Chapter 9

Subsurface Stratigraphic Cross Sections of Cretaceous and Lower Tertiary Rocks in the Wind River Basin, Central Wyoming

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Subsurface Stratigraphic Cross Sections of Cretaceous and Lower Tertiary Rocks in the Wind River Basin, Central Wyoming

By Thomas M. Finn

Introduction

The stratigraphic cross sections presented in this report were constructed as part of a project conducted by the U.S. Geological Survey to characterize and evaluate the undiscovered oil and gas resources of the Wind River Basin (WRB) in central Wyoming. The primary purpose of the cross sections is to show the stratigraphic framework and facies relations of Cretaceous and lower Tertiary rocks in this large, intermontane structural and sedimentary basin, which formed in the Rocky Mountain foreland during the Laramide orogeny (Late Cretaceous through early Eocene time). The WRB is nearly 200 miles (mi) long, 70 mi wide, and encompasses about 7,400 square miles ($mi^{2)}$ (fig. 1). The basin is structurally bounded by the Owl Creek and Bighorn Mountains on the north, the Casper arch on the east, the Granite Mountains on the south, and the Wind River Range on the west (fig. 2).

The cross sections were constructed from borehole geophysical logs of 77 wells drilled for oil and gas exploration and production. The stratigraphic interval extends from the base of the Cretaceous into the lower Eocene. The sections are hung on an arbitrary datum, generally approximating the top of the Cody Shale, or in some cases the top of the Teapot Sandstone Member of the Mesaverde Formation. Plate 1 is a correlation chart showing the stratigraphic relations of the units presented on cross sections A-A' through J-J' (fig. 3; pls. 2-11). Sources of stratigraphic data used to compile the correlation chart presented on plate 1 include: Yenne and Pipiringos (1954), Keefer and Rich (1957), Van Houten (1964), Keefer (1965a, 1972), Gill and others (1970), Merewether and others (1977a,b; 1997), Merewether (1983, 1996), Merewether and Cobban (1986), Cobban and Kennedy (1989), Hogle and Jones (1991), Lillegraven (1993), Love and others (1993), Nichols and Flores (1993), Obradovich (1993), Szmajter (1993), Flores, Keighin, and Roberts (1994), Flores, Roberts, and Perry (1994), May and others (1995), Roberts and Kirschbaum (1995), Johnson and others (1996), Obradovich and others (1996), and Palmer and Geissman (1999).

In most wells, a gamma-ray or spontaneous potential log was used in combination with a resistivity or conductivity log to identify and correlate units. The gamma-ray and spontaneous potential logs are typically used to differentiate between sandstone and shale; however, in the WRB the spontaneous potential response is subdued in some sandstone intervals showing little curve deflection. In areas of greater drilling density, logs from wells located between control wells on the cross sections were used to aid in making correlations. Coal beds were identified from gamma-ray logs in combination with density and (or) sonic logs and are shown as a long, heavy black bar on the depth track of each log. The heavy black bars representing coal beds only show the position of the coal bed(s) and are not proportional to true thickness. In addition to the stratigraphic information, oil and gas shows, oil and gas-producing intervals, perforated intervals, and drillstem test intervals also are shown on the cross sections. This information was compiled from IHS Energy Group (2003) well data, the Wyoming Oil and Gas Conservation Commission Web site (2005), and drilling reports in the U.S. Geological Survey well log files.

The locations of the 10 stratigraphic cross sections are as follows (figs. 2, 3):

- Section A-A' extends from the Shotgun Butte area in the northwestern part of the basin south about 33 mi to McGowan anticline near the south margin of the basin (pl. 2).
- Section B-B' extends east-west from McGowan anticline for about 40 mi along the south margin of the basin to Muskrat anticline (pl. 3).
- Section C-C' extends east-west 13 mi along the south margin of the basin from Muskrat anticline to Castle Gardens (pl. 4).
- Section D-D' extends for 32 mi from the Coalbank Hills southeast along the northeast flank of the Rattlesnake Hills (pl. 5).
- Section E-E' extends from Coalbank Hills northeast for 15 mi to Hells Half Acre (pl. 6).
- Section F-F' extends approximately 21 mi from the central part of the Rattlesnake Hills east to West Poison Spider oil field (pl. 7).

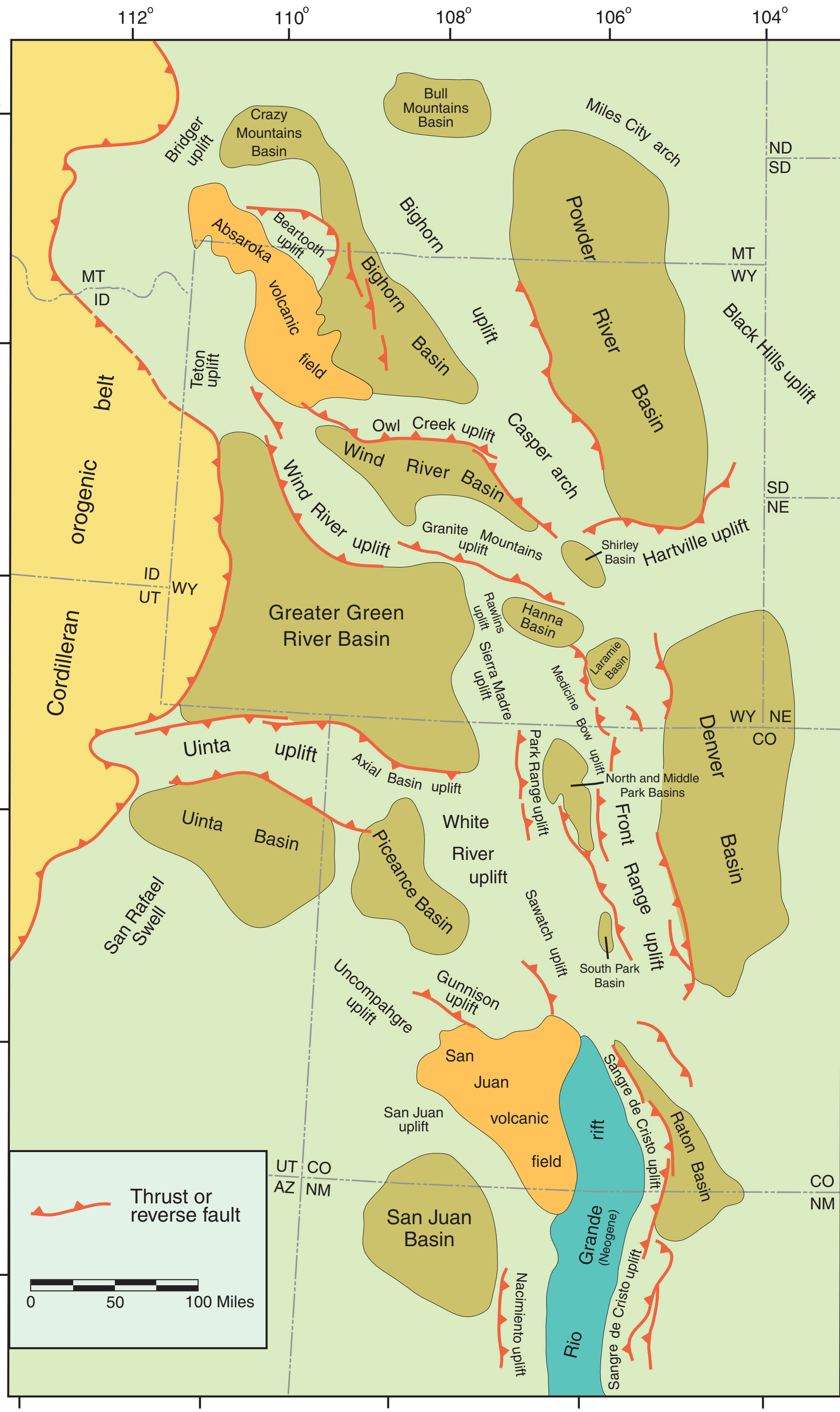

Figure 1. Map of the Rocky Mountain region extending from southern Montana to northern New Mexico showing the locations of Laramide sedimentary and structural basins (in brown) and intervening uplifts. Modified from Dickinson and others (1988).

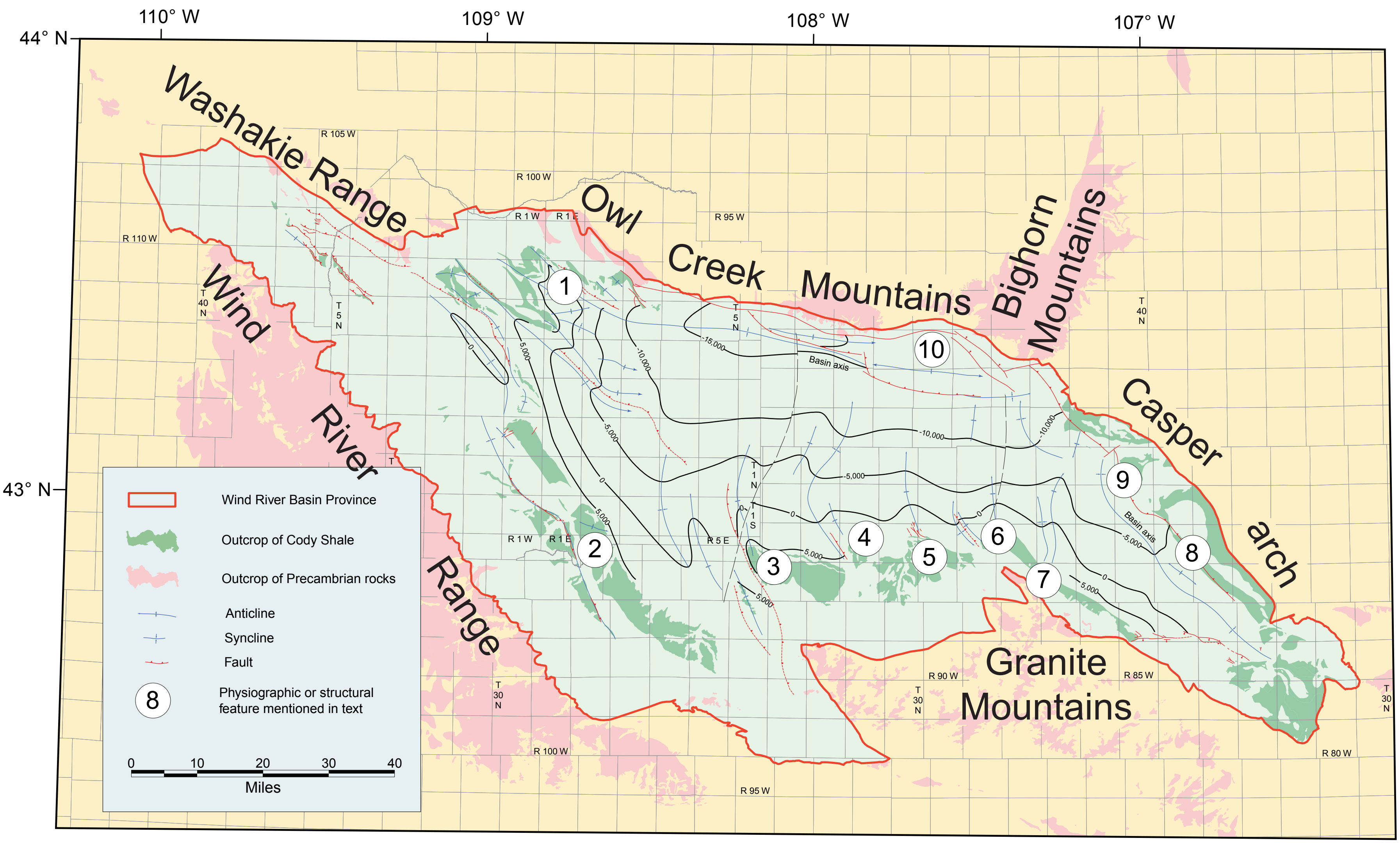

Figure 2. Index map of the Wind River Basin in central Wyoming showing major structural and physiographic features discussed in the text: (1) Shotgun Butte, (2) McGowan anticline, (3) Alkali Butte anticline, (4) Muskrat anticline, (5) Castle Gardens, (6) Coalbank Hills, (7) Rattlesnake Hills, (8) West Poison Spider oil field, (9) Hells Half Acre, and (10) Madden anticline. Structure contours are drawn on top of the Cody Shale. Contour interval = 5,000 feet.

