy the basin center, where no conventional trapping is expected are also shown. TPS, Total Petroleum System; AU, Assessment Unit.

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Appendix A. Input parameters for the Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas Assessment Unit (50340261), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]

FORSPAN ASSESSMENT MODEL FOR CONTINUOUS ACCUMULATIONS--BASIC INPUT DATA FORM (NOGA, Version 9, 2-10-03)

IDENTIFICATION INFORMATION

Assessment Geologist:	M.A. Kirschbaum and S.M. Condon	Date:	19-Feb-08
Region:	North America	Number:	5
Province:	Bighorn Basin	Number:	5034
Total Petroleum System:	Cretaceous-Tertiary Composite	Number:	503402
Assessment Unit:	Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas	Number:	50340261
Based on Data as of:	IHS Energy (2007); Cardinal and others (1989)		
Notes from Assessor:			

CHARACTERISTICS OF ASSESSMENT UNIT

Assessment-unit type: Oil (<20,000 cfg/bo) **or Gas** (≥20,000 cfg/bo), incl. disc. & pot. additions: Gas
What is the minimum total recovery per cell? 0.02 (mmbo for oil A.U.; bcfg for gas A.U.)
Number of tested cells: 23
Number of tested cells with total recovery per cell ≥ minimum: 5
Established (discovered cells): X Hypothetical (no cells): ____
Median total recovery per cell (for cells ≥ min.): (mmbo for oil A.U.; bcfg for gas A.U.)
1st 3rd discovered ____ 2nd 3rd ____ 3rd 3rd ____

Assessment-Unit Probabilities:

Attribute	Probability of occurrence (0-1.0)
1. **CHARGE:** Adequate petroleum charge for an untested cell with total recovery ≥ minimum.	1.0
2. **ROCKS:** Adequate reservoirs, traps, seals for an untested cell with total recovery ≥ minimum.	1.0
3. **TIMING:** Favorable geologic timing for an untested cell with total recovery ≥ minimum.	1.0

Assessment-Unit GEOLOGIC Probability (Product of 1, 2, and 3): 1.0

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES

1. Total assessment-unit area (acres): (uncertainty of a fixed value)

   calculated mean 969,000 minimum 872,000 mode 969,000 maximum 1,066,000

2. Area per cell of untested cells having potential for additions to reserves (acres): (values are inherently variable)

   calculated mean 130 minimum 40 mode 50 maximum 300

   uncertainty of mean: minimum 100 maximum 160

3. Percentage of total assessment-unit area that is untested (%): (uncertainty of a fixed value)

   calculated mean 99.6 minimum 99.2 mode 99.7 maximum 99.9

Appendix A. Input parameters for the Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas Assessment Unit (50340261), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas, 5034

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES (Continued)

4. Percentage of untested assessment-unit area that has potential for additions to reserves (%):
(a necessary criterion is that total recovery per cell ≥ minimum; uncertainty of a fixed value)

calculated mean 8.4 minimum 0.6 mode 2 maximum 22.5

Geologic evidence for estimates:

TOTAL RECOVERY PER CELL

Total recovery per cell for untested cells having potential for additions to reserves:
(values are inherently variable; mmbo for oil A.U.; bcfg for gas A.U.)

calculated mean 0.57 minimum 0.02 median 0.35 maximum 7.5

AVERAGE COPRODUCT RATIOS FOR UNTESTED CELLS, TO ASSESS COPRODUCTS
(uncertainty of fixed but unknown values)

	minimum	mode	maximum
Oil assessment unit:			
Gas/oil ratio (cfg/bo)			
NGL/gas ratio (bngl/mmcfg)			
Gas assessment unit:			
Liquids/gas ratio (bliq/mmcfg)	0	0.5	2

Appendix A. Input parameters for the Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas Assessment Unit (50340261), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas, 50340261

SELECTED ANCILLARY DATA FOR UNTESTED CELLS
(values are inherently variable)

Oil assessment unit:	minimum	mode	maximum
API gravity of oil (degrees)			
Sulfur content of oil (%)			
Depth (m) of water (if applicable)			

Drilling depth (m)

minimum	F75	mode	F25	maximum

Gas assessment unit:	minimum	mode	maximum
Inert-gas content (%)	0.00	0.50	2.00
CO_2 content (%)	0.00	3.00	5.00
Hydrogen sulfide content (%)	0.00	0.00	0.00
Heating value (BTU)	950	1000	1100
Depth (m) of water (if applicable)			

Drilling depth (m)

minimum	F75	mode	F25	maximum
3000	3500	4000	5800	6700

Success ratios:	calculated mean	minimum	mode	maximum
Future success ratio (%)	35	10	20	75

Historic success ratio, tested cells (%) 22

Completion practices:

1. Typical well-completion practices (conventional, open hole, open cavity, other) conventional
2. Fraction of wells drilled that are typically stimulated 100
3. Predominant type of stimulation (none, frac, acid, other) hydrofrac
4. Fraction of wells drilled that are horizontal 0

Appendix A. Input parameters for the Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas Assessment Unit (50340261), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas, 50340261

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO STATES
Surface Allocations (uncertainty of a fixed value)

1. Wyoming represents 100 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		100	

2. ____ represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

3. ____ represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

4. ____ represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

5. ____ represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

6. ____ represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix A. Input parameters for the Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas Assessment Unit (50340261), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas, 50340261

7. ______________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

8. ______________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

9. ______________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

10. ______________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

11. ______________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

12. ______________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

Appendix A. Input parameters for the Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas Assessment Unit (50340261), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas, 50340261

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO GENERAL LAND OWNERSHIPS
Surface Allocations (uncertainty of a fixed value)

1. Federal Lands represents 75.09 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		75	

2. Private Lands represents 19.95 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		20	

3. Tribal Lands represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

4. Other Lands represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

5. WY State Lands represents 4.96 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		5	

6. ____ represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

Appendix A. Input parameters for the Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas Assessment Unit (50340261), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas, 50340261

7. ______________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

8. ______________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

9. ______________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

10. ______________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

11. ______________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

12. ______________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix A. Input parameters for the Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas Assessment Unit (50340261), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas, 50340261

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO FEDERAL LAND SUBDIVISIONS
Surface Allocations (uncertainty of a fixed value)

1. Bureau of Land Management (BLM) represents 72.58 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		74.9	

2. BLM Wilderness Areas (BLMW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

3. BLM Roadless Areas (BLMR) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

4. National Park Service (NPS) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

5. NPS Wilderness Areas (NPSW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

6. NPS Protected Withdrawals (NPSP) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix A. Input parameters for the Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas Assessment Unit (50340261), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas, 50340261

7. US Forest Service (FS) represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

8. USFS Wilderness Areas (FSW) represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

9. USFS Roadless Areas (FSR) represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

10. USFS Protected Withdrawals (FSP) represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

11. US Fish and Wildlife Service (FWS) represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

12. USFWS Wilderness Areas (FWSW) represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix A. Input parameters for the Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas Assessment Unit (50340261), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas, 50340261

13. USFWS Protected Withdrawals (FWSP) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

14. Wilderness Study Areas (WS) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

15. Department of Energy (DOE) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

16. Department of Defense (DOD) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

17. Bureau of Reclamation (BOR) represents 2.51 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		0.1	

18. Tennessee Valley Authority (TVA) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix A. Input parameters for the Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas Assessment Unit (50340261), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.) ____________________

19. Other Federal ____________ represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

20. ____________ represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

Appendix A. Input parameters for the Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas Assessment Unit (50340261), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas, 50340261

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO ECOSYSTEMS
Surface Allocations (uncertainty of a fixed value)

1. Bighorn Basin (BHBA) represents 85.95 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		80	

2. Yellowstone Highlands (YSHL) represents 14.05 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		20	

3. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

4. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

5. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

6. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix A. Input parameters for the Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas Assessment Unit (50340261), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Muddy-Frontier Sandstone and Mowry Fractured Shale Continuous Gas, 50340261

7. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

8. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

9. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

10. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

11. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

12. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

Appendix B. Input parameters for the Mowry Fractured Shale Continuous Oil Assessment Unit (50340262), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]

FORSPAN ASSESSMENT MODEL FOR CONTINUOUS ACCUMULATIONS--BASIC INPUT DATA FORM (NOGA, Version 9, 2-10-03)

IDENTIFICATION INFORMATION

Assessment Geologist:	M.A. Kirschbaum	Date:	19-Feb-08
Region:	North America	Number:	5
Province:	Bighorn Basin	Number:	5034
Total Petroleum System:	Cretaceous-Tertiary Composite	Number:	503402
Assessment Unit:	Mowry Fractured Shale Continuous Oil	Number:	50340262
Based on Data as of:	IHS Energy (2007)		

Notes from Assessor: Powder River Basin Mowry Continuous Oil (50330261) assessment unit used as analog.

