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by Dianna Gentry Hogle and Richard W. Jones

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Subsurface Geology of Upper Cretaceous and Lower Tertiary Coal-Bearing Rocks, Wind River Basin, Wyoming

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ABSTRACT

A refined stratigraphic framework has been established for more than 20,000 ft (6,000+ m) of Upper Cretaceous through lower Eocene sedimentary rocks in the Wind River Basin, Wyoming. This study refines and expands previous work and conclusions by assembling and using a much larger data base than previously available, including a correlation net of 325 geophysical well logs (electric logs showing resistivity, spontaneous potential and/or gamma ray - neutron curves), 36 drill holes with palynological age dates, 80 drill hole lithology logs, and limited surface exposures. Stratigraphic and structural data were generated for that portion of the basin in front of the South Owl Creek Mountains thrust fault and for the hanging wall of this thrust. Because of the lack of data, the geology of that portion of the stratigraphic/structural basin beneath the thrust is only speculative. Significant results and conclusions from this study include: (1) The lower part of the Mesaverde Formation intertongues with marine sandstones and shales in the upper part of the Cody Shale to the east and with marine sandstones in the lower part of the Mesaverde Formation in the Bighorn Basin to the north. (2) An unconformity between the Upper Cretaceous Mesaverde Formation and the overlying Paleocene Fort Union Formation in the southwestern part of the Wind River Basin can be correlated for more than twenty miles in the subsurface. (3) During the latest Cretaceous and Paleocene, more than 7,000 ft (2,100+ m) of Lance Formation and more than 8,500 ft (2,600 m) of Fort Union Formation were deposited in the northeastern part of the basin. Ponding during the Paleocene occurred primarily in the northeastern Wind River Basin with the deposition of 2,800 ft (850+ m) of shale and siltstone in the Waltman Shale Member of the Fort Union Formation. (4) The Lance and Fort Union formations occur in the subsurface throughout much of the basin; however, the Lance and the underlying Meeteetse Formation were eroded in the western part of the basin. (5) Formation thicknesses are controlled locally, in part, by synorogenic structural features that were developing during the deposition of sediments, as shown for example, in the Shotgun Butte syncline and Madden anticline. (6) Regional coal isopach and isopleth maps generated for the first time, for the Mesaverde Formation and combined Meeteetse/Lance Formations, indicate possible target areas for coal and related hydrocarbon exploration.

INTRODUCTION

The purpose of the investigation was to establish a regional stratigraphic framework for coal-bearing Upper Cretaceous and lower Tertiary rocks in the Wind River Basin to assist in further exploration and development of mineral resources. Previously published data from both subsurface and surface studies was integrated with a large amount of new subsurface data to update, expand and refine earlier interpretations of the subsurface geology of the basin.

Background

This study is restricted to a part of the Wind River structural basin of central Wyoming known as the Wind River Coal Basin. The boundary of this coal basin is defined by the extent of the stratigraphically lowest major coal-bearing formation in the