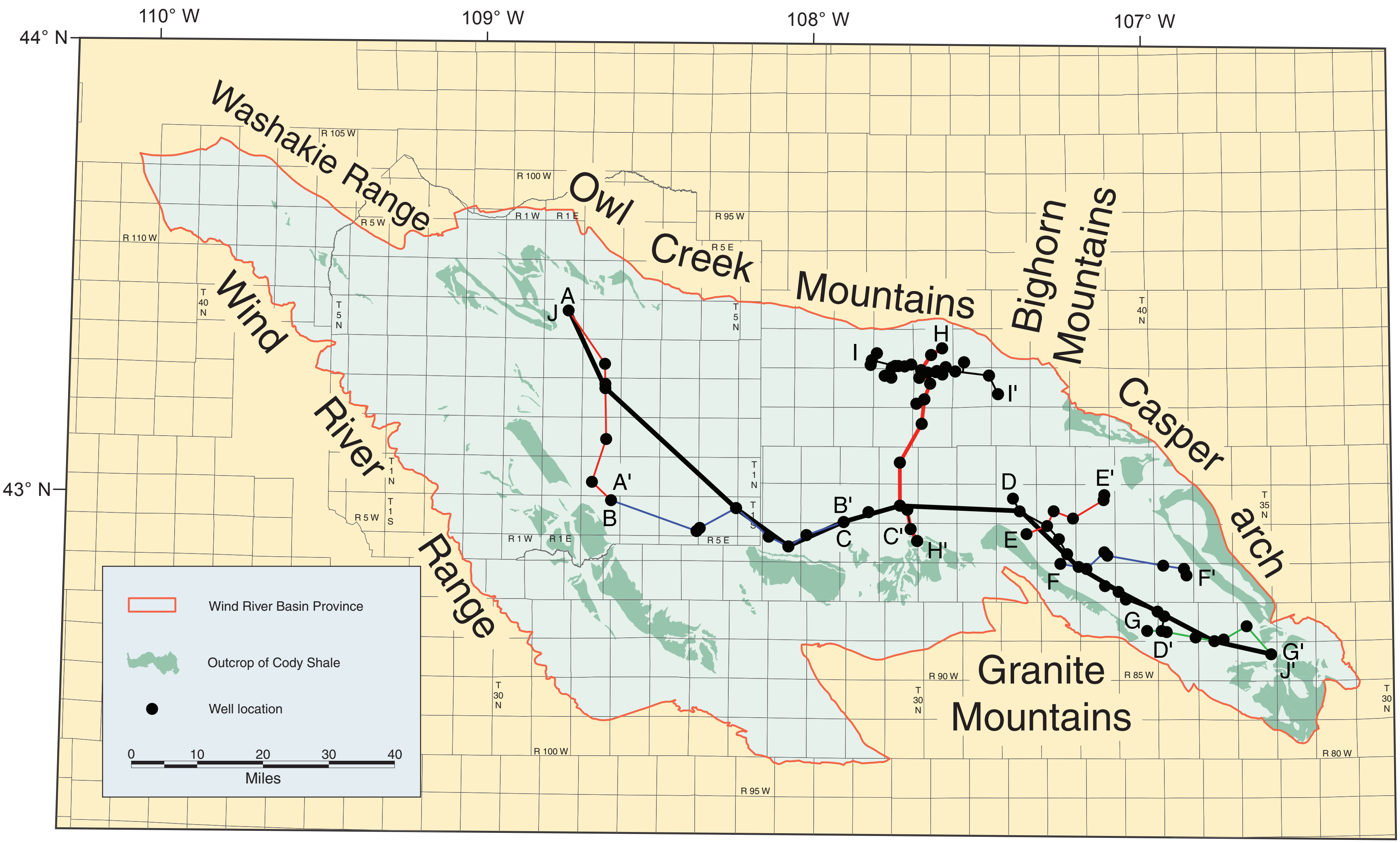

Figure 3. Index map of the Wind River Basin, showing the network of cross sections presented in this report. Section A-A′, plate 2; section B-B′, plate 3; section C-C′, plate 4; section D-D′, plate 5; section E-E′, plate 6; section F-F′, plate 7; section G-G′, plate 8; section H-H′, plate 9; section I-I′, plate 10; section J-J′, plate 11.

- Section G-G’ extends for 22 mi from the southern part of the Rattlesnake Hills to the extreme southeastern part of the basin (pl. 8).
- Section H-H’ extends from Madden anticline in the north-central part of the basin south for nearly 33 mi to Castle Gardens on the southern margin of the basin (pl. 9).
- Section I-I’ extends east-west for about 20 mi along the crest of the Madden anticline (pl. 10).
- Section J-J’ extends northwest-southeast roughly 130 mi from Shotgun Butte to the extreme southeast corner of the basin (pl. 11).

Cross sections A-A’-D-D’, and I-I’ (pls. 2-4 and 11) include the stratigraphic interval from the base of the Lower Cretaceous Cloverly Formation into the lower part of the Upper Cretaceous Meeteetse Formation. Cross section G-G’ (pl. 8) extends from the base of the Cloverly Formation into the lower part of the Upper Cretaceous Lance Formation. These sections illustrate the complex intertonguing relations of marine and nonmarine rocks that were deposited when the Western Interior Seaway periodically flooded and retreated from the Rocky Mountain foreland basin to the east of the tectonically active Western Cordilleran highlands prior to onset of the Laramide orogeny (figs. 4, 5). Sections E-E’, F-F’, and H-H’ (pls. 6, 7 and 9) extend from the basin margins into the deep trough of the WRB and include the entire stratigraphic interval from the base of the Cloverly Formation through the lower Eocene rocks. These sections demonstrate the effects of a rapidly subsiding basin trough on the thicknesses of the uppermost Cretaceous, Paleocene, and lower Eocene rocks during the Laramide orogeny (fig. 6). Cross section J-J’ (pl. 11) extends from the base of the Cretaceous into the lower part of the Lance Formation. This is a generalized section that illustrates the stratigraphic relations of the various marine and nonmarine tongues across the basin on a basinwide scale.

For sections A-A’-I-I’ (pls. 2-10) the horizontal scale is about 1 inch (in) = .75 mi and the vertical scale is about 1 in = 500 ft; for section J-J’ (pl. 11) the horizontal scale is about 1 in = 3 mi and the vertical scale is about .75 in = 500 ft.

Stratigraphy of Cretaceous Rocks

Lower Cretaceous Rocks

Cloverly Formation

According to Love and others (1945), Keefer and Troyer (1964), and Pekarek (1978), the Cloverly Formation in the WRB consists of three distinct units (which are undifferentiated on the cross sections): (1) a lower unit about 30 feet (ft) thick of conglomerate and sandstone that contains chert pebbles as much as 1 in. in diameter; (2) a middle variegated unit of variable thickness composed of red and purple claystone and interbedded sandstone; and (3) an upper sandstone unit generally referred to as the Rusty Beds Member, which is as much as about 150 ft thick. The lower and middle units were deposited in fluvial systems and the upper sandstones were deposited in a marginal marine setting. May and others (1995) restricted these three units to the upper part of the Cloverly Formation in the eastern part of the basin, where they included about 100 ft of underlying variegated beds with the Cloverly. According to May and others (1995), the Cloverly is of Neocomian to Aptian age; whereas, Merewether and others (1997) considered the Cloverly to be Aptian to Albian in age.

Thermopolis Shale

The Thermopolis Shale in the WRB (known as the Skull Creek Shale in some other Rocky Mountain Basins) consists of 100 to 175 ft of marine shales and siltstones that were deposited during the initial transgression of the Cretaceous sea in Albian time (Burtner and Warner, 1984; Hagen and Surdam, 1984). The shales are dark gray to black and contain thin layers of siltstone, sandy claystone, and bentonite. The basal contact is gradational with the underlying Cloverly Formation; the upper contact is sharp and unconformable with the overlying Muddy Sandstone.

Muddy Sandstone

The Muddy Sandstone is composed of fine- to coarse-grained sandstone with interbedded shales of Albian age (Dresser, 1974; Curry, 1985). The formation was deposited in fluvial, marginal marine, and estuarine environments and ranges in thickness from zero to about 100 ft. The thickest accumulations being associated with incised valley systems that developed on the exposed surface of the Thermopolis Shale during sea level lowstand (Dolson and others, 1991; Van Wagoner and others, 1990).

Upper Cretaceous Rocks

Mowry Shale

According to Keefer and Johnson (1997), the Mowry Shale in the WRB consists of two distinct units. The lower 50 to 125 ft is soft fissile clay rich shale similar to the Thermopolis Shale that has been referred to as the Shell Creek Shale in the adjacent Bighorn and Powder River Basins

Figure 4.—Extent of the Cretaceous Western Interior seaway during Campanian time. Brown areas show the approximate geographic distribution of land areas. Modified from Gill and Cobban (1973).

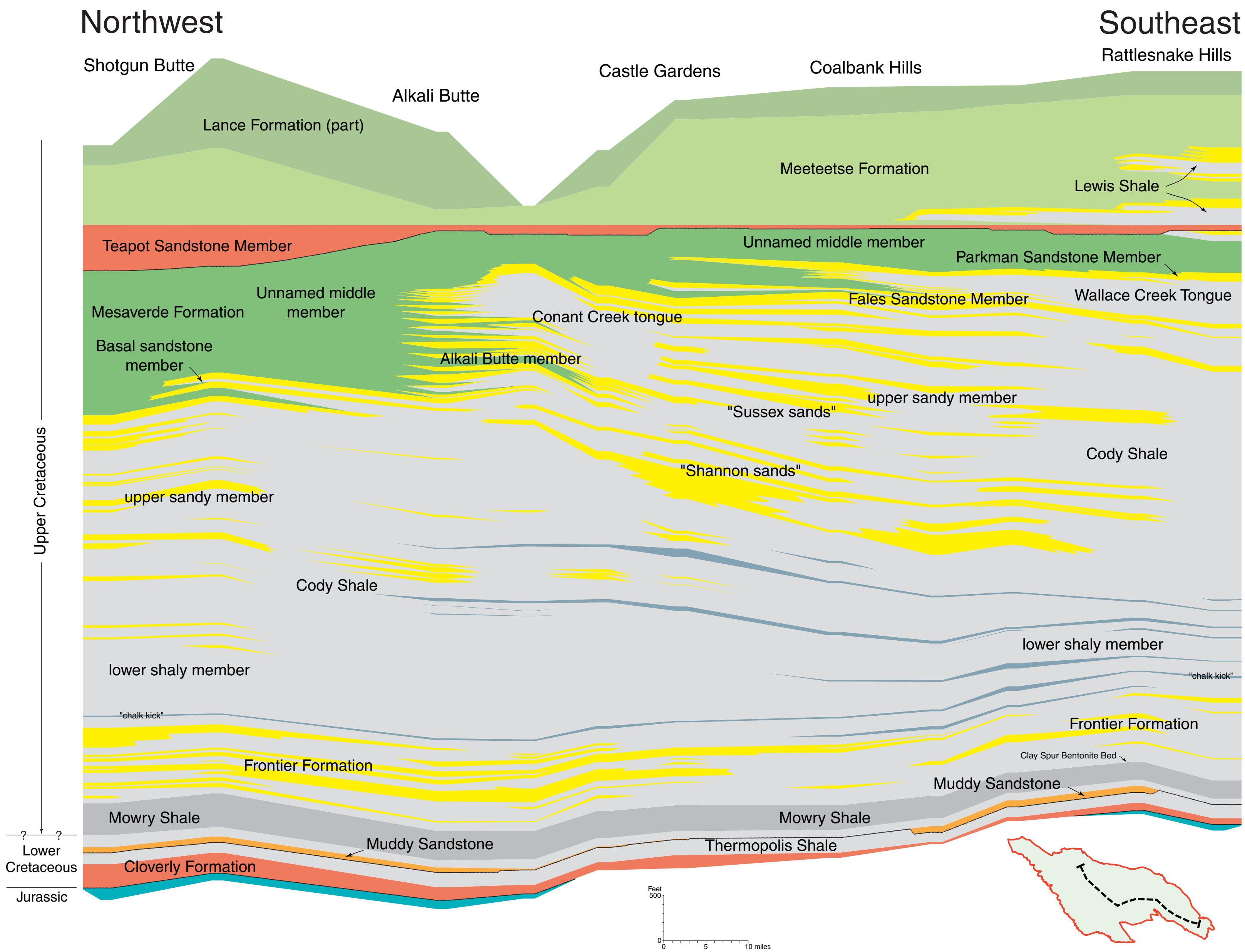

Figure 5. Generalized east-west stratigraphic cross section of Cretaceous rocks in the Wind River Basin showing the complex intertonguing relations of marine and nonmarine strata. Sandstones and conglomerates of predominantly fluvial origin are shown in red; marine and marginal marine sandstones, yellow; coastal plain and alluvial plain sandstone, shale, and coal, various shades of green; marine shales, various shades of gray; estuarine and fluvial sandstones shown in orange; undifferentiated deposits, blue.