CHARACTERISTICS OF ASSESSMENT UNIT

Assessment-unit type: Oil (<20,000 cfg/bo) **or Gas** (>20,000 cfg/bo), incl. disc. & pot. additions: Oil

What is the minimum total recovery per cell? 0.002 (mmbo for oil A.U.; bcfg for gas A.U.)

Number of tested cells: 0

Number of tested cells with total recovery per cell > minimum: 0

Established (discovered cells): ______ Hypothetical (no cells): X

Median total recovery per cell (for cells > min.): (mmbo for oil A.U.; bcfg for gas A.U.)

1st 3rd discovered ______ 2nd 3rd ______ 3rd 3rd ______

Assessment-Unit Probabilities:

Attribute	Probability of occurrence (0-1.0)
1. **CHARGE:** Adequate petroleum charge for an untested cell with total recovery > minimum.	1.0
2. **ROCKS:** Adequate reservoirs, traps, seals for an untested cell with total recovery > minimum.	1.0
3. **TIMING:** Favorable geologic timing for an untested cell with total recovery > minimum.	1.0

Assessment-Unit GEOLOGIC Probability (Product of 1, 2, and 3): 1.0

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES

1. Total assessment-unit area (acres): (uncertainty of a fixed value)

   calculated mean 646,000 minimum 581,000 mode 646,000 maximum 710,000

2. Area per cell of untested cells having potential for additions to reserves (acres): (values are inherently variable)

   calculated mean 290 minimum 40 mode 185 maximum 640

   uncertainty of mean: minimum 240 maximum 340

3. Percentage of total assessment-unit area that is untested (%): (uncertainty of a fixed value)

   calculated mean 100 minimum 100 mode 100 maximum 100

Appendix B. Input parameters for the Mowry Fractured Shale Continuous Oil Assessment Unit (50340262), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mowry Fractured Shale Continuous Oil, 50340262

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES (Continued)

4. Percentage of untested assessment-unit area that has potential for additions to reserves (%):
(a necessary criterion is that total recovery per cell ≥ minimum; uncertainty of a fixed value)

calculated mean 6 minimum 0.1 mode 1.25 maximum 17

Geologic evidence for estimates:

TOTAL RECOVERY PER CELL

Total recovery per cell for untested cells having potential for additions to reserves:
(values are inherently variable; mmbo for oil A.U.; bcfg for gas A.U.)

calculated mean 0.04 minimum 0.002 median 0.025 maximum 0.35

AVERAGE COPRODUCT RATIOS FOR UNTESTED CELLS, TO ASSESS COPRODUCTS
(uncertainty of fixed but unknown values)

Oil assessment unit:	minimum	mode	maximum
Gas/oil ratio (cfg/bo)	500	1000	1500
NGL/gas ratio (bngl/mmcfg)	30	60	90
Gas assessment unit:			
Liquids/gas ratio (bliq/mmcfg)			

Appendix B. Input parameters for the Mowry Fractured Shale Continuous Oil Assessment Unit (50340262), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mowry Fractured Shale Continuous Oil, 50340262

SELECTED ANCILLARY DATA FOR UNTESTED CELLS
(values are inherently variable)

Oil assessment unit:	minimum	mode	maximum
API gravity of oil (degrees)	40	45	50
Sulfur content of oil (%)	0	0.1	0.3
Depth (m) of water (if applicable)			

Drilling depth (m)

minimum	F75	mode	F25	maximum
2400	2800	3000	3300	3600

Gas assessment unit:	minimum	mode	maximum
Inert-gas content (%)			
CO_2 content (%)			
Hydrogen sulfide content (%)			
Heating value (BTU)			
Depth (m) of water (if applicable)			

Drilling depth (m)

minimum	F75	mode	F25	maximum

Success ratios:	calculated mean	minimum	mode	maximum
Future success ratio (%)	28	10	25	50

Historic success ratio, tested cells (%) __________

Completion practices:

1. Typical well-completion practices (conventional, open hole, open cavity, other)	conventional
2. Fraction of wells drilled that are typically stimulated	100
3. Predominant type of stimulation (none, frac, acid, other)	hydrofrac
4. Fraction of wells drilled that are horizontal	90

Appendix B. Input parameters for the Mowry Fractured Shale Continuous Oil Assessment Unit (50340262), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mowry Fractured Shale Continuous Oil, 50340262

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO STATES
Surface Allocations (uncertainty of a fixed value)

1. Wyoming ______ represents 100 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	100	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

2. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

3. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

4. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

5. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

6. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

Appendix B. Input parameters for the Mowry Fractured Shale Continuous Oil Assessment Unit (50340262), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mowry Fractured Shale Continuous Oil, 50340262

7. ______ represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

8. ______ represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

9. ______ represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

10. ______ represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

11. ______ represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

12. ______ represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

Appendix B. Input parameters for the Mowry Fractured Shale Continuous Oil Assessment Unit (50340262), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mowry Fractured Shale Continuous Oil, 50340262

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO GENERAL LAND OWNERSHIPS
Surface Allocations (uncertainty of a fixed value)

1. Federal Lands represents 74.43 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity		75	
Gas in gas assessment unit:			
Volume % in entity			

2. Private Lands represents 20.77 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity		21	
Gas in gas assessment unit:			
Volume % in entity			

3. Tribal Lands represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

4. Other Lands represents 0.18 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity		0	
Gas in gas assessment unit:			
Volume % in entity			

5. WY State Lands represents 4.62 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity		4	
Gas in gas assessment unit:			
Volume % in entity			

6. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix B. Input parameters for the Mowry Fractured Shale Continuous Oil Assessment Unit (50340262), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mowry Fractured Shale Continuous Oil, 50340262

7. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

8. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

9. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

10. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

11. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

12. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

Appendix B. Input parameters for the Mowry Fractured Shale Continuous Oil Assessment Unit (50340262), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mowry Fractured Shale Continuous Oil, 50340262

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO FEDERAL LAND SUBDIVISIONS
Surface Allocations (uncertainty of a fixed value)

1. Bureau of Land Management (BLM) represents 73.04 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity		74.9	
Gas in gas assessment unit:			
Volume % in entity			

2. BLM Wilderness Areas (BLMW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

3. BLM Roadless Areas (BLMR) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

4. National Park Service (NPS) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

5. NPS Wilderness Areas (NPSW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

6. NPS Protected Withdrawals (NPSP) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix B. Input parameters for the Mowry Fractured Shale Continuous Oil Assessment Unit (50340262), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mowry Fractured Shale Continuous Oil, 50340262

7. US Forest Service (FS) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

8. USFS Wilderness Areas (FSW) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

9. USFS Roadless Areas (FSR) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

10. USFS Protected Withdrawals (FSP) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

11. US Fish and Wildlife Service (FWS) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

12. USFWS Wilderness Areas (FWSW) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

Appendix B. Input parameters for the Mowry Fractured Shale Continuous Oil Assessment Unit (50340262), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mowry Fractured Shale Continuous Oil, 50340262

13. USFWS Protected Withdrawals (FWSP) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

14. Wilderness Study Areas (WS) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

15. Department of Energy (DOE) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

16. Department of Defense (DOD) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

17. Bureau of Reclamation (BOR) represents 1.39 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity		0.1	
Gas in gas assessment unit:			
Volume % in entity			

18. Tennessee Valley Authority (TVA) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix B. Input parameters for the Mowry Fractured Shale Continuous Oil Assessment Unit (50340262), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)

19. Other Federal ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

20. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix B. Input parameters for the Mowry Fractured Shale Continuous Oil Assessment Unit (50340262), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mowry Fractured Shale Continuous Oil, 50340262

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO ECOSYSTEMS
Surface Allocations (uncertainty of a fixed value)

1. Bighorn Basin (BHBA) represents 100.00 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity		100	
Gas in gas assessment unit:			
Volume % in entity			

2. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

3. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

4. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

5. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

6. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix B. Input parameters for the Mowry Fractured Shale Continuous Oil Assessment Unit (50340262), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mowry Fractured Shale Continuous Oil, 50340262

7. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

8. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

9. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

10. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

11. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

12. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

Appendix C. Input parameters for the Cody Sandstone Continuous Gas Assessment Unit (50340263), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]

FORSPAN ASSESSMENT MODEL FOR CONTINUOUS ACCUMULATIONS--BASIC INPUT DATA FORM (NOGA, Version 9, 2-10-03)

IDENTIFICATION INFORMATION

Assessment Geologist:	T.M. Finn and R.C. Johnson	Date:	19-Feb-08
Region:	North America	Number:	5
Province:	Bighorn Basin	Number:	5034
Total Petroleum System:	Cretaceous-Tertiary Composite	Number:	503402
Assessment Unit:	Cody Sandstone Continuous Gas	Number:	50340263
Based on Data as of:	IHS Energy (2007)		

Notes from Assessor: Wind River Basin Cody Sandstone Continuous Gas (50350262) assessment unit used as analog.