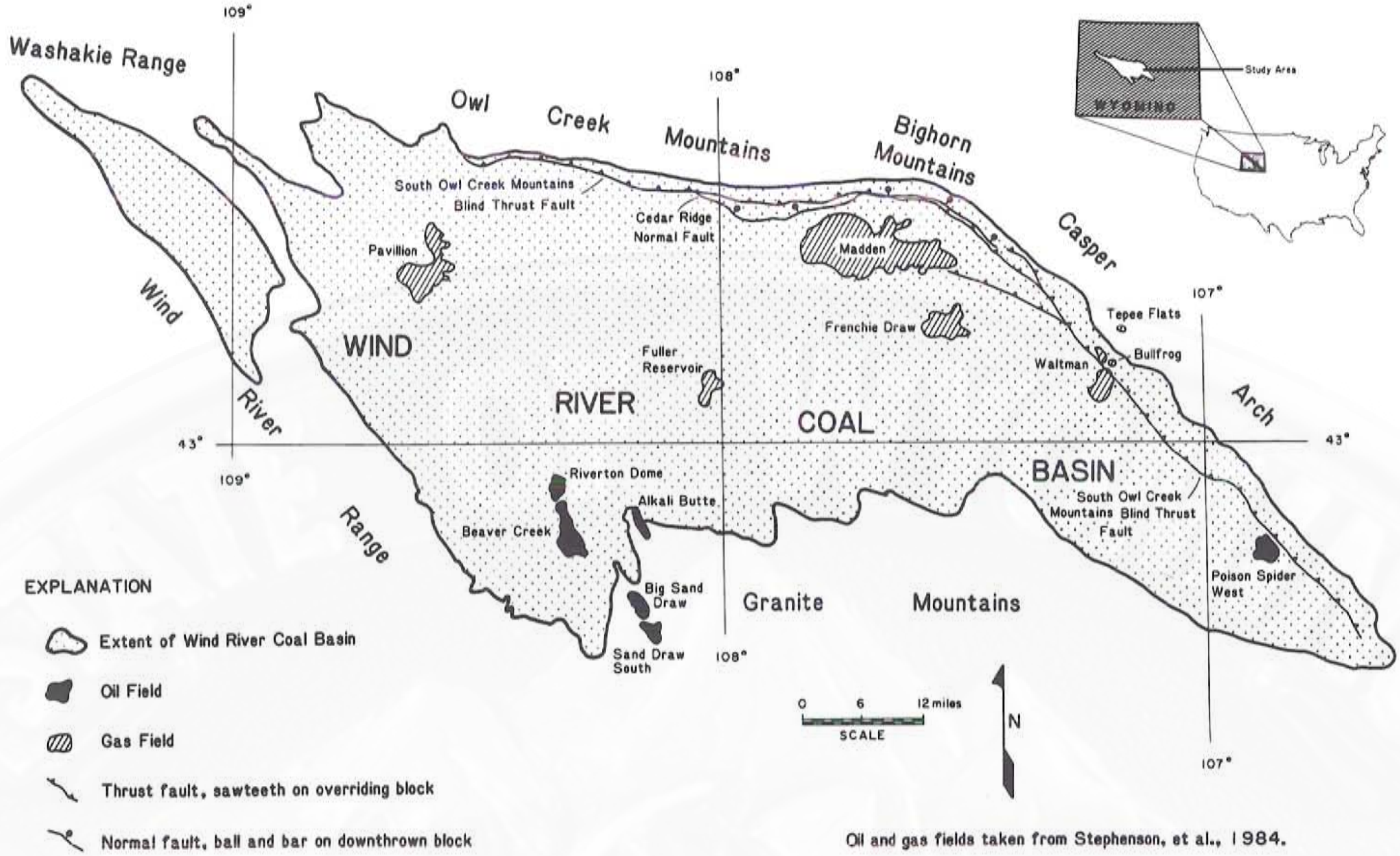


Figure 1. *Study area location map, major geologic features surrounding the basin, and other selected features, Wind River Basin, Wyoming.*

Wind River Basin, the Mesaverde Formation (Fig. 1). The major coal-bearing rocks present in the Wind River Coal Basin include the Upper Cretaceous Mesaverde Formation through the lower Eocene Wind River Formation. Ages and the stratigraphic sequence of formations are after Keefer (1965, 1972) (Fig. 2). For ease in description, the terms Wind River Coal Basin and the Wind River Basin are synonymous in this paper.

The Wind River Coal Basin occupies approximately 8,500 mi^2 (13,600+ km^2) and is bounded by the Owl Creek Mountains to the north, the Casper Arch to the east, the Granite Mountains to the south and the Wind River Mountains to the west (Fig. 1). Only part of the structural basin had formed prior to the emplacement of the thrusts that overrode perhaps half of the northern and eastern parts of the basin. Possibly beginning in latest Paleocene time and then during the earliest Eocene, the South Owl Creek Mountains thrust fault brought the Owl Creek Mountains and the Casper Arch nearly over the present day basin axis.