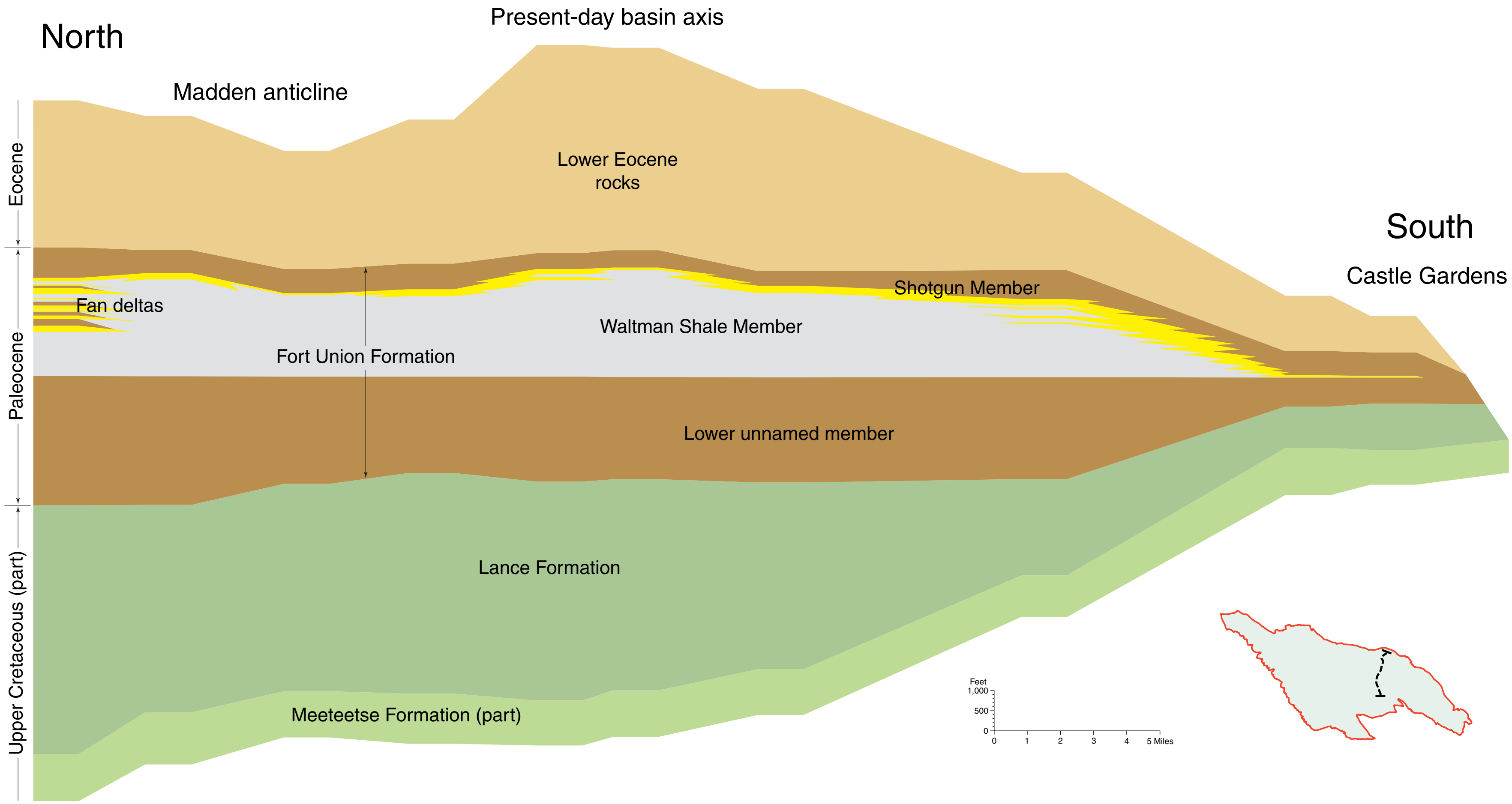

Figure 6. Generalized north-south stratigraphic cross section of uppermost Cretaceous, Paleocene, and lower Eocene rocks in the Wind River Basin. The section extends from north to south across the basin and shows the rapid thickening of sediments that were deposited along the rapidly subsiding basin trough during the Laramide orogeny. Coastal plain and alluvial plain sandstone, shale, and coal of Cretaceous age are shown as various shades of green; marginal lacustrine sandstones, yellow; lacustrine shale, gray; sandstone, siltstone, shale, coal, and conglomerate of continental origin, brown; variegated basin fill deposits, tan.

(Burtner and Warner, 1984). The upper part consists of 200 to 350 ft of hard brittle siliceous shale (Keefer and Johnson, 1997). Numerous gray to tan bentonite beds are common throughout the unit and range in thickness from a fraction of an inch to about 7 ft (Byers and Larson, 1979). The siliceous shales are dark brown to black, organic rich, and contain an abundance of fish scales (Burtner and Warner, 1984). For subsurface correlations, the contact between the Mowry Shale and overlying Frontier Formation is drawn at the Clay Spur Bentonite Bed; a distinctive geophysical log marker that separates the underlying siliceous shale of the Mowry from the overlying softer nonsiliceous shales of the basal Frontier Formation (Keefer, 1972; Szmajter, 1993). The Mowry is marine in origin and is 300 to 400 ft thick throughout the basin. Paleontologic evidence and radiometric dating indicate that 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

Throughout most of the WRB the Frontier Formation consists of alternating sandstone, shale, and bentonite that accumulated in marine and marginal marine environments. In the western part of the basin the Frontier also contains some nonmarine strata, including minor coal deposits. The sandstones are typically gray, brown, and tan, fine to medium grained and contain abundant dark mineral grains that give a distinctive “salt and pepper” appearance (Keefer, 1972; Merewether, 1983; for detailed descriptions see Merewether and Cobban, Chapter 11, this CD-ROM). The sandstones are generally in the upper part of the unit and the lower Frontier is generally shale except in the western part of the basin where the lower part includes several sandstones. Individual sandstones are blanket-like and in many cases can be traced over several miles but appear to pinch out into marine shale in all directions. The shales are generally sandy or silty and gray or black in color. The Frontier Formation is Cenomanian to Coniacian in age and ranges in thickness from 400 to 800 ft. Merewether (1983) recognized several intraformational unconformities within the Frontier that were interpreted to have formed in response to sealevel changes and (or) tectonic activity. These unconformities are based on the study of ammonite zones in surface sections and were not identified in the subsurface for this study.

Cody Shale

The Cody Shale consists of marine shale, sandstone, and siltstone deposited during a major transgressive-regressive cycle referred to as the Niobrara Cyclothem by Kauffman (1977). The Cody ranges in thickness from 3,250 ft in the western part of the basin to about 5,500 ft in the eastern part (Johnson and others, Chapter 4, this CD-ROM). The lower and upper contacts of the Cody are conformable and interfinger extensively with the underlying Frontier and overlying Mesaverde Formations (fig. 5). Four members are recognized in the Wind River Basin (pl.1); these are, in ascending order: (1) unnamed lower shaly member (Thompson and White, 1954; Yenne and Pipiringos, 1954; and Keefer and Troyer, 1964), (2) unnamed upper sandy member (Thompson and White, 1954; Yenne and Pipiringos, 1954; and Keefer and Troyer, 1964), (3) informally named “Conant Creek tongue” (Szmajter, 1993), and (4) Wallace Creek Tongue (Barwin, 1961). The age of the Cody Shale ranges from Coniacian to middle Campanian (Keefer, 1972).

The unnamed lower shaly member is about 1,750 ft thick in the western part of the basin and thickens to the east to more than 2,250 ft (see Johnson and others, Chapter 4, this CD-ROM). It is composed of gray to black shale, bentonite, and is locally calcareous. A thin glauconitic sandstone is present several hundred feet above the Cody-Frontier contact in the western part of the basin (Keefer and Johnson, 1993). According to Keefer and Johnson (1993), this sand is about 5 ft thick, contains black chert pebbles as much as 1 in. in diameter, and can be traced to the east edge of the Wind River Reservation. A persistent zone in the lower 100-300 ft of the member, recognized on geophysical logs (known as the “chalk kick”) can be traced in the subsurface throughout most of the basin. The “chalk kick” separates overlying calcareous shales from underlying softer noncalcareous shales in the lower part of the unnamed shaly member. Merewether and others (1977a,b) correlated the noncalcareous interval below the “chalk kick” and the top of the uppermost sandstone in the Frontier Formation with the Carlile Shale in the Powder River Basin. This calcareous interval in the eastern part of the basin is about 1,000 ft thick on the basis of sample descriptions from well cuttings, and Merewether and others (1977a,b) correlated it with the Niobrara Formation in the Powder River Basin. Above this interval and below the base of the overlying sandy member the shaly member is less calcareous and commonly contains numerous bentonite beds.

The unnamed upper sandy member is about 1,800 ft thick in the western part of the basin and thickens to the east to about 3,500 ft (see Johnson and others, Chapter 4, this CD-ROM). The member consists of light to medium gray sandstones, bentonite beds, and tan and gray shales. Like those in the underlying Frontier Formation, many of the individual sandstones are blanket-like, and in many cases can be traced over several miles but appear to pinch out into marine shale in all directions. Sandstones in the upper sandy member are the most important reservoirs for oil and gas in the Cody Shale in the WRB. Dunleavy and Gilbertson (1986) referred to the most productive units in the upper sandy member as the “Sussex and Shannon sandstones” (fig. 5, and pls. 9 and 10). They (Dunleavy and Gilbertson, 1986) described the sandstones as poorly sorted, very fine- to fine-grained and consisting mainly of quartz grains, with small amounts of chert, feldspar, and rock fragments deposited "as a near-shore bar complex along the edge of a delta". According to Dunleavy and Gilbertson (1986), these sandstones grade westward into time equivalent nonmarine sandstones, shales, and coals of the Mesaverde Formation. These same sandstones pinch out to the east into the sandy and shaly facies of the upper Cody and are older than the Sussex-Shannon interval in the Powder River Basin. According to Finn (1993), in the southeast part of the basin the upper sandy member becomes less distinct as it grades laterally into a more shaly facies (pl. 8).

The Conant Creek tongue of the Cody Shale, informally named by Szmajter (1993), occupies the central part of the basin and is separated from the upper sandy member by an eastward thinning clastic wedge of marginal marine, and nonmarine rocks informally referred to as the "Alkali Butte member" of the Mesaverde Formation (figs. 3, 5; pls. 3, 11) (Hogle and Jones, 1991). The Conant Creek tongue is typically 400 to 900 ft thick, but thins to zero to the west where it grades into the Mesaverde Formation. (fig. 5; pls. 3, 11).

The Wallace Creek Tongue of the Cody Shale occupies the eastern and southeastern parts of the Wind River Basin and is stratigraphically higher and younger than the Conant Creek tongue to the west. The Wallace Creek Tongue is a westward thinning tongue of marine shale that splits the basal Fales Sandstone Member of the Mesaverde Formation from the upper part of the Mesaverde Formation (Barwin, 1961) (fig. 5; pls. 5-8, 11). According to Barwin (1961), the Wallace Creek Tongue at the type section in the Rattlesnake Hills is approximately 180 ft thick. It thins to zero in the northern part of the Coalbank Hills, where it grades into the main part of the Mesaverde Formaton, and thickens to nearly 500 ft in the southeast corner of the basin (pls. 5, 11).