CHARACTERISTICS OF ASSESSMENT UNIT

Assessment-unit type: Oil (<20,000 cfg/bo) **or Gas** (≥20,000 cfg/bo), incl. disc. & pot. additions: Gas
What is the minimum total recovery per cell? 0.02 (mmbo for oil A.U.; bcfg for gas A.U.)
Number of tested cells: 0
Number of tested cells with total recovery per cell ≥ minimum: 0
Established (discovered cells): ____ Hypothetical (no cells): X
Median total recovery per cell (for cells ≥ min.): (mmbo for oil A.U.; bcfg for gas A.U.)
1st 3rd discovered ____ 2nd 3rd ____ 3rd 3rd ____

Assessment-Unit Probabilities:

Attribute	Probability of occurrence (0-1.0)
1. **CHARGE:** Adequate petroleum charge for an untested cell with total recovery ≥ minimum.	1.0
2. **ROCKS:** Adequate reservoirs, traps, seals for an untested cell with total recovery ≥ minimum.	1.0
3. **TIMING:** Favorable geologic timing for an untested cell with total recovery ≥ minimum.	1.0

Assessment-Unit GEOLOGIC Probability (Product of 1, 2, and 3): 1.0

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES

1. Total assessment-unit area (acres): (uncertainty of a fixed value)

   calculated mean 420,000 minimum 378,000 mode 420,000 maximum 462,000

2. Area per cell of untested cells having potential for additions to reserves (acres): (values are inherently variable)

   calculated mean 280 minimum 40 mode 160 maximum 640

   uncertainty of mean: minimum 160 maximum 400

3. Percentage of total assessment-unit area that is untested (%): (uncertainty of a fixed value)

   calculated mean 100 minimum 100 mode 100 maximum 100

Appendix C. Input parameters for the Cody Sandstone Continuous Gas Assessment Unit (50340263), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Cody Sandstone Continuous Gas, 50340263

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES (Continued)

4. Percentage of untested assessment-unit area that has potential for additions to reserves (%):
   (a necessary criterion is that total recovery per cell ≥ minimum; uncertainty of a fixed value)

   calculated mean 7.6 minimum 0.3 mode 3 maximum 19.6

   Geologic evidence for estimates:

TOTAL RECOVERY PER CELL

Total recovery per cell for untested cells having potential for additions to reserves:
(values are inherently variable; mmbo for oil A.U.; bcfg for gas A.U.)

calculated mean 0.34 minimum 0.02 median 0.2 maximum 5

AVERAGE COPRODUCT RATIOS FOR UNTESTED CELLS, TO ASSESS COPRODUCTS
(uncertainty of fixed but unknown values)

	minimum	mode	maximum
Oil assessment unit:			
Gas/oil ratio (cfg/bo)			
NGL/gas ratio (bngl/mmcfg)			
Gas assessment unit:			
Liquids/gas ratio (bliq/mmcfg)	0	0.015	1

Appendix C. Input parameters for the Cody Sandstone Continuous Gas Assessment Unit (50340263), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Cody Sandstone Continuous Gas, 50340263

SELECTED ANCILLARY DATA FOR UNTESTED CELLS
(values are inherently variable)

Oil assessment unit:	minimum	mode	maximum
API gravity of oil (degrees)			
Sulfur content of oil (%)			
Depth (m) of water (if applicable)			

Drilling depth (m)

minimum	F75	mode	F25	maximum

Gas assessment unit:	minimum	mode	maximum
Inert-gas content (%)	0.00	0.50	2.00
CO_2 content (%)	0.00	3.00	5.00
Hydrogen sulfide content (%)	0.00	0.00	0.00
Heating value (BTU)	950	1050	1100
Depth (m) of water (if applicable)			

Drilling depth (m)

minimum	F75	mode	F25	maximum
3750		4575		5800

Success ratios:	calculated mean	minimum	mode	maximum
Future success ratio (%)	40	10	40	70

Historic success ratio, tested cells (%) ____________

Completion practices:

1. Typical well-completion practices (conventional, open hole, open cavity, other)	conventional
2. Fraction of wells drilled that are typically stimulated	100
3. Predominant type of stimulation (none, frac, acid, other)	hydrofrac
4. Fraction of wells drilled that are horizontal	0

Appendix C. Input parameters for the Cody Sandstone Continuous Gas Assessment Unit (50340263), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Cody Sandstone Continuous Gas, 50340263

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO STATES
Surface Allocations (uncertainty of a fixed value)

1. Wyoming represents 100 area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		100	

2. ______ represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

3. ______ represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

4. ______ represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

5. ______ represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

6. ______ represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix C. Input parameters for the Cody Sandstone Continuous Gas Assessment Unit (50340263), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Cody Sandstone Continuous Gas, 50340263

7. ____________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

8. ____________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

9. ____________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

10. ____________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

11. ____________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

12. ____________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

Appendix C. Input parameters for the Cody Sandstone Continuous Gas Assessment Unit (50340263), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Cody Sandstone Continuous Gas, 50340263

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO GENERAL LAND OWNERSHIPS
Surface Allocations (uncertainty of a fixed value)

1. Federal Lands represents 81.21 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		88	

2. Private Lands represents 13.68 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		8	

3. Tribal Lands represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

4. Other Lands represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

5. WY State Lands represents 5.11 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		4	

6. ____ represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

Appendix C. Input parameters for the Cody Sandstone Continuous Gas Assessment Unit (50340263), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Cody Sandstone Continuous Gas, 50340263

7. ________________________ represents ________ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

8. ________________________ represents ________ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

9. ________________________ represents ________ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

10. ________________________ represents ________ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

11. ________________________ represents ________ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

12. ________________________ represents ________ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

Appendix C. Input parameters for the Cody Sandstone Continuous Gas Assessment Unit (50340263), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Cody Sandstone Continuous Gas, 50340263

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO FEDERAL LAND SUBDIVISIONS
Surface Allocations (uncertainty of a fixed value)

1. Bureau of Land Management (BLM) represents 81.01 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		88	

2. BLM Wilderness Areas (BLMW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

3. BLM Roadless Areas (BLMR) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

4. National Park Service (NPS) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

5. NPS Wilderness Areas (NPSW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

6. NPS Protected Withdrawals (NPSP) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix C. Input parameters for the Cody Sandstone Continuous Gas Assessment Unit (50340263), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Cody Sandstone Continuous Gas, 50340263

7. US Forest Service (FS) represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity			

Gas in gas assessment unit:			
Volume % in entity			

8. USFS Wilderness Areas (FSW) represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity			

Gas in gas assessment unit:			
Volume % in entity			

9. USFS Roadless Areas (FSR) represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity			

Gas in gas assessment unit:			
Volume % in entity			

10. USFS Protected Withdrawals (FSP) represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity			

Gas in gas assessment unit:			
Volume % in entity			

11. US Fish and Wildlife Service (FWS) represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity			

Gas in gas assessment unit:			
Volume % in entity			

12. USFWS Wilderness Areas (FWSW) represents ______ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity			

Gas in gas assessment unit:			
Volume % in entity			

Appendix C. Input parameters for the Cody Sandstone Continuous Gas Assessment Unit (50340263), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Cody Sandstone Continuous Gas, 50340263

13. USFWS Protected Withdrawals (FWSP) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

14. Wilderness Study Areas (WS) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

15. Department of Energy (DOE) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

16. Department of Defense (DOD) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

17. Bureau of Reclamation (BOR) represents 0.20 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		0	

18. Tennessee Valley Authority (TVA) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

Appendix C. Input parameters for the Cody Sandstone Continuous Gas Assessment Unit (50340263), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.) ______________________

19. Other Federal ______________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

20. ______________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

Appendix C. Input parameters for the Cody Sandstone Continuous Gas Assessment Unit (50340263), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Cody Sandstone Continuous Gas, 50340263

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO ECOSYSTEMS
Surface Allocations (uncertainty of a fixed value)

1. Bighorn Basin (BHBA) represents 87.49 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		92	

2. Yellowstone Highlands (YSHL) represents 12.51 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		8	

3. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

4. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

5. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

6. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix C. Input parameters for the Cody Sandstone Continuous Gas Assessment Unit (50340263), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Cody Sandstone Continuous Gas, 50340263

7. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

8. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

9. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

10. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

11. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

12. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix D. Input parameters for the Mesaverde Sandstone Continuous Gas Assessment Unit (50340264), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit].