The Upper Cretaceous Mesaverde Formation (Fig. 2) primarily Campanian with slight overlap of the Campanian-Maastrichtian boundary (Lillegraven and McKenna, 1986). The Clarkforkian, a North American land mammal age defined in the Bighorn Basin to the north, has not been identified in the Wind River Basin (Brown, 1989, personal communication).

Previous geologic investigations of the Wind River Basin include work by Bauer (1934), Gill et al (1970), Hickling et al (1989), Love (1939, 1948, 1970, and 1978), Nace (1936), Paape (1961), and Rich (1962). Structural studies of the basin include Blackstone (1948), Gries (1983), Keefer (1970), Love (1978), and Reynolds (1976). The last major comprehensive, basin-wide study of Upper Cretaceous through lower Eocene rocks was published by Keefer (1965, 1972); these publications include stratigraphic definitions, ages, and depositional settings of units in this rock sequence. Windolph and others (1986) studied the coal-bearing Cretaceous and Tertiary rocks in the western part of the basin. However, they used a unique stratigraphic classification for some of the rock units and ignored the North American Stratigraphic Code (American Association of Petroleum Geologists, 1983). Some of their stratigraphic nomenclature has not been used by previous or subsequent workers. Our stratigraphic nomenclature is that used by Keefer (1970) and on the geologic map of Wyoming (Love and Christiansen, 1985).

Since 1965 a much larger data base has been created by the oil and gas industry; almost 70% more data now exists. Figure 3 illustrates the amount of oil and gas drill hole data available for the coal basin in 1965 versus the amount of data generated post-1965 through 1988. This large data base was used to establish the detailed stratigraphy of this thick (more than 20,000 ft/6,000 m) sequence of sedimentary rocks. This understanding is important to future exploration and development of mineral resources such as coal, oil and gas, coalbed methane, and uranium within both the basin in front of the South Owl Creek Mountains thrust and the subthrust half of the Wind River Basin.

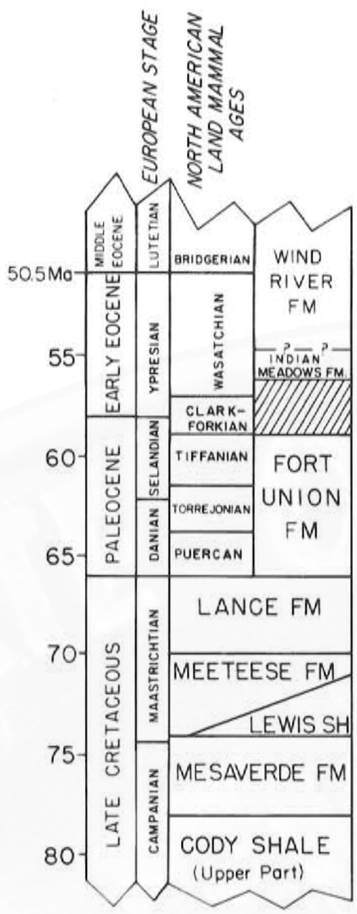


Figure 2. *Stratigraphic column of Late Cretaceous through early Eocene rocks in the Wind River Coal Basin, Wyoming.*