Mesaverde Formation

The Mesaverde Formation consists of interbedded marginal marine sandstone, nonmarine sandstone, siltstone, shale, carbonaceous shale, and coal of Campanian age that were deposited in coastal plain and marginal marine environments as the western shoreline of the Cretaceous sea retreated eastward across the WRB (Keefer, 1972). Keefer and Troyer (1964) identified three distinct units in the western part of the basin, a basal marine sandstone, a middle sandstone and shale unit of nonmarine origin, and an upper fluvial sandstone known as the white sandstone member, which Keefer (1972) later renamed the Teapot Sandstone Member. In the central part of the basin the basal Mesaverde, referred to informally as the Alkali Butte Member by Hogle and Jones (1991) is separated from the upper part of the formation by the Conant Creek tongue of the Cody Shale (fig. 5; pls. 3, 11). Both the Alkali Butte member and the strata above the Conant Creek tongue but below the Teapot Sandstone Member correlate with the middle member of the Mesaverde farther west as distinguished by Keefer and Troyer (1964). In the eastern part of the basin there are four members, in ascending order: the Fales Sandstone Member, the Parkman Sandstone Member, the unnamed middle member, and the Teapot Sandstone Member (fig. 5; pls. 5-8 and 11)(Rich, 1958; Barwin, 1961; Keefer, 1972).

The basal Mesaverde unit in the western part of the WRB is a progradational marginal marine sandstone that varies in thickness from 50 to 200 feet (Keefer and Johnson, 1993; also see detailed measured surface sections by Johnson, Chapter 10, this CD-ROM). It climbs stratigraphically from west to east and in some locations may consist of several stacked sandstones (Keefer and Johnson, 1993). According to Johnson and Clark (1993), this unit was deposited in a shoreface setting and is gradational with the upper part of the underlying Cody Shale.

The middle member of the Mesaverde Formation consists of interbedded sandstone, siltstone, shale, carbonaceous shale and coal that were deposited in coastal plain and fluvial environments (Keefer, 1972; Johnson and others, 1996). The sandstones are tan to gray in color, and are fine- to medium-grained. The shales are gray to black and commonly carbonaceous. The sandstones are highly lenticular and originated as stream channel and splay deposits, with individual beds as much as 100 ft thick (Johnson and others, 1996; also see detailed measured surface sections by Johnson, Chapter 10, this CD-ROM).

The Alkali Butte member described by Hogle and Jones (1991) ranges in thickness from about 1,000 ft near Alkali Butte to zero about 30 mi east near Castle Gardens, where it grades into the upper sandy member of the Cody Shale (pl. 11). The Alkali Butte member grades into the main body of the Mesaverde Formation to the west (pl. 3). The Alkali Butte member was deposited during numerous transgressive-regressive cycles that formed a vertically stacked package of marginal marine sandstone, shale, carbonaceous shale, and coal that accumulated during a period of time when the paleoshoreline was at a relative stillstand position (Johnson and others, 1996). The Alkali Butte member is conformable with the underlying sandy member of the Cody Shale, and is overlain, and extensively interfingers with, the Conant Creek tongue of the Cody Shale.

In the eastern part of the WRB the lowest member of the Mesavarde Formation, referred to as the "lower Parkman tongue" by Rich (1958) and the "Phayles member" by Barwin (1961), and later renamed the Fales Sandstone Member by Gill and others (1970), is an eastward thinning clastic wedge of marginal marine and nonmarine strata. It is stratigraphically higher and younger than the Alkali Butte member to the west (fig. 5; pls. 1, 11). It conformably overlies the upper sandy member of the Cody Shale and is separated from the middle member of the Mesaverde by the Wallace Creek Tongue of the Cody Shale, with which the Fales interfingers (fig. 5). The Fales consists of tan and gray fine- to medium-grained sandstone, gray and brown siltstone and shale, carbonaceous shale, and coal that were deposited as an eastward-prograding fluvial-deltaic complex (Barwin, 1961; Johnson and others, 1996; also see detailed measured surface sections by Johnson, Chapter 10, this CD-ROM). The thickness at the type locality is 240 ft (Barwin, 1961). To the west, the Fales grades into the main part of the Mesaverde Formation in the vicinity of the Coalbank Hills (pls. 5, 11); thinning to the east to less than 20 ft at West Poison Spider oil field where the Fales is represented by a single sandstone bed (pl. 7).

The Parkman Sandstone Member (termed the upper Parkman by Rich, 1958) of the Mesaverde Formation is a progradational marginal marine sandstone composed of very fine-to medium-grained sandstone, with minor amounts of gray shale and siltstone (Rich, 1958; Barwin, 1961; Keefer, 1972; also see detailed measured surface sections by Johnson, Chapter 10, this CD-ROM). The upper and lower contacts of the Parkman Sandstone Member are conformable with the underlying marine shales of the Wallace Creek Tongue of the Cody Shale and the overlying nonmarine rocks of the unnamed middle member of the Mesaverde.

In the eastern part of the basin, the unnamed middle member of the Mesaverde Formation is about 350 to 550 ft thick. It consists of nonmarine sandstone, siltstone, shale, carbonaceous shale, and coal that accumulated in coastal swamps and fluvial environments (Barwin, 1961; Johnson and others, 1996; also see detailed measured surface sections by Johnson, Chapter 10, this CD-ROM). In the extreme southeastern part of the basin the upper part of the member grades into thin marine deposits that are overlain, and appear to be truncated, by the Teapot Sandstone Member (pl. 8) (Barwin, 1961; Merewether and others, 1977b). This marine tongue represents a minor western readvance of the Cretaceous sea across the south end of the Casper arch.

The Teapot Sandstone Member is the youngest member of the Mesaverde Formation, and has a basinwide distribution except at some localities along the south basin margin where it is truncated beneath younger rocks (Keefer and Johnson, 1997). The Teapot ranges in thickness from about 500 ft in the Shotgun Butte area to less than 20 ft in the southeastern part of the basin (Finn, 1993; Johnson and others, 1996; also see detailed measured surface sections by Johnson, Chapter 10, this CD-ROM). The Teapot is typically very light gray to white in color and consists of fine- to coarse-grained sandstone with minor amounts of siltstone and shale (Barwin, 1961; Keefer, 1972; Johnson and others, 1996). The Teapot is considered to be fluvial in origin throughout most of the basin, based on the presence of plant fragments and a lack of marine fossils (Rich, 1958; Barwin, 1961); this interpretation is supported by outcrop studies by Johnson and others (1996) and Johnson (Chapter 10, this CD-ROM). In the eastern part of the basin, however, bedding features indicate a marginal marine origin. The upper contact of the Teapot is conformable with the Meeteetse Formation or, where present, the overlying Lewis Shale. The lower contact of the Teapot Sandstone Member with the unnamed middle member is sharp and considered a regional unconformity by Gill and Cobban (1966), Reynolds (1967), Gill and others (1970), Van Wagoner and others (1990), Merewether (1996), and Merewether and others (1977b).

Meeteetse Formation and Lewis Shale

The Meeteetse Formation and Lewis Shale are laterally equivalent, intertonguing marine, marginal marine, and nonmarine strata of latest Campanian and early Maastrichtian age (Gill and others, 1970; Keefer, 1972) (fig. 5; pls. 5-8, 11). The marine and marginal marine strata are in the Lewis Shale, the nonmarine strata in the Meeteetse Formation (Keefer, 1965a; Johnson and others, 1996). The maximum combined thickness is about 1,750 ft in the northeastern part of the basin (Johnson and others, Chapter 4, this CD-ROM).

The Meeteetse Formation is composed of alternating thin beds of white, gray, and tan sandstone, siltstone, gray shale, brown carbonaceous shale, and coal that accumulated in poorly drained coastal environments west of the Lewis seaway (Johnson and others, 1996; also see detailed measured surface sections by Johnson, Chapter 10, this CD-ROM). The sandstones are very fine- to coarse-grained and lenticular. According to Johnson and others (1996), coal beds in the Meeteetse are more numerous than in the other Cretaceous coal-bearing units in the basin, but are commonly only a few inches to a few feet thick. Throughout the basin, where the Lewis is absent, the Meeteetse is about 500 to 1,500 ft thick except along the south margin where it is truncated by younger rocks (pls. 2, 3) (Keefer and Johnson, 1997; Johnson and others, Chapter 4, this CD-ROM).

The Lewis Shale represents the last stages of marine sedimentation in the WRB and is distributed over the eastern and northeastern parts of the basin. The Lewis Shale consists of an upper and lower tongue of interbedded marginal marine sandstone and siltstone and marine shale separated by nonmarine deposits of the Meeteetse Formation (pls. 5-8, 11). The Lewis Shale is predominantly gray to green marine shale interbedded with fine- to medium-grained sandstone, and siltstone (Keefer, 1965a). The lower tongue is 300 ft thick in the southeastern part of the basin and thins to zero near the north end of the Coalbank Hills where it grades laterally in to the lower part of the Meeteetse Formation (pls. 5, 11). Dunleavy and Gilbertson (1986) and Johnson and others (Chapter 4, this CD-ROM) identified a thin shale above the Teapot Sandstone Member at Madden anticline in the northern part of the basin that they believed also was the lower tongue of the Lewis Shale. The upper tongue is nearly 600 ft thick in the southeastern part of the basin and thins rapidly to the west where it pinches out in the southern part of the Rattlesnake Hills (pl. 8). The northern limit of the upper tongue appears to be in the vicinity of West Poison Spider oil field, where it is less than 50 ft thick (pl. 7).

Lance Formation

The Lance Formation consists of interbedded sandstone, claystone, shale, carbonaceous shale, coal, and in the Shotgun Butte area conglomerate (fig. 2) (Johnson and others, 1996; Keefer and Johnson, 1997; also see detailed measured surface sections by Johnson, Chapter 10, this CD-ROM). According to Johnson and others (1996) and Keefer and Johnson (1997), the lower part of the Lance Formation is predominantly sandstone and the upper part is composed of primarily shale and claystone. The sandstones are white, tan, and gray and fine- to coarse-grained were deposited as fluvial channel, delta front, and splay deposits (Gillespie and Fox, 1991; Johnson and others, 1996). The Lance is generally considered to be Maastrichtian in age; however, palynostratigraphic studies by Nichols and Flores (1993) indicate that the uppermost part of the Lance in the Shotgun Butte area, in part, may be earliest Paleocene in age. The onset of the Laramide orogeny and initial partitioning of the Rocky Mountain foreland basin into the smaller Laramide basins are indicated by the Lance thickness patterns in the WRB, which range from zero along the south margin of the basin where it is truncated beneath younger rocks to more than 6,000 ft in the northeastern part of the basin (fig. 6) (Johnson and others, Chapter 4, this CD-ROM).

Stratigraphy of Tertiary Rocks

Paleocene Rocks

Fort Union Formation

According to Keefer (1965a), the Fort Union Formation in the Wind River Basin can be divided into two general lithologic units: a lower fluvial unit, and an upper marginal lacustrine and lacustrine unit. The lower unit is referred to as the lower unnamed member, and the upper part is divided into two laterally equivalent members—the Shotgun Member and the Waltman Shale Member (fig. 6). The Fort Union Formation is Paleocene in age and, according to Nichols and Flores (1993), all Paleocene biozones are represented. These biozones are based on fossil pollen and are designated from oldest to youngest P1 through P6 (Nichols, 1994). Biozones P1 and P2 are considered to be early Paleocene in age, P3 and P4 middle Paleocene, and P5 and P6 late Paleocene; however, it should be noted that these subdivisions are not equal in duration (Nichols and Flores, 1993). The age of the lower unnamed member is generally considered to be P1 through P4, and that of the Waltman Shale Member P5 and P6 (Nichols and Flores; 1993). The overall thickness pattern of the Fort Union Formation is similar to the underlying Lance Formation, in that the Fort Union records continued subsidence of the basin trough as the Laramide orogeny progressed. Its thickness exceeds 6,000 ft (pl. 9) in the northeastern part of the basin, then thins rapidly to the south and west to 200 to 1,000 ft along those margins of the basin (Keefer, 1965a). The geologic map by Keefer (1970) shows the Fort Union to be truncated beneath younger rocks in the southwestern part of the basin.