FORSPAN ASSESSMENT MODEL FOR CONTINUOUS ACCUMULATIONS--BASIC INPUT DATA FORM (NOGA, Version 9, 2-10-03)

IDENTIFICATION INFORMATION

Assessment Geologist:	T.M. Finn and R.C. Johnson	Date:	19-Feb-08
Region:	North America	Number:	5
Province:	Bighorn Basin	Number:	5034
Total Petroleum System:	Cretaceous-Tertiary Composite	Number:	503402
Assessment Unit:	Mesaverde Sandstone Continuous Gas	Number:	50340264
Based on Data as of:	IHS Energy (2007); Cardinal and others (1989); MGS (1985)		

Notes from Assessor: Wind River Basin Mesaverde-Meeteetse Sandstone Gas (50350264) assessment unit used as analog.

CHARACTERISTICS OF ASSESSMENT UNIT

Assessment-unit type: Oil (<20,000 cfg/bo) **or Gas** (>20,000 cfg/bo), incl. disc. & pot. additions: Gas
What is the minimum total recovery per cell? 0.02 (mmbo for oil A.U.; bcfg for gas A.U.)
Number of tested cells: 1
Number of tested cells with total recovery per cell > minimum: 0
Established (discovered cells): ____ Hypothetical (no cells): X
Median total recovery per cell (for cells > min.): (mmbo for oil A.U.; bcfg for gas A.U.)
1st 3rd discovered ____ 2nd 3rd ____ 3rd 3rd ____

Assessment-Unit Probabilities:

Attribute	Probability of occurrence (0-1.0)
1. **CHARGE:** Adequate petroleum charge for an untested cell with total recovery > minimum.	1.0
2. **ROCKS:** Adequate reservoirs, traps, seals for an untested cell with total recovery > minimum.	1.0
3. **TIMING:** Favorable geologic timing for an untested cell with total recovery > minimum.	1.0

Assessment-Unit GEOLOGIC Probability (Product of 1, 2, and 3): 1.0

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES

1. Total assessment-unit area (acres): (uncertainty of a fixed value)

   calculated mean 221,000 minimum 199,000 mode 221,000 maximum 243,000

2. Area per cell of untested cells having potential for additions to reserves (acres): (values are inherently variable)

   calculated mean 83.3 minimum 20 mode 50 maximum 180

   uncertainty of mean: minimum 60 maximum 100

3. Percentage of total assessment-unit area that is untested (%): (uncertainty of a fixed value)

   calculated mean 100 minimum 100 mode 100 maximum 100

Appendix D. Input parameters for the Mesaverde Sandstone Continuous Gas Assessment Unit (50340264), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mesaverde Sandstone Continuous Gas, 50340264

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES (Continued)

4. Percentage of untested assessment-unit area that has potential for additions to reserves (%):
(a necessary criterion is that total recovery per cell ≥ minimum; uncertainty of a fixed value)

calculated mean 3.6 minimum 0.2 mode 2.1 maximum 8.5

Geologic evidence for estimates:

TOTAL RECOVERY PER CELL

Total recovery per cell for untested cells having potential for additions to reserves:
(values are inherently variable; mmbo for oil A.U.; bcfg for gas A.U.)

calculated mean 0.34 minimum 0.02 median 0.2 maximum 5

AVERAGE COPRODUCT RATIOS FOR UNTESTED CELLS, TO ASSESS COPRODUCTS
(uncertainty of fixed but unknown values)

	minimum	mode	maximum
Oil assessment unit:			
Gas/oil ratio (cfg/bo)			
NGL/gas ratio (bngl/mmcfg)			
Gas assessment unit:			
Liquids/gas ratio (bliq/mmcfg)	0	3	6

Appendix D. Input parameters for the Mesaverde Sandstone Continuous Gas Assessment Unit (50340264), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mesaverde Sandstone Continuous Gas, 50340264

SELECTED ANCILLARY DATA FOR UNTESTED CELLS
(values are inherently variable)

Oil assessment unit:	minimum	mode	maximum
API gravity of oil (degrees)			
Sulfur content of oil (%)			
Depth (m) of water (if applicable)			

Drilling depth (m)

minimum	F75	mode	F25	maximum

Gas assessment unit:	minimum	mode	maximum
Inert-gas content (%)	0.00	0.50	4.00
CO_2 content (%)	0.00	0.25	1.00
Hydrogen sulfide content (%)	0.00	0.00	0.00
Heating value (BTU)	1000	1150	1300
Depth (m) of water (if applicable)			

Drilling depth (m)

minimum	F75	mode	F25	maximum
3800		4270		5340

Success ratios:	calculated mean	minimum	mode	maximum
Future success ratio (%)	30	10	30	50

Historic success ratio, tested cells (%) ______

Completion practices:

1. Typical well-completion practices (conventional, open hole, open cavity, other)	conventional
2. Fraction of wells drilled that are typically stimulated	100
3. Predominant type of stimulation (none, frac, acid, other)	hydrofrac
4. Fraction of wells drilled that are horizontal	0

Appendix D. Input parameters for the Mesaverde Sandstone Continuous Gas Assessment Unit (50340264), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mesaverde Sandstone Continuous Gas, 50340264

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO STATES
Surface Allocations (uncertainty of a fixed value)

1. Wyoming represents 100 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		100	

2. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

3. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

4. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

5. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

6. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix D. Input parameters for the Mesaverde Sandstone Continuous Gas Assessment Unit (50340264), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mesaverde Sandstone Continuous Gas, 50340264

7. ______________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

8. ______________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

9. ______________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

10. ______________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

11. ______________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

12. ______________________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

Appendix D. Input parameters for the Mesaverde Sandstone Continuous Gas Assessment Unit (50340264), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mesaverde Sandstone Continuous Gas, 50340264

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO GENERAL LAND OWNERSHIPS
Surface Allocations (uncertainty of a fixed value)

1. Federal Lands represents 78.83 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		92	

2. Private Lands represents 15.64 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		0	

3. Tribal Lands represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

4. Other Lands represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

5. WY State Lands represents 5.52 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		8	

6. ____ represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

Appendix D. Input parameters for the Mesaverde Sandstone Continuous Gas Assessment Unit (50340264), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mesaverde Sandstone Continuous Gas, 50340264

7. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

8. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

9. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

10. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

11. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

12. ____________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

Appendix D. Input parameters for the Mesaverde Sandstone Continuous Gas Assessment Unit (50340264), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mesaverde Sandstone Continuous Gas, 50340264

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO FEDERAL LAND SUBDIVISIONS
Surface Allocations (uncertainty of a fixed value)

1. Bureau of Land Management (BLM) represents 78.83 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		92	

2. BLM Wilderness Areas (BLMW) represents ___ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

3. BLM Roadless Areas (BLMR) represents ___ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

4. National Park Service (NPS) represents ___ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

5. NPS Wilderness Areas (NPSW) represents ___ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

6. NPS Protected Withdrawals (NPSP) represents ___ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

Appendix D. Input parameters for the Mesaverde Sandstone Continuous Gas Assessment Unit (50340264), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mesaverde Sandstone Continuous Gas, 50340264