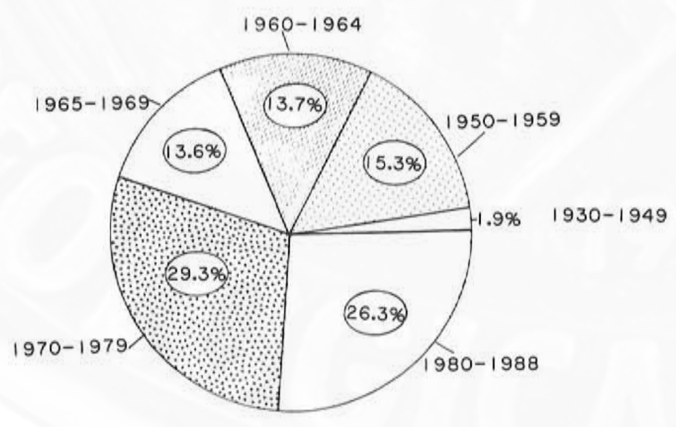


Figure 3. *History of exploratory drilling, Wind River Coal Basin, Wyoming.*

Methods

Formation boundaries and thicknesses were determined by correlating 325 geophysical well logs (see Figure 4, in pocket, for drill hole locations and Table 1, in pocket, for corresponding drill hole data). These correlations were refined using palynological age dates for 36 drill holes furnished by Chevron Oil Company and Amoco Production Company. Approximately 80 lithologic logs (with formation picks) were made available by the USGS for comparison with geophysical logs, and field reconnaissance was done along limited exposures around the basin margins. Published measured sections (Keefer, 1965, 1972; Keefer and Troyer, 1964; Rich, 1962; and Yenne and Pipiringos, 1954) were also incorporated into the correlations.

From this data base, eleven cross sections (Fig. 5, 6–16) were constructed across the basin to illustrate the correlations. An east-west cross section summarizes more than 125 mi (200+ km) of subsurface geology (Fig. 16, in pocket). Two structure contour maps (Figs. 4, 17), five isopachous maps (Figs. 18–22) and two coal isopachous/isopleth maps (Figs. 23, 24) were also generated. The coal isopachous and isopleth maps were constructed using coal beds measured at outcrops and as determined from the geophysical logs. Coal bed "picks" were determined from resistivity curves and then confirmed by comparison with gamma ray curves on geophysical well logs. Delineation of coals on the geophysical logs was possible for coals 2 feet (.6 m) and greater in thickness. Coal will appear in drill hole cuttings long after it has been drilled, indicating greater numbers of coal beds than are actually present in the subsurface. For this reason, coal beds shown on drill hole lithologic logs were not included in this study unless they could be confirmed by the geophysical logs.

STRATIGRAPHY

Cody Shale

The upper part of the Cody Shale interfingers with the lower portion of the coal-bearing Mesaverde Formation. This study includes detailed correlations where this interfingering occurs and does not include the lower part of the Cody Shale. The Cody Shale was deposited in a marine environment and the Mesaverde is the nonmarine Cody equivalent. In the west-central and southwestern portions of the basin, this interfingering relationship is the most complex. The edge of the Cretaceous seaway transgressed and regressed many times in the west-central portion of the basin, evidenced by the complex intertonguing of marine and nonmarine rocks. In this portion of the basin an additional 2,000 feet (610 m) of Mesaverde was deposited and is stratigraphically below the Mesaverde in the central and eastern portions of the basin. This unnamed lower sequence of Mesaverde Formation is here informally named the "Alkali Butte member." Contemporaneous with the deposition of the Alkali Butte member in the west was deposition of marine sands in the Cody Shale to the east. Keefer (1972) described the upper part of the Cody Shale as interbedded sandstone and shale. The thick marine sandstones in the Cody Shale of the eastern Wind River Basin can be correlated with coal-bearing, nonmarine Mesaverde rocks in the western and southwestern portion of the basin. In the southern end of the Bighorn Basin, marine sandstones assigned to the Mesaverde Formation can be correlated with the thick marine sandstones in the Cody Shale of the eastern Wind River Basin (Keefer, 1972). The Wallace Creek Tongue of the Mesaverde Formation is a major tongue within the Cody Shale. The Wallace Creek Tongue reaches a maximum thickness of 345 ft (105+ m) in the southeastern part of the basin.

Mesaverde Formation

The Mesaverde Formation is the oldest and stratigraphically