The lower unnamed member consists of interbedded conglomerate, fine- to coarse-grained sandstone, shale, carbonaceous shale, and coal that accumulated as fluvial channel and splay deposits, and associated floodplain deposits. According to Johnson and others (Chapter 4, this CD-ROM), the lower Fort Union is about 3,500 ft in the northeastern part of the basin, and thins towards the south and west margins to about 500 feet.

The Waltman Shale Member is predominantly dark brown to black organic-rich shale with interbedded sandstone, and siltstone that accumulated in a large body of water that occupied the central part of the basin known as Lake Waltman (Keefer, 1965a). According to Johnson and others (1996), the Waltman is more than 2,500 ft thick along the deep trough of the basin in the northeast and thins to zero to the south and west where it grades laterally into sandstones of the fluvial-deltaic facies of the Shotgun Member. The contact with the underlying lower member is sharp but conformable. The upper contact is conformable and interfingers extensively with the overlying Shotgun Member in many areas.

The Shotgun Member represents fluvial-deltaic deposits that are in part laterally equivalent to and in part younger than the Waltman Shale Member that accumulated adjacent to and in the marginal areas of "Lake Waltman" (Keefer, 1965a). The Shotgun Member is composed of white and light gray, fine- to coarse-grained sandstone, conglomerate, siltstone, shale, carbonaceous shale, and coal that were deposited in marginal lacustrine, fluvial and floodplain settings. Numerous prominent coarsening-upward sandstones have been interpreted as fan deltas that accumulated in the marginal area of the lake with sediments sourced from the surrounding highlands (Phillips, 1983). However, Roberts and others (Chapter 5, this CD-ROM) restricted the fan-delta model to the deposits along the north margin of the basin adjacent to the Bighorn and Owl Creek Mountains and believed the deposits along the south margin accumulated as part of a progradational fluvial-deltaic complex.

Eocene Rocks

Wind River and Indian Meadows Formations -Undivided

Strata that represent the lower Eocene in the Wind River Basin are assigned to the Indian Meadows and Wind River Formations (Love and others, 1993). The two units in marginal areas are separated by a major angular unconformity. The rocks below the unconformity were involved in the final stages of Laramide deformation and are highly deformed; these are assigned to the Indian Meadows Formation. The rocks above the unconformity, assigned to the Wind

River Formation are relatively undeformed and overlap all older rocks along the basin margins (Keefer, 1969). The magnitude of the unconformity separating the two formations diminishes basinward and along the trough of the basin they are essentially conformable, represent continuous deposition, and are lithologically similar. Consequently, all of the lower Eocene rocks are combined into one unit on the cross sections in this report. According to Keefer (1965a,b; 1969) the lower Eocene rocks in the WRB consist of as much as 8,000 ft of variegated red, purple, white, and gray claystone, siltstone, coarse-grained sandstone, and conglomerate. The conglomerates accumulated mainly as alluvial fans around the margins of the basin fed by streams along the flanks of the bounding mountain ranges and extending some distance into the basin. The finer grained deposits accumulated in lakes that occupied the basin center (Keefer, 1969).

Summary of Depositional History

All but the uppermost Cretaceous rocks in the WRB were deposited in or adjacent to a broad foreland basin that was periodically flooded by an epicontinental seaway that covered much of the western interior of the United States (fig. 4). 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). The seaway developed in response to the formation of a subsiding foreland basin east of the tectonically active Cordilleran orogenic belt, and as a consequence of a eustatic sea-level rise (Steidtmann, 1993).

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. 5). The lowermost Cretaceous rocks are represented by conglomerates and shales of the Cloverly Formation, that were deposited by river systems that flowed northeastward from the thrust belt across the foreland basin (MacKenzie and Ryan, 1962; McGookey and others, 1972; May and others, 1995). The uppermost sandstone beds in the Cloverly, referred to as the “Rusty beds” by many workers because of the distinct rusty color in outcrop (Love and others, 1945; Young, 1970), were deposited in a variety of nearshore and marginal marine environments during the initial transgression of the Cretaceous sea and are transitional with the overlying Thermopolis Shale (Curry, 1962). Marine conditions prevailed throughout much of the remainder of Early Cretaceous time as muds of the Thermopolis Shale were deposited. This was followed by a major regression forming a regional lowstand surface that exposed the Thermopolis Shale to subaerial erosion and incisement of stream valleys (Mitchum, 1977; Dolson and others, 1991; Weimer, 1992). Initial flooding by the Mowry sea deposited the Muddy Sandstone as transgressive deposits in deltaic, strandline, fluvial, and estuarine environments (Dresser, 1974; Mitchell, 1978; Curry, 1985; Pritchard, 1993; Steidtman, 1993).

Marine flooding continued into Cenomanian time as thick organic-rich strata of the Mowry Shale record a return to marine conditions in the region (Reeside and Cobban, 1960; Byers and Larson, 1979). Following the deposition of the Mowry Shale, the Cretaceous sea withdrew to the east as deltaic and offshore marine sandstones, and interbedded marine shales of the Frontier Formation were deposited (Keefer, 1972). Within the Frontier Formation, Merewether (1983) identified several transgressive and regressive cycles, and intraformational unconformities that formed in response to local tectonism, eustatic sea level change, or a combination of both. Throughout all but latest Cretaceous time, the area was again inundated by shallow seas that repeatedly advanced and retreated across the area depositing a complex intertonguing sequence of eastward-thinning clastic wedges of nonmarine and marginal marine sandstones, siltstones, shales, and coal of the Mesaverde and Meeteetse Formations, and westward thinning marine tongues of Cody and Lewis Shale (fig. 5, pl. 11) (Rich, 1958; Barwin, 1961; Keefer, 1972; Fox and Priestley, 1983a, b; Finn, 1993; Szmajter, 1993). The Mesaverde and Meeteeste Formations were deposited in fluvial, coastal plain, and marginal marine environments as the Cretaceous sea retreated eastward. The Lewis Shale tongues record the final marine transgressions into the WRB that, at maximum extent, covered the eastern and northeastern parts of the basin (pls. 5-8, and Johnson and others, Chapter 4, this CD-ROM).

Marine deposition ended near the close of the Cretaceous Period (early Maastrichtian) as the foreland basin was gradually being filled and the western shoreline of the seaway retreated eastward. The end of Cretaceous marine sedimentation marks the onset of the Laramide orogeny (Dickinson and others, 1988), 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. 2). Basins, such as the WRB, subsided rapidly and became depocenters for thick accumulations of clastic debris eroded from the surrounding uplifts during latest Cretaceous and early Tertiary time. The uppermost Cretaceous and lower Paleocene rocks consist of sandstone, siltstone, shale, coal, and conglomerate that were deposited on extensive alluvial plains within the intermontane basin. During latest Cretaceous (Maastrichtian) time, downwarping along the basin trough and uplift of the basin margins mark the onset of Laramide deformation in the area of the WRB. The oldest formation to exhibit Laramide influence is the Lance Formation that thins toward the southern basin margins and thickens (as much as 6,000 ft.) toward the basin axis (Gillespie and Fox, 1991; Johnson and others, Chapter 4, this CD-ROM). Continental sediments of the Lance Formation were deposited by fluvial systems that eroded the surrounding highlands and flowed into the subsiding basin.

Fluvial conditions persisted into early and middle Paleocene time with deposition of several thousand feet of lower Fort Union Formation sediments (Keefer, 1965a; Flores, Keighin, and Roberts, 1994; Flores, Roberts, and Perry, 1994). Within both the Lance Formation and lower unnamed member of the Fort Union Formation, the coarser-grained strata are typically in the marginal areas of the basin and grade into a finer mud-dominated facies in the central part (Johnson and others, 1994). Contemporaneous uplift, folding, and truncation of older rocks along the basin margins resulted in an unconformity at the base of the Fort Union Formation (Rich, 1962, Keefer, 1960; Keefer, 1965a,b), but downdip in the deeper parts of the basin Fort Union and underlying rocks are conformable. In later Paleocene time as much as 3,000 ft of dark brown to black organic-rich lacustrine muds of the Waltman Shale Member and associated marginal fluvial deltaic sands of the Shotgun Member were deposited as the central part of the basin continued to subside and was flooded by Lake Waltman (Keefer, 1965a). By early Eocene time, Laramide deformation had reached its final stages and all major mountain ranges surrounding the basin had formed (Love, 1988). Subsequent erosion of these uplifts deposited coarse-grained alluvial fans of the Indian Meadows Formation along the flanks of the rising highlands. As Laramide deformation ceased, extensive erosion of the surrounding uplifts through the remainder of early Eocene time resulted in the deposition of nearly 8,000 ft of variegated basin fill sediments of the Wind River Formation (Keefer, 1965a,b; 1969).

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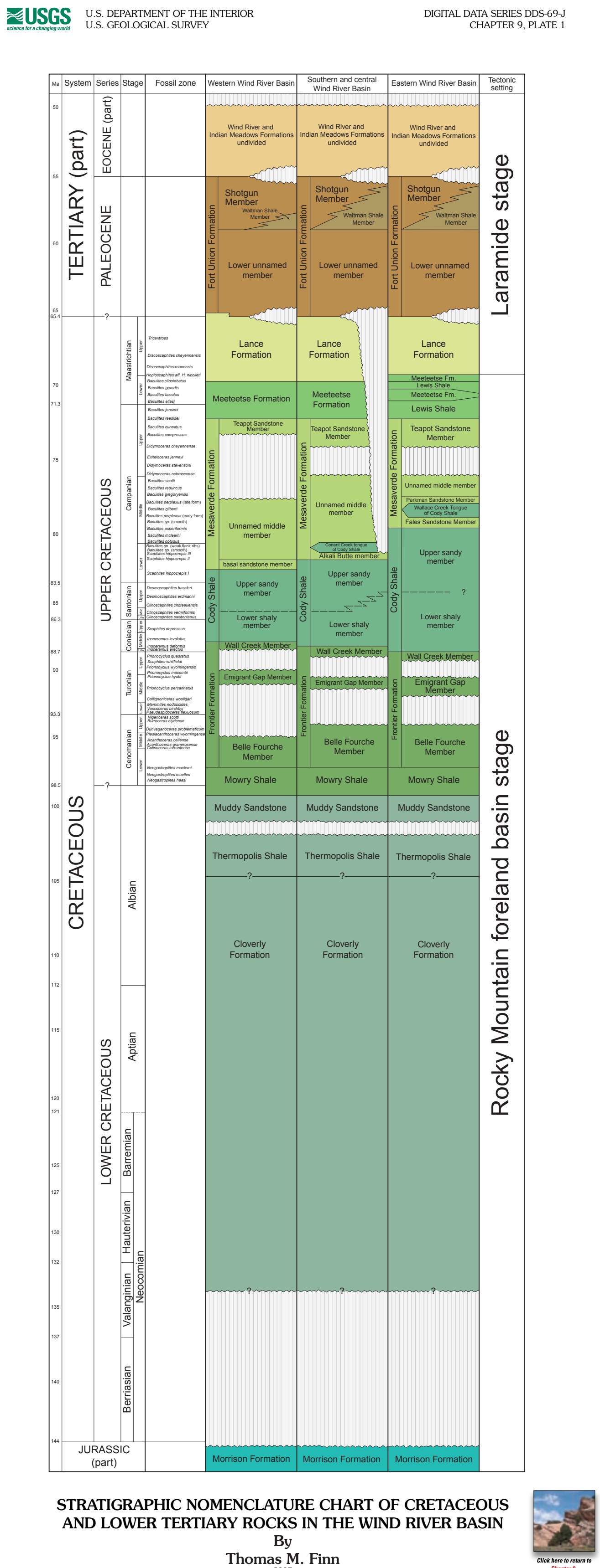

Plate 1. Correlation diagram of Cretaceous and lower Tertiary rocks, Wind River Basin. (Click on image to view and print full size).