7. US Forest Service (FS) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

8. USFS Wilderness Areas (FSW) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

9. USFS Roadless Areas (FSR) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

10. USFS Protected Withdrawals (FSP) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

11. US Fish and Wildlife Service (FWS) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

12. USFWS Wilderness Areas (FWSW) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix D. Input parameters for the Mesaverde Sandstone Continuous Gas Assessment Unit (50340264), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mesaverde Sandstone Continuous Gas, 50340264

13. USFWS Protected Withdrawals (FWSP) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

14. Wilderness Study Areas (WS) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

15. Department of Energy (DOE) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

16. Department of Defense (DOD) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

17. Bureau of Reclamation (BOR) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

18. Tennessee Valley Authority (TVA) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

Appendix D. Input parameters for the Mesaverde Sandstone Continuous Gas Assessment Unit (50340264), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.) ______________________________

19. Other Federal ______________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

20. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

Appendix D. Input parameters for the Mesaverde Sandstone Continuous Gas Assessment Unit (50340264), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mesaverde Sandstone Continuous Gas, 50340264

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO ECOSYSTEMS
Surface Allocations (uncertainty of a fixed value)

1. Bighorn Basin (BHBA) represents 78.23 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		83	

2. Yellowstone Highlands (YSHL) represents 21.77 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		17	

3. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

4. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

5. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

6. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix D. Input parameters for the Mesaverde Sandstone Continuous Gas Assessment Unit (50340264), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mesaverde Sandstone Continuous Gas, 50340264

7. ____________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

8. ____________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

9. ____________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

10. ____________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

11. ____________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

12. ____________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

Appendix E. Input parameters for the Mesaverde-Meeteetse Coalbed Gas Assessment Unit (50340281), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]

FORSPAN ASSESSMENT MODEL FOR CONTINUOUS ACCUMULATIONS--BASIC INPUT DATA FORM (NOGA, Version 9, 2-10-03)

IDENTIFICATION INFORMATION

Assessment Geologist:	S.B. Roberts	Date:	20-Feb-08
Region:	North America	Number:	5
Province:	Bighorn Basin	Number:	5034
Total Petroleum System:	Cretaceous-Tertiary Composite	Number:	503402
Assessment Unit:	Mesaverde-Meeteetse Formation Coalbed Gas	Number:	50340281
Based on Data as of:	IHS Energy (2007)		

Notes from Assessor: Powder River Basin Fort Union Formation and Piceance Basin Mesaverde Formation coalbed gas wells used as analogs.

CHARACTERISTICS OF ASSESSMENT UNIT

Assessment-unit type: Oil (<20,000 cfg/bo) **or Gas** (≥20,000 cfg/bo), incl. disc. & pot. additions: Gas
What is the minimum total recovery per cell? 0.02 (mmbo for oil A.U.; bcfg for gas A.U.)
Number of tested cells: 16
Number of tested cells with total recovery per cell ≥ minimum: 0
Established (discovered cells): ____ Hypothetical (no cells): X
Median total recovery per cell (for cells ≥ min.): (mmbo for oil A.U.; bcfg for gas A.U.)
1st 3rd discovered ____ 2nd 3rd ____ 3rd 3rd ____

Assessment-Unit Probabilities:

Attribute	Probability of occurrence (0-1.0)
1. **CHARGE:** Adequate petroleum charge for an untested cell with total recovery ≥ minimum.	1.0
2. **ROCKS:** Adequate reservoirs, traps, seals for an untested cell with total recovery ≥ minimum.	1.0
3. **TIMING:** Favorable geologic timing for an untested cell with total recovery ≥ minimum.	1.0

Assessment-Unit GEOLOGIC Probability (Product of 1, 2, and 3): 1.0

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES

1. Total assessment-unit area (acres): (uncertainty of a fixed value)

   calculated mean 1,619,000 minimum 1,457,000 mode 1,619,000 maximum 1,781,000

2. Area per cell of untested cells having potential for additions to reserves (acres): (values are inherently variable)

   calculated mean 127 minimum 40 mode 100 maximum 240

   uncertainty of mean: minimum 80 maximum 170

3. Percentage of total assessment-unit area that is untested (%): (uncertainty of a fixed value)

   calculated mean 99.9 minimum 99.9 mode 99.9 maximum 99.9

Appendix E. Input parameters for the Mesaverde-Meeteetse Coalbed Gas Assessment Unit (50340281), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mesaverde-Meeteetse Formation Coalbed Gas, 50340281

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES (Continued)

4. Percentage of untested assessment-unit area that has potential for additions to reserves (%):
(a necessary criterion is that total recovery per cell ≥ minimum; uncertainty of a fixed value)

calculated mean 5.7 minimum 0.5 mode 2.5 maximum 14

Geologic evidence for estimates:

TOTAL RECOVERY PER CELL

Total recovery per cell for untested cells having potential for additions to reserves:
(values are inherently variable; mmbo for oil A.U.; bcfg for gas A.U.)

calculated mean 0.14 minimum 0.02 median 0.1 maximum 1.2

AVERAGE COPRODUCT RATIOS FOR UNTESTED CELLS, TO ASSESS COPRODUCTS
(uncertainty of fixed but unknown values)

Oil assessment unit:	minimum	mode	maximum
Gas/oil ratio (cfg/bo)			
NGL/gas ratio (bngl/mmcfg)			
Gas assessment unit:			
Liquids/gas ratio (bliq/mmcfg)	0	2	5

Appendix E. Input parameters for the Mesaverde-Meeteetse Coalbed Gas Assessment Unit (50340281), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mesaverde-Meeteetse Formation Coalbed Gas, 50340281

SELECTED ANCILLARY DATA FOR UNTESTED CELLS
(values are inherently variable)

Oil assessment unit:	minimum	mode	maximum
API gravity of oil (degrees)			
Sulfur content of oil (%)			
Depth (m) of water (if applicable)			

Drilling depth (m)

minimum	F75	mode	F25	maximum

Gas assessment unit:	minimum	mode	maximum
Inert-gas content (%)	0.10	0.30	1.00
CO_2 content (%)	0.50	1.80	20.00
Hydrogen sulfide content (%)	0.00	0.00	0.00
Heating value (BTU)	850	950	1050
Depth (m) of water (if applicable)			

Drilling depth (m)

minimum	F75	mode	F25	maximum
150	650	750	1150	1800

Success ratios:	calculated mean	minimum	mode	maximum
Future success ratio (%)	47	20	40	80

Historic success ratio, tested cells (%) ______

Completion practices:

1. Typical well-completion practices (conventional, open hole, open cavity, other)	conventional
2. Fraction of wells drilled that are typically stimulated	0
3. Predominant type of stimulation (none, frac, acid, other)	none
4. Fraction of wells drilled that are horizontal	none

Appendix E. Input parameters for the Mesaverde-Meeteetse Coalbed Gas Assessment Unit (50340281), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mesaverde-Meeteetse Formation Coalbed Gas, 50340281

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO STATES
Surface Allocations (uncertainty of a fixed value)

1. Wyoming represents 85.50 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		99	

2. Montana represents 14.50 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		1	

3. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

4. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

5. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

6. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix E. Input parameters for the Mesaverde-Meeteetse Coalbed Gas Assessment Unit (50340281), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mesaverde-Meeteetse Formation Coalbed Gas, 50340281

7. ________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

8. ________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

9. ________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

10. ________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

11. ________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

12. ________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	________	________	________
Gas in gas assessment unit:			
Volume % in entity	________	________	________

Appendix E. Input parameters for the Mesaverde-Meeteetse Coalbed Gas Assessment Unit (50340281), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mesaverde-Meeteetse Formation Coalbed Gas, 50340281

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO GENERAL LAND OWNERSHIPS
Surface Allocations (uncertainty of a fixed value)

1. Federal Lands represents 58.63 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		90	

2. Private Lands represents 35.11 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		7	

3. Tribal Lands represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

4. Other Lands represents 0.16 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		0	

5. WY State Lands represents 5.49 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		2	

6. MT State Lands represents 0.61 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		1	

Appendix E. Input parameters for the Mesaverde-Meeteetse Coalbed Gas Assessment Unit (50340281), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mesaverde-Meeteetse Formation Coalbed Gas, 50340281

7. ____________________ represents ________ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

8. ____________________ represents ________ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

9. ____________________ represents ________ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

10. ____________________ represents ________ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

11. ____________________ represents ________ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

12. ____________________ represents ________ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	____	____	____
Gas in gas assessment unit:			
Volume % in entity	____	____	____