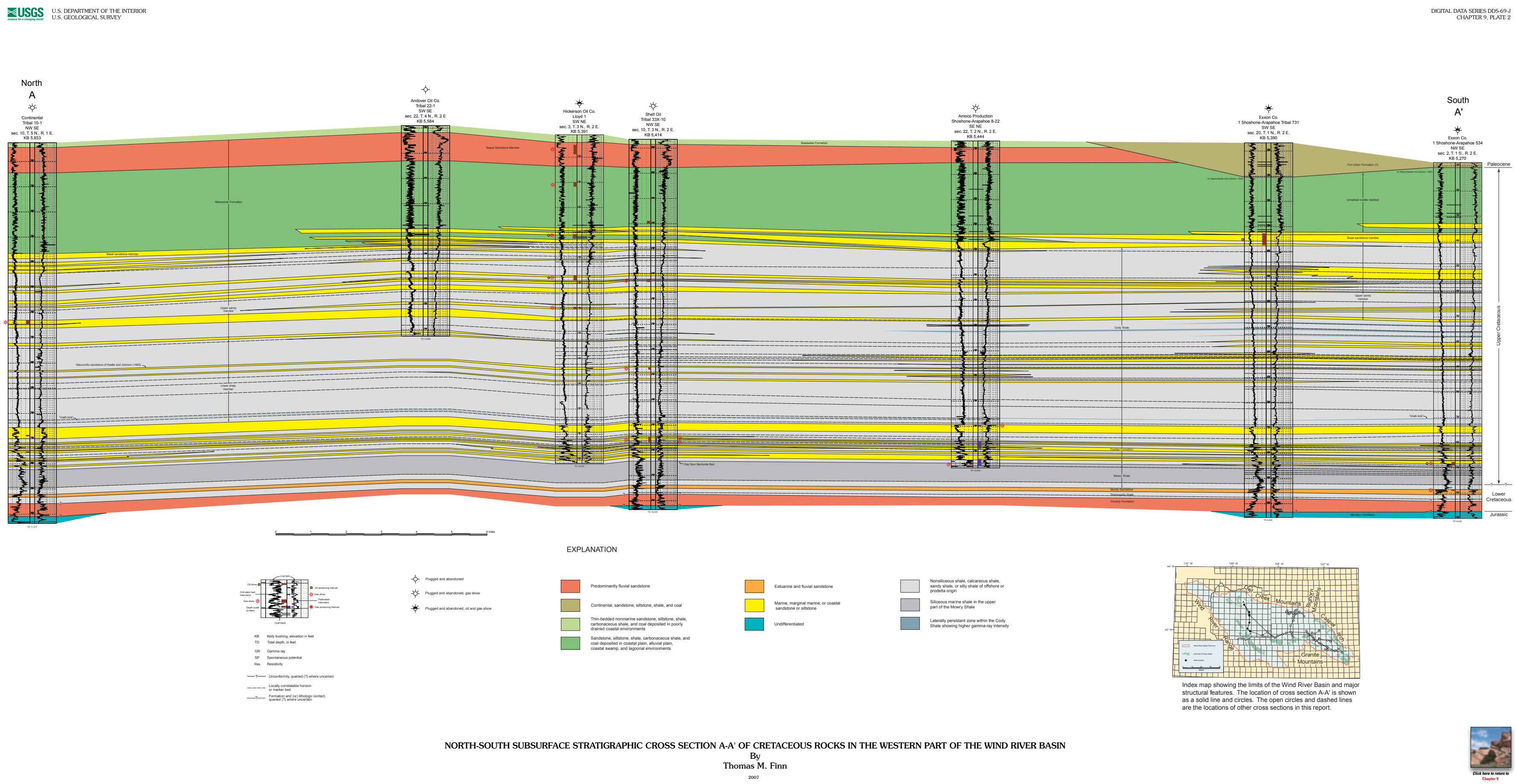

Plate 2. North-south cross section A-A', Shotgun Butte to McGowan anticline. (Click on image to view and print full size).

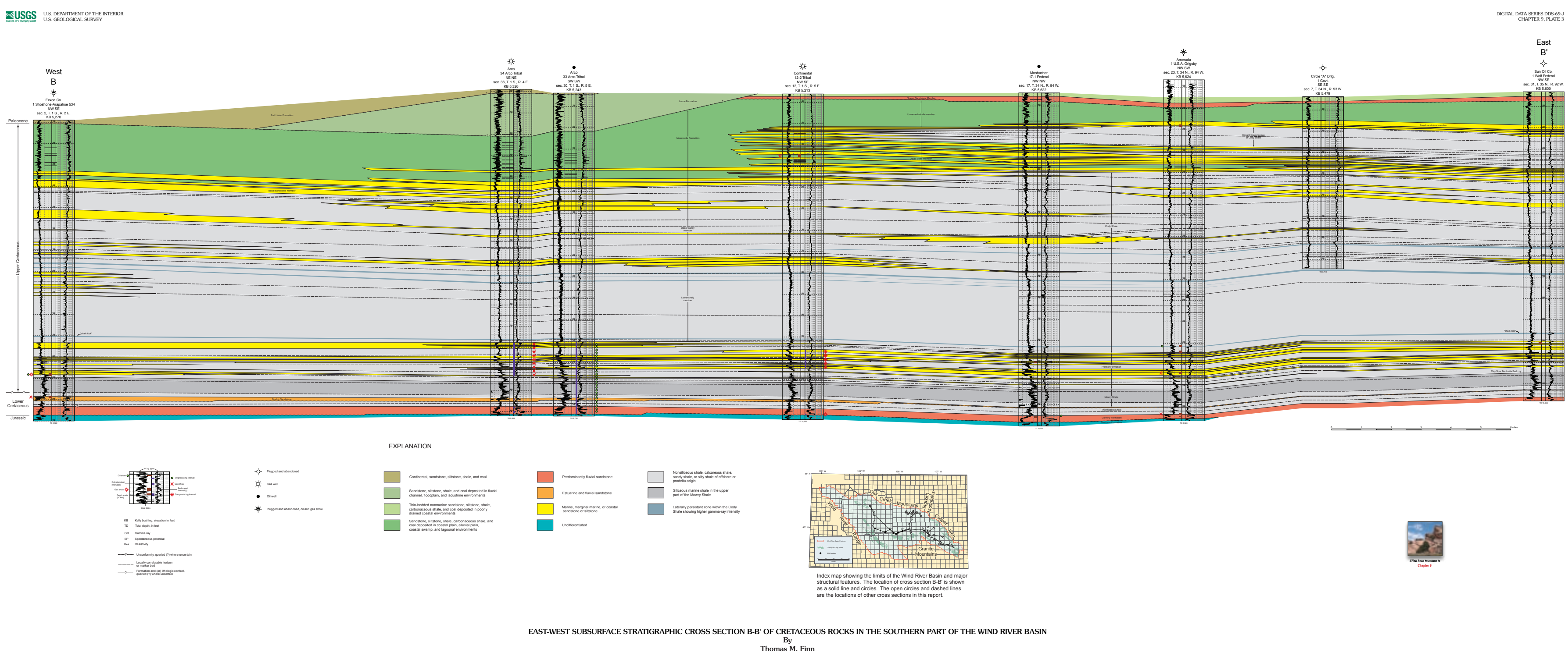

Plate 3. East-west cross section B-B′, from McGowan anticline to Muscrat anticline. (Click on image to view and print full size).

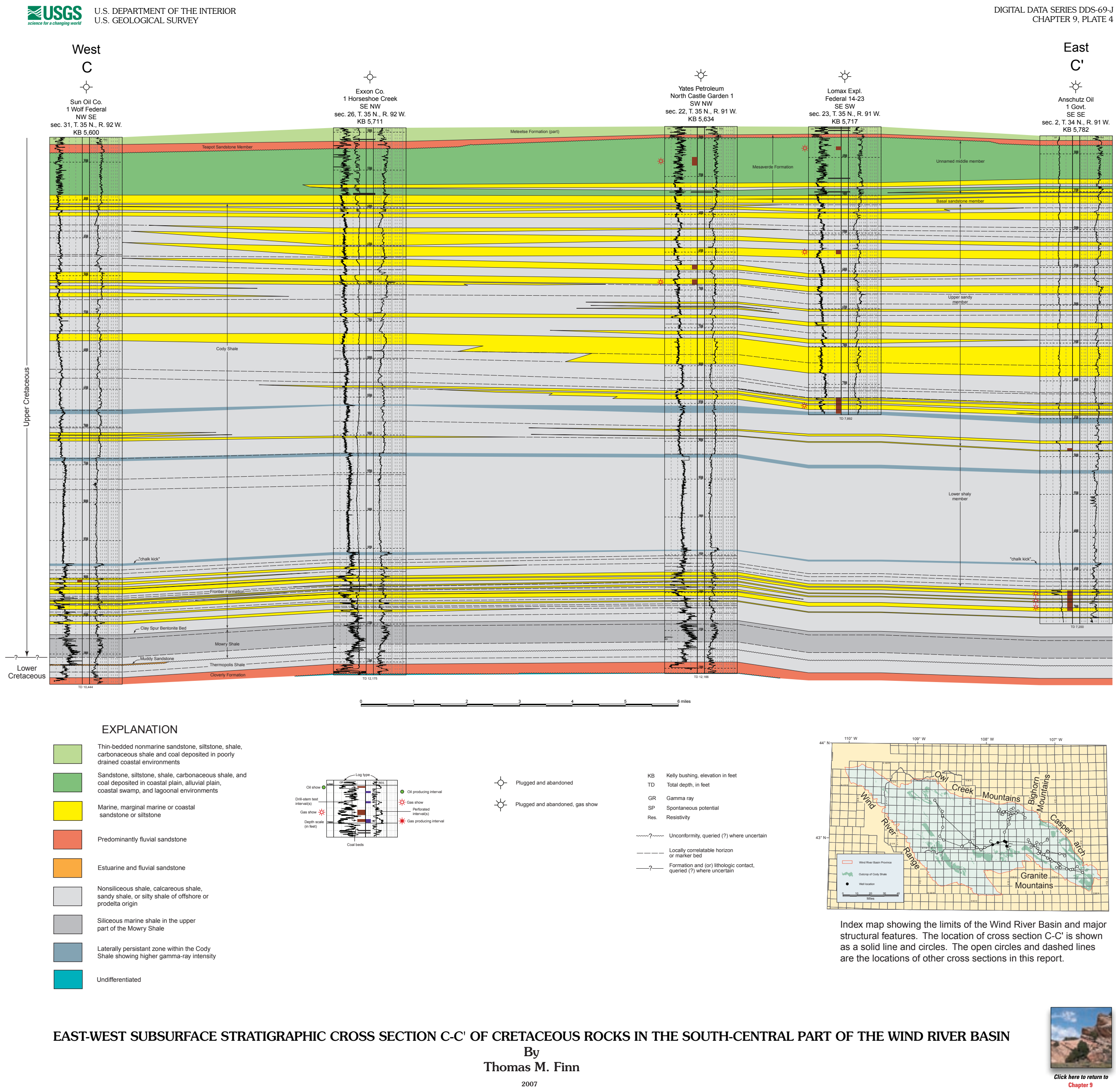

Plate 4. East-west cross section C-C′, Muskrat anticline to Castle Gardens. (Click on image to view and print full size).

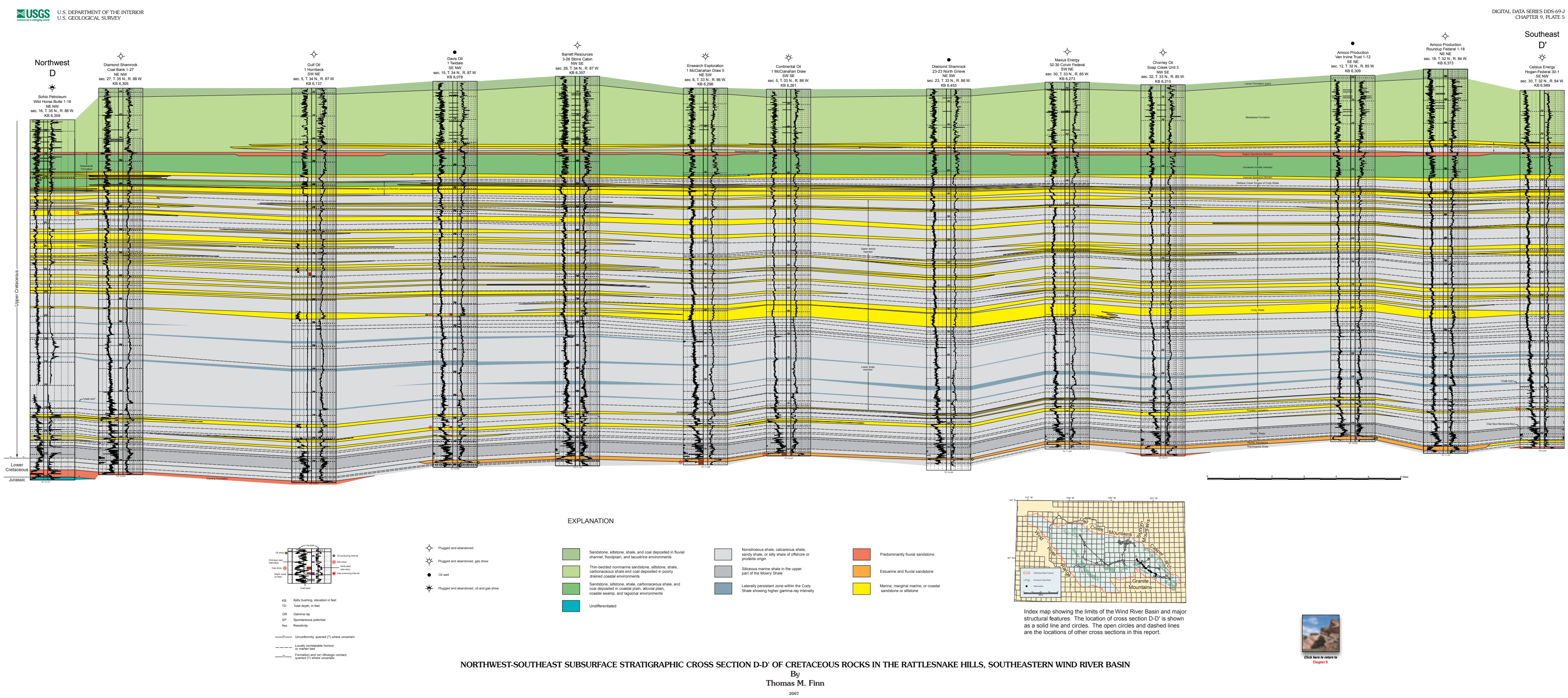

Plate 5. Northwest-southeast cross section D-D', northeast flank of Rattlesnake Hills. (Click on image to view and print full size).

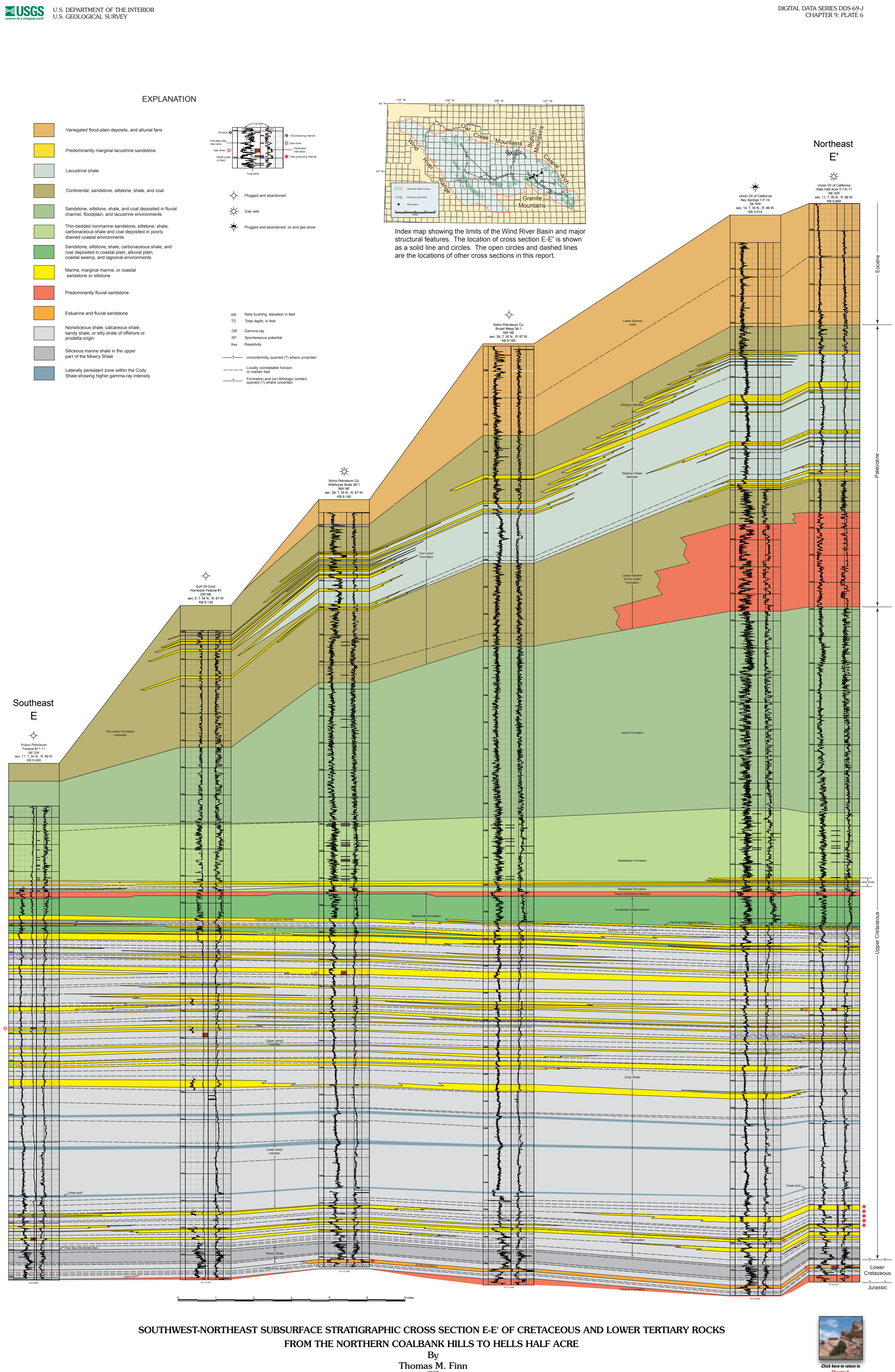

Plate 6. East-west cross section E-E′, Coalbank Hills to Hells Half Acre. (Click on image to view and print full size).

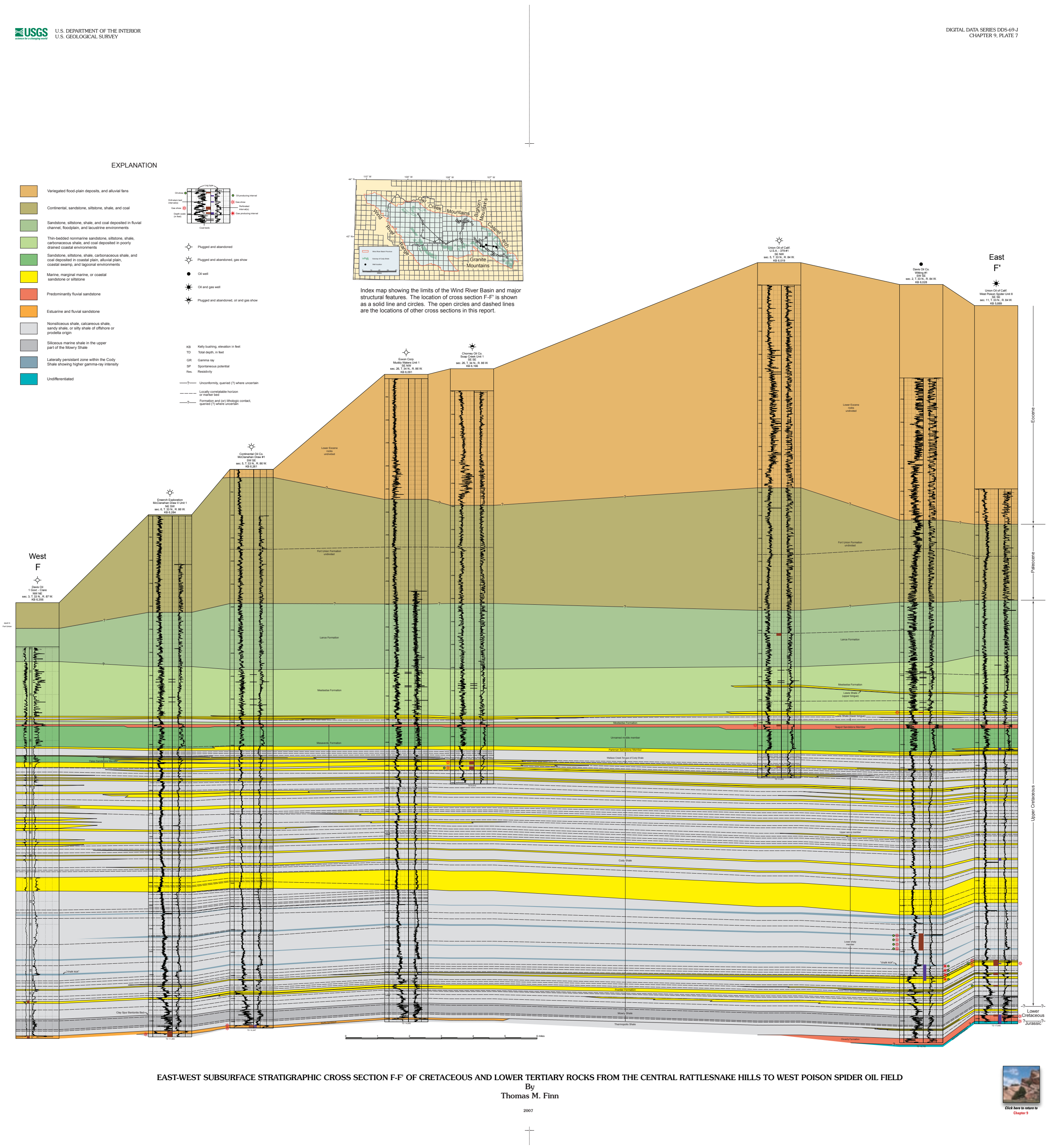

Plate 7. East-west cross section F-F′, central Rattlesnake Hills to West Poison Spider. (Click on image to view and print full size).

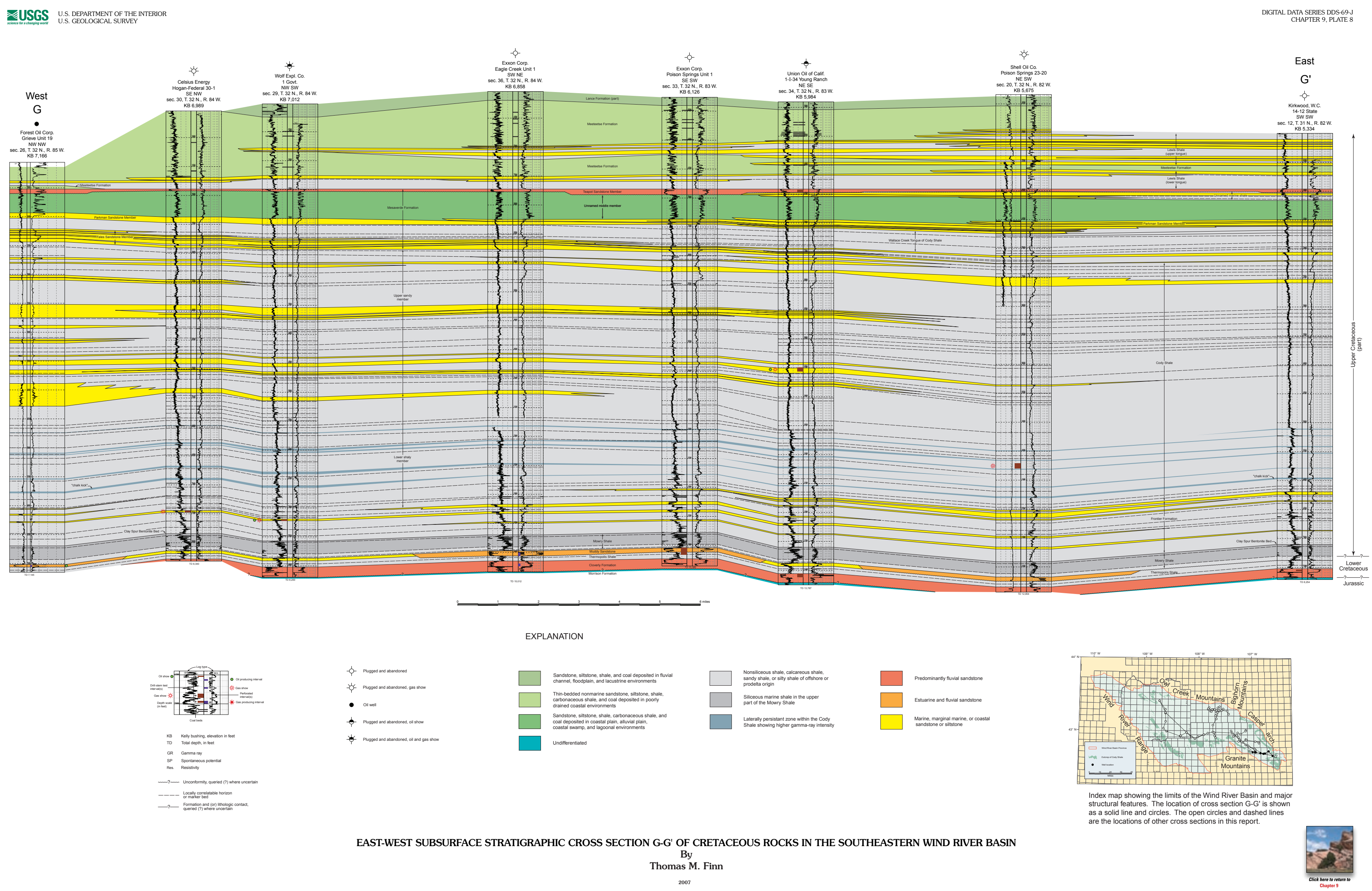

Plate 8. East-west cross section G-G', southeast Wind River Basin. (Click on image to view and print full size).