Appendix E. Input parameters for the Mesaverde-Meeteetse Coalbed Gas Assessment Unit (50340281), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mesaverde-Meeteetse Formation Coalbed Gas, 50340281

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO FEDERAL LAND SUBDIVISIONS
Surface Allocations (uncertainty of a fixed value)

1. Bureau of Land Management (BLM) represents 56.89 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		89	

2. BLM Wilderness Areas (BLMW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

3. BLM Roadless Areas (BLMR) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

4. National Park Service (NPS) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

5. NPS Wilderness Areas (NPSW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

6. NPS Protected Withdrawals (NPSP) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix E. Input parameters for the Mesaverde-Meeteetse Coalbed Gas Assessment Unit (50340281), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mesaverde-Meeteetse Formation Coalbed Gas, 50340281

7. US Forest Service (FS) represents 0.37 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		0	

8. USFS Wilderness Areas (FSW) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

9. USFS Roadless Areas (FSR) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

10. USFS Protected Withdrawals (FSP) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

11. US Fish and Wildlife Service (FWS) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

12. USFWS Wilderness Areas (FWSW) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix E. Input parameters for the Mesaverde-Meeteetse Coalbed Gas Assessment Unit (50340281), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mesaverde-Meeteetse Formation Coalbed Gas, 50340281

13. USFWS Protected Withdrawals (FWSP) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

14. Wilderness Study Areas (WS) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

15. Department of Energy (DOE) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

16. Department of Defense (DOD) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

17. Bureau of Reclamation (BOR) represents 1.37 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		1	

18. Tennessee Valley Authority (TVA) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

Appendix E. Input parameters for the Mesaverde-Meeteetse Coalbed Gas Assessment Unit (50340281), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.) ______________________

19. Other Federal ______________ represents ________ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	________	________	________

Gas in gas assessment unit:			
Volume % in entity	________	________	________

20. ______________________ represents ________ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	________	________	________

Gas in gas assessment unit:			
Volume % in entity	________	________	________

Appendix E. Input parameters for the Mesaverde-Meeteetse Coalbed Gas Assessment Unit (50340281), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mesaverde-Meeteetse Formation Coalbed Gas, 50340281

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO ECOSYSTEMS
Surface Allocations (uncertainty of a fixed value)

1. Bighorn Basin (BHBA) represents 74.38 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		97	

2. Powder River Basin (PRBA) represents 4.18 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		1	

3. Yellowstone Highlands (YSHL) represents 21.44 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		2	

4. ____________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

5. ____________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

6. ____________ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix E. Input parameters for the Mesaverde-Meeteetse Coalbed Gas Assessment Unit (50340281), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Mesaverde-Meeteetse Formation Coalbed Gas, 50340281

7. ________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

8. ________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

9. ________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

10. ________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

11. ________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

12. ________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix F. Input parameters for the Fort Union Formation Coalbed Gas Assessment Unit (50340282), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]

FORSPAN ASSESSMENT MODEL FOR CONTINUOUS ACCUMULATIONS--BASIC INPUT DATA FORM (NOGA, Version 9, 2-10-03)

IDENTIFICATION INFORMATION

Assessment Geologist:	S.B. Roberts	Date:	20-Feb-08
Region:	North America	Number:	5
Province:	Bighorn Basin	Number:	5034
Total Petroleum System:	Cretaceous-Tertiary Composite	Number:	503402
Assessment Unit:	Fort Union Formation Coalbed Gas	Number:	50340282
Based on Data as of:	IHS Energy (2007)		
Notes from Assessor:	Powder River Basin coalbed gas wells used as analog.		

CHARACTERISTICS OF ASSESSMENT UNIT

Assessment-unit type: Oil (<20,000 cfg/bo) **or Gas** (>20,000 cfg/bo), incl. disc. & pot. additions ____Gas____

What is the minimum total recovery per cell? ___0.02___ (mmbo for oil A.U.; bcfg for gas A.U.)

Number of tested cells: ___0___

Number of tested cells with total recovery per cell > minimum: ___0___

Established (discovered cells): ______ Hypothetical (no cells): ___X___

Median total recovery per cell (for cells > min.): (mmbo for oil A.U.; bcfg for gas A.U.)

1st 3rd discovered ______ 2nd 3rd ______ 3rd 3rd ______

Assessment-Unit Probabilities:

Attribute	Probability of occurrence (0-1.0)
1. **CHARGE:** Adequate petroleum charge for an untested cell with total recovery > minimum.	1.0
2. **ROCKS:** Adequate reservoirs, traps, seals for an untested cell with total recovery > minimum.	1.0
3. **TIMING:** Favorable geologic timing for an untested cell with total recovery > minimum.	1.0

Assessment-Unit GEOLOGIC Probability (Product of 1, 2, and 3): ___1.0___

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES

1. Total assessment-unit area (acres): (uncertainty of a fixed value)

calculated mean 2,419,000 minimum 2,177,000 mode 2,419,000 maximum 2,661,000

2. Area per cell of untested cells having potential for additions to reserves (acres): (values are inherently variable)

calculated mean 113 minimum 40 mode 100 maximum 200

uncertainty of mean: minimum 60 maximum 160

3. Percentage of total assessment-unit area that is untested (%): (uncertainty of a fixed value)

calculated mean 100 minimum 100 mode 100 maximum 100

Appendix F. Input parameters for the Fort Union Formation Coalbed Gas Assessment Unit (50340282), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Fort Union Formation Coalbed Gas, 50340282

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES (Continued)

4. Percentage of untested assessment-unit area that has potential for additions to reserves (%):
(a necessary criterion is that total recovery per cell ≥ minimum; uncertainty of a fixed value)

calculated mean 1.4 minimum 0.1 mode 1 maximum 3

Geologic evidence for estimates:

TOTAL RECOVERY PER CELL

Total recovery per cell for untested cells having potential for additions to reserves:
(values are inherently variable; mmbo for oil A.U.; bcfg for gas A.U.)

calculated mean 0.1 minimum 0.02 median 0.08 maximum 1

AVERAGE COPRODUCT RATIOS FOR UNTESTED CELLS, TO ASSESS COPRODUCTS
(uncertainty of fixed but unknown values)

	minimum	mode	maximum
Oil assessment unit:			
Gas/oil ratio (cfg/bo)			
NGL/gas ratio (bngl/mmcfg)			
Gas assessment unit:			
Liquids/gas ratio (bliq/mmcfg)	0	0.25	0.5

Appendix F. Input parameters for the Fort Union Formation Coalbed Gas Assessment Unit (50340282), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Fort Union Formation Coalbed Gas, 50340282

SELECTED ANCILLARY DATA FOR UNTESTED CELLS
(values are inherently variable)

Oil assessment unit:	minimum	mode	maximum
API gravity of oil (degrees)			
Sulfur content of oil (%)			
Depth (m) of water (if applicable)			

Drilling depth (m)

minimum	F75	mode	F25	maximum

Gas assessment unit:	minimum	mode	maximum
Inert-gas content (%)	0.10	0.30	1.00
CO_2 content (%)	0.50	1.80	20.00
Hydrogen sulfide content (%)	0.00	0.00	0.00
Heating value (BTU)	850	950	1050
Depth (m) of water (if applicable)			

Drilling depth (m)

minimum	F75	mode	F25	maximum
150	580	600	1100	1800

Success ratios:	calculated mean	minimum	mode	maximum
Future success ratio (%)	40	10	40	70

Historic success ratio, tested cells (%) ____________

Completion practices:

1. Typical well-completion practices (conventional, open hole, open cavity, other)	conventional
2. Fraction of wells drilled that are typically stimulated	0
3. Predominant type of stimulation (none, frac, acid, other)	none
4. Fraction of wells drilled that are horizontal	none

Appendix F. Input parameters for the Fort Union Formation Coalbed Gas Assessment Unit (50340282), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Fort Union Formation Coalbed Gas, 50340282

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO STATES
Surface Allocations (uncertainty of a fixed value)

1. Wyoming represents 88.26 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		30	

2. Montana represents 11.74 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity		70	

3. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

4. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

5. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

6. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit: Volume % in entity			
Gas in gas assessment unit: Volume % in entity			

Appendix F. Input parameters for the Fort Union Formation Coalbed Gas Assessment Unit (50340282), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Fort Union Formation Coalbed Gas, 50340282

7. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

8. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

9. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

10. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

11. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

12. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

Appendix F. Input parameters for the Fort Union Formation Coalbed Gas Assessment Unit (50340282), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Fort Union Formation Coalbed Gas, 50340282

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO GENERAL LAND OWNERSHIPS
Surface Allocations (uncertainty of a fixed value)

1. Federal Lands represents 66.41 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		34	

2. Private Lands represents 28.58 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		64	

3. Tribal Lands represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

4. Other Lands represents 0.08 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		0	

5. WY State Lands represents 4.28 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		1	

6. MT State Lands represents 0.64 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		1	

Appendix F. Input parameters for the Fort Union Formation Coalbed Gas Assessment Unit (50340282), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Fort Union Formation Coalbed Gas, 50340282

7. ____________________ represents ________ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

8. ____________________ represents ________ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

9. ____________________ represents ________ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

10. ____________________ represents ________ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

11. ____________________ represents ________ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

12. ____________________ represents ________ area % of the AU

Oil in oil assessment unit:	minimum	mode	maximum
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

Appendix F. Input parameters for the Fort Union Formation Coalbed Gas Assessment Unit (50340282), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Fort Union Formation Coalbed Gas, 50340282

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO FEDERAL LAND SUBDIVISIONS
Surface Allocations (uncertainty of a fixed value)

1. Bureau of Land Management (BLM) represents 63.40 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		34	

2. BLM Wilderness Areas (BLMW) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

3. BLM Roadless Areas (BLMR) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

4. National Park Service (NPS) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

5. NPS Wilderness Areas (NPSW) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

6. NPS Protected Withdrawals (NPSP) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix F. Input parameters for the Fort Union Formation Coalbed Gas Assessment Unit (50340282), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Fort Union Formation Coalbed Gas, 50340282

7. US Forest Service (FS) represents 0.81 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		0	

8. USFS Wilderness Areas (FSW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

9. USFS Roadless Areas (FSR) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

10. USFS Protected Withdrawals (FSP) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

11. US Fish and Wildlife Service (FWS) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

12. USFWS Wilderness Areas (FWSW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix F. Input parameters for the Fort Union Formation Coalbed Gas Assessment Unit (50340282), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Fort Union Formation Coalbed Gas, 50340282

13. USFWS Protected Withdrawals (FWSP) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

14. Wilderness Study Areas (WS) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

15. Department of Energy (DOE) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

16. Department of Defense (DOD) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

17. Bureau of Reclamation (BOR) represents 2.19 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		0	

18. Tennessee Valley Authority (TVA) represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix F. Input parameters for the Fort Union Formation Coalbed Gas Assessment Unit (50340282), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)

19. Other Federal ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

20. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

Appendix F. Input parameters for the Fort Union Formation Coalbed Gas Assessment Unit (50340282), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Fort Union Formation Coalbed Gas, 50340282

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO ECOSYSTEMS
Surface Allocations (uncertainty of a fixed value)

1. Bighorn Basin (BHBA) represents 81.18 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		30	

2. Powder River Basin (PRBA) represents 2.91 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		0	

3. Yellowstone Highlands (YSHL) represents 15.91 area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity		70	

4. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

5. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

6. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity			
Gas in gas assessment unit:			
Volume % in entity			

Appendix F. Input parameters for the Fort Union Formation Coalbed Gas Assessment Unit (50340282), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; m, meters; A.U., assessment unit]—Continued

Assessment Unit (name, no.)
Fort Union Formation Coalbed Gas, 50340282

7. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

8. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

9. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

10. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

11. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

12. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in oil assessment unit:			
Volume % in entity	______	______	______
Gas in gas assessment unit:			
Volume % in entity	______	______	______

Appendix G. Input parameters for the Cretaceous-Tertiary Conventional Oil and Gas Assessment Unit (50340201), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; mmboe, million barrels of oil equivalent; m, meters]

SEVENTH APPROXIMATION
DATA FORM FOR CONVENTIONAL ASSESSMENT UNITS (Version 6, 9 April 2003)

IDENTIFICATION INFORMATION

Assessment Geologist:	T.M. Finn, M.A. Kirschbaum, and S.M. Condon	Date:	19-Feb-08
Region:	North America	Number:	5
Province:	Bighorn Basin	Number:	5034
Total Petroleum System:	Cretaceous-Tertiary Composite	Number:	503402
Assessment Unit:	Cretaceous-Tertiary Conventional Oil and Gas	Number:	50340201
Based on Data as of:	NRG (2007, data current through 2005); IHS Energy (2007)		
Notes from Assessor:	Cardinal and others (1989); NRG reservoir growth factor, 30 years		
	Powder River Basin Sussex-Shannon (50330302) and Mesaverde-Lewis Sandstones (50330303) assessment units used as analogs		

CHARACTERISTICS OF ASSESSMENT UNIT

Oil (<20,000 cfg/bo overall) **or** Gas (≥20,000 cfg/bo overall): Oil

What is the minimum accumulation size? 0.5 mmboe grown
(the smallest accumulation that has potential to be added to reserves)

No. of discovered accumulations exceeding minimum size: Oil: 9 Gas: 15
Established (>13 accums.) X Frontier (1-13 accums.) ____ Hypothetical (no accums.) ____

Median size (grown) of discovered oil accumulations (mmbo):
1st 3rd 3.7 2nd 3rd 1.5 3rd 3rd ____
Median size (grown) of discovered gas accumulations (bcfg):
1st 3rd 19.3 2nd 3rd 40.3 3rd 3rd 59.6

Assessment-Unit Probabilities:

Attribute	Probability of occurrence (0-1.0)
1. **CHARGE:** Adequate petroleum charge for an undiscovered accum. ≥ minimum size:	1.0
2. **ROCKS:** Adequate reservoirs, traps, and seals for an undiscovered accum. ≥ minimum size:	1.0
3. **TIMING OF GEOLOGIC EVENTS:** Favorable timing for an undiscovered accum. ≥ minimum s	1.0

Assessment-Unit GEOLOGIC Probability (Product of 1, 2, and 3): 1.0

UNDISCOVERED ACCUMULATIONS

No. of Undiscovered Accumulations: How many undiscovered accums. exist that are ≥ min. size?:
(uncertainty of fixed but unknown values)

Oil Accumulations:	minimum (>0)	1	mode	5	maximum	15
Gas Accumulations:	minimum (>0)	1	mode	10	maximum	40

Sizes of Undiscovered Accumulations: What are the sizes (**grown**) of the above accums?:
(variations in the sizes of undiscovered accumulations)

Oil in Oil Accumulations (mmbo):	minimum	0.5	median	1.5	maximum	12
Gas in Gas Accumulations (bcfg):	minimum	3	median	9	maximum	72

Appendix G. Input parameters for the Cretaceous-Tertiary Conventional Oil and Gas Assessment Unit (50340201), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; mmboe, million barrels of oil equivalent; m, meters]—Continued

Assessment Unit (name, no.)
Cretaceous-Tertiary Conventional Oil and Gas, 50340201

AVERAGE RATIOS FOR UNDISCOVERED ACCUMS., TO ASSESS COPRODUCTS
(uncertainty of fixed but unknown values)

Oil Accumulations:	minimum	mode	maximum
Gas/oil ratio (cfg/bo)	1200	2500	3800
NGL/gas ratio (bngl/mmcfg)	30	60	90

Gas Accumulations:	minimum	mode	maximum
Liquids/gas ratio (bliq/mmcfg)	8	16	24
Oil/gas ratio (bo/mmcfg)			

SELECTED ANCILLARY DATA FOR UNDISCOVERED ACCUMULATIONS
(variations in the properties of undiscovered accumulations)

Oil Accumulations:	minimum	mode	maximum
API gravity (degrees)	36	45	50
Sulfur content of oil (%)	0	0.1	0.3
Depth (m) of water (if applicable)			

	minimum	F75	mode	F25	maximum
Drilling Depth (m)	150		3000		4600

Gas Accumulations:	minimum	mode	maximum
Inert gas content (%)	0	1.5	10
CO_2 content (%)	0	0.3	1
Hydrogen-sulfide content (%)	0	0	0
Depth (m) of water (if applicable)			

	minimum	F75	mode	F25	maximum
Drilling Depth (m)	150		3000		4600

Appendix G. Input parameters for the Cretaceous-Tertiary Conventional Oil and Gas Assessment Unit (50340201), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; mmboe, million barrels of oil equivalent; m, meters]—Continued

Assessment Unit (name, no.)
Cretaceous-Tertiary Conventional Oil and Gas, 50340201

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO STATES
Surface Allocations (uncertainty of a fixed value)

1. Wyoming represents 90.88 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity		99	
Gas in Gas Accumulations:			
Volume % in entity		99	

2. Montana represents 9.12 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity		1	
Gas in Gas Accumulations:			
Volume % in entity		1	

3. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

4. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

5. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

6. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

Appendix G. Input parameters for the Cretaceous-Tertiary Conventional Oil and Gas Assessment Unit (50340201), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; mmboe, million barrels of oil equivalent; m, meters]—Continued

Assessment Unit (name, no.)
Cretaceous-Tertiary Conventional Oil and Gas, 50340201

7. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	________	________	________
Gas in Gas Accumulations:			
Volume % in entity	________	________	________

8. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	________	________	________
Gas in Gas Accumulations:			
Volume % in entity	________	________	________

9. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	________	________	________
Gas in Gas Accumulations:			
Volume % in entity	________	________	________

10. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	________	________	________
Gas in Gas Accumulations:			
Volume % in entity	________	________	________

11. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	________	________	________
Gas in Gas Accumulations:			
Volume % in entity	________	________	________

12. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	________	________	________
Gas in Gas Accumulations:			
Volume % in entity	________	________	________

Appendix G. Input parameters for the Cretaceous-Tertiary Conventional Oil and Gas Assessment Unit (50340201), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; mmboe, million barrels of oil equivalent; m, meters]—Continued

Assessment Unit (name, no.)
Cretaceous-Tertiary Conventional Oil and Gas, 50340201

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO LAND ENTITIES
Surface Allocations (uncertainty of a fixed value)

1. Federal Lands represents 58.70 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity		70	
Gas in Gas Accumulations:			
Volume % in entity		70	

2. Private Lands represents 33.39 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity		25	
Gas in Gas Accumulations:			
Volume % in entity		25	

3. Tribal Lands represents 1.01 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity		0	
Gas in Gas Accumulations:			
Volume % in entity		0	

4. Other Lands represents 0.23 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity		0	
Gas in Gas Accumulations:			
Volume % in entity		0	

5. WY State Lands represents 6.19 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity		5	
Gas in Gas Accumulations:			
Volume % in entity		5	

6. MT State Lands represents 0.47 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity		0	
Gas in Gas Accumulations:			
Volume % in entity		0	

Appendix G. Input parameters for the Cretaceous-Tertiary Conventional Oil and Gas Assessment Unit (50340201), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; mmboe, million barrels of oil equivalent; m, meters]—Continued

Assessment Unit (name, no.)
Cretaceous-Tertiary Conventional Oil and Gas, 50340201

7. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	________	________	________
Gas in Gas Accumulations:			
Volume % in entity	________	________	________

8. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	________	________	________
Gas in Gas Accumulations:			
Volume % in entity	________	________	________

9. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	________	________	________
Gas in Gas Accumulations:			
Volume % in entity	________	________	________

10. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	________	________	________
Gas in Gas Accumulations:			
Volume % in entity	________	________	________

11. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	________	________	________
Gas in Gas Accumulations:			
Volume % in entity	________	________	________

12. ______________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	________	________	________
Gas in Gas Accumulations:			
Volume % in entity	________	________	________

Appendix G. Input parameters for the Cretaceous-Tertiary Conventional Oil and Gas Assessment Unit (50340201), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; mmboe, million barrels of oil equivalent; m, meters]—Continued

Assessment Unit (name, no.)
Cretaceous-Tertiary Conventional Oil and Gas, 50340201

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO FEDERAL LAND SUBDIVISIONS
Surface Allocations (uncertainty of a fixed value)

1. Bureau of Land Management (BLM) represents 55.09 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity		70	
Gas in Gas Accumulations:			
Volume % in entity		70	

2. BLM Wilderness Areas (BLMW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

3. BLM Roadless Areas (BLMR) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

4. National Park Service (NPS) represents 0.11 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity		0	
Gas in Gas Accumulations:			
Volume % in entity		0	

5. NPS Wilderness Areas (NPSW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

6. NPS Protected Withdrawals (NPSP) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

Appendix G. Input parameters for the Cretaceous-Tertiary Conventional Oil and Gas Assessment Unit (50340201), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; mmboe, million barrels of oil equivalent; m, meters]—Continued

Assessment Unit (name, no.)
Cretaceous-Tertiary Conventional Oil and Gas, 50340201

7. US Forest Service (FS) represents 1.78 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity		0	
Gas in Gas Accumulations:			
Volume % in entity		0	

8. USFS Wilderness Areas (FSW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

9. USFS Roadless Areas (FSR) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

10. USFS Protected Withdrawals (FSP) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

11. US Fish and Wildlife Service (FWS) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

12. USFWS Wilderness Areas (FWSW) represents ____ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

Appendix G. Input parameters for the Cretaceous-Tertiary Conventional Oil and Gas Assessment Unit (50340201), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; mmboe, million barrels of oil equivalent; m, meters]—Continued

Assessment Unit (name, no.)
Cretaceous-Tertiary Conventional Oil and Gas, 50340201

13. USFWS Protected Withdrawals (FWSP) represents ______ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

14. Wilderness Study Areas (WS) represents ______ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

15. Department of Energy (DOE) represents ______ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

16. Department of Defense (DOD) represents 0.05 area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

17. Bureau of Reclamation (BOR) represents 1.67 area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity		0	
Gas in Gas Accumulations:			
Volume % in entity		0	

18. Tennessee Valley Authority (TVA) represents ______ area % of the AU

Oil in Oil Accumulations:	minimum	mode	maximum
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

Appendix G. Input parameters for the Cretaceous-Tertiary Conventional Oil and Gas Assessment Unit (50340201), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; mmboe, million barrels of oil equivalent; m, meters]—Continued

Assessment Unit (name, no.)
Paleozoic-Mesozoic Conventional Oil and Gas, 50340101

19. Other Federal ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

20. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

Appendix G. Input parameters for the Cretaceous-Tertiary Conventional Oil and Gas Assessment Unit (50340201), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; mmboe, million barrels of oil equivalent; m, meters]—Continued

Assessment Unit (name, no.)
Cretaceous-Tertiary Conventional Oil and Gas, 50340201

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO ECOSYSTEMS
Surface Allocations (uncertainty of a fixed value)

1. Bighorn Basin (BHBA) represents 74.11 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity		95	
Gas in Gas Accumulations:			
Volume % in entity		95	

2. Bighorn Mountains (BHMT) represents 0.09 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity		0	
Gas in Gas Accumulations:			
Volume % in entity		0	

3. Powder River Basin (PRBA) represents 1.53 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity		0	
Gas in Gas Accumulations:			
Volume % in entity		0	

4. Yellowstone Highlands (YSHL) represents 24.27 area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity		5	
Gas in Gas Accumulations:			
Volume % in entity		5	

5. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

6. ______ represents ______ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity			
Gas in Gas Accumulations:			
Volume % in entity			

Appendix G. Input parameters for the Cretaceous-Tertiary Conventional Oil and Gas Assessment Unit (50340201), Cretaceous-Tertiary Composite Total Petroleum System, Bighorn Basin Province. [bcfg, billion cubic feet of gas; mmcfg, million cubic feet of gas; cfg, cubic feet of gas; mmbo, million barrels of oil; bo, barrel of oil; bliq, barrel of liquid; bngl, barrel of natural gas liquids; mmboe, million barrels of oil equivalent; m, meters]—Continued

Assessment Unit (name, no.)
Cretaceous-Tertiary Conventional Oil and Gas, 50340201

7. ________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	________	________	________
Gas in Gas Accumulations:			
Volume % in entity	________	________	________

8. ________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	________	________	________
Gas in Gas Accumulations:			
Volume % in entity	________	________	________

9. ________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	________	________	________
Gas in Gas Accumulations:			
Volume % in entity	________	________	________

10. ________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	________	________	________
Gas in Gas Accumulations:			
Volume % in entity	________	________	________

11. ________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	________	________	________
Gas in Gas Accumulations:			
Volume % in entity	________	________	________

12. ________________ represents ________ area % of the AU

	minimum	mode	maximum
Oil in Oil Accumulations:			
Volume % in entity	________	________	________
Gas in Gas Accumulations:			
Volume % in entity	________	________	________

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