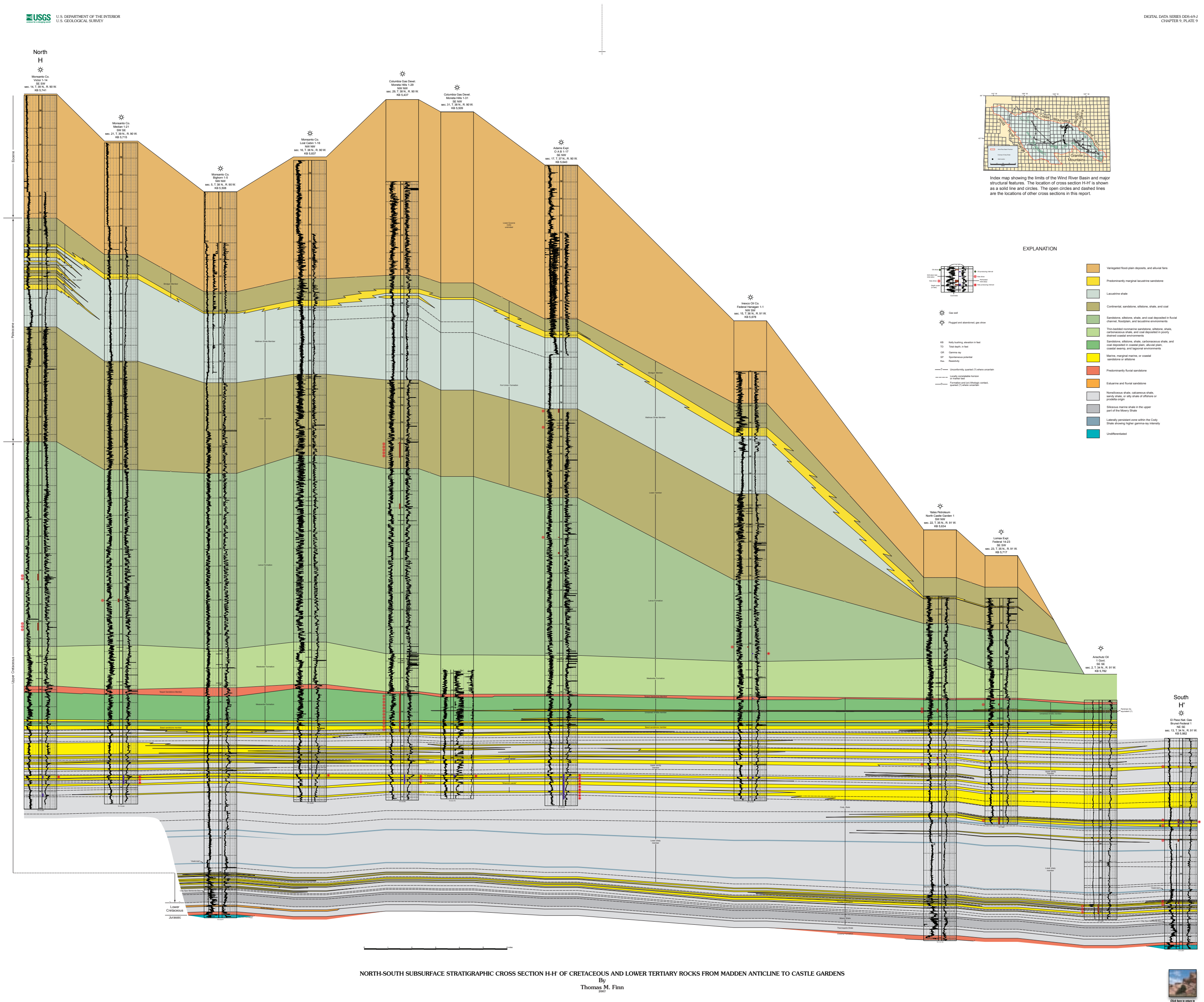

Plate 9. North-south cross section H-H', from Madden anticline to Castle Gardens. (Click on image to view and print full size).

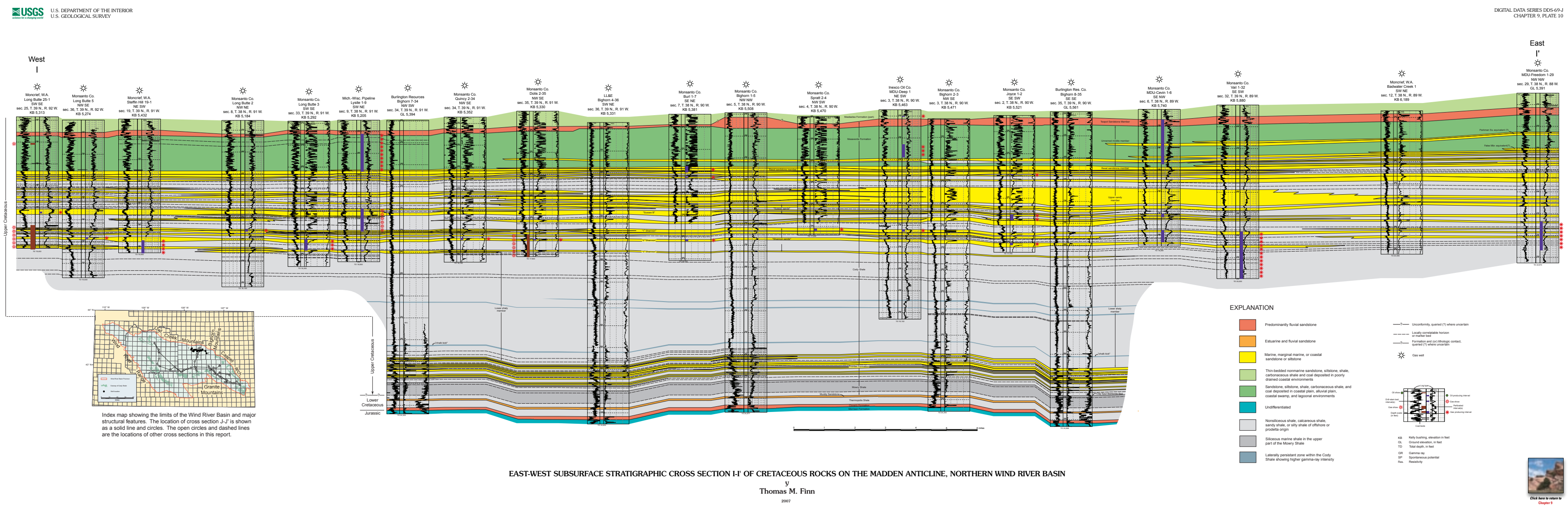

Plate 10. East-west cross section I-I' along the crest of Madden anticline. (Click on image to view and print full size).

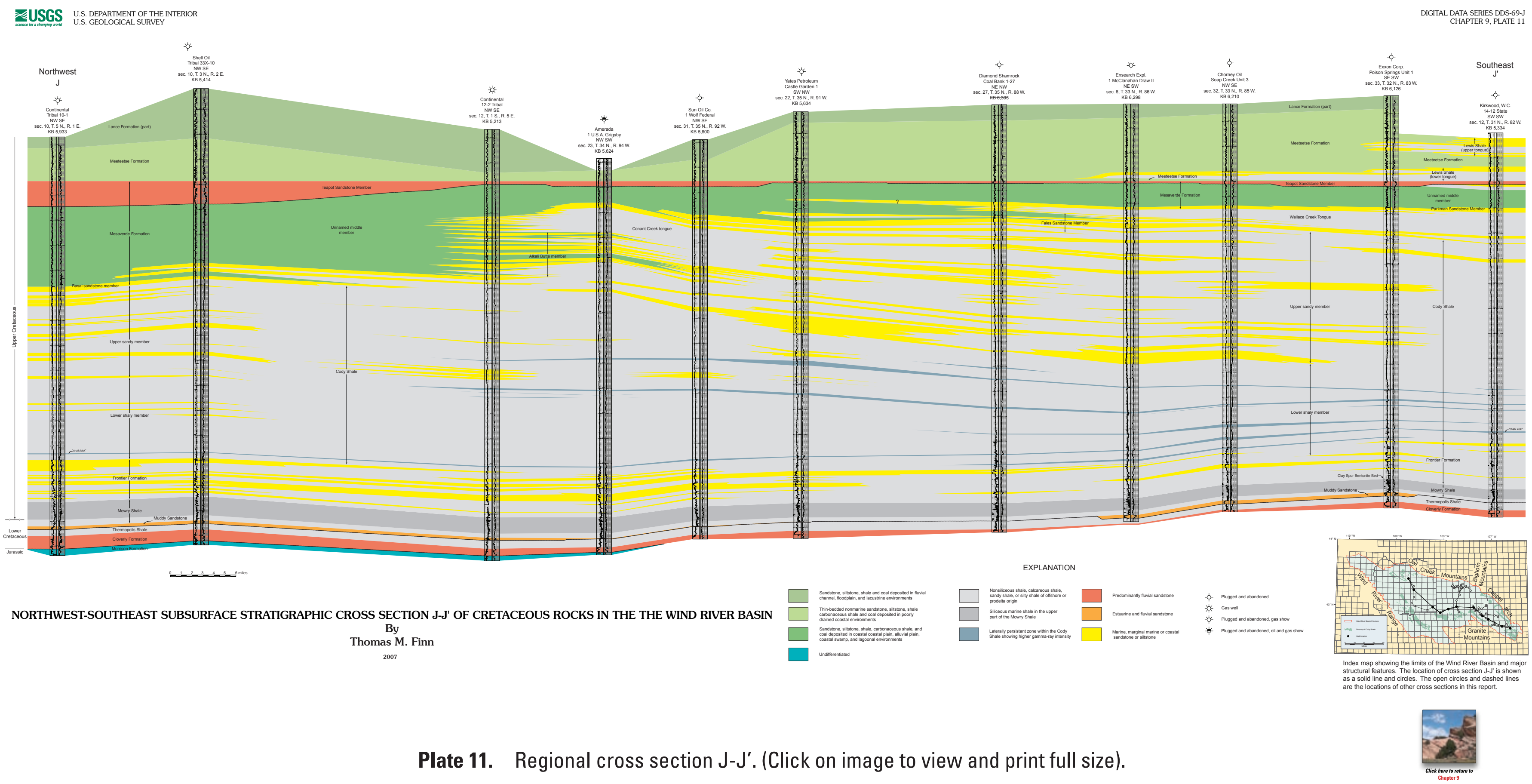

Plate 11. Regional cross section J-J'. (Click on image to view and print full size).

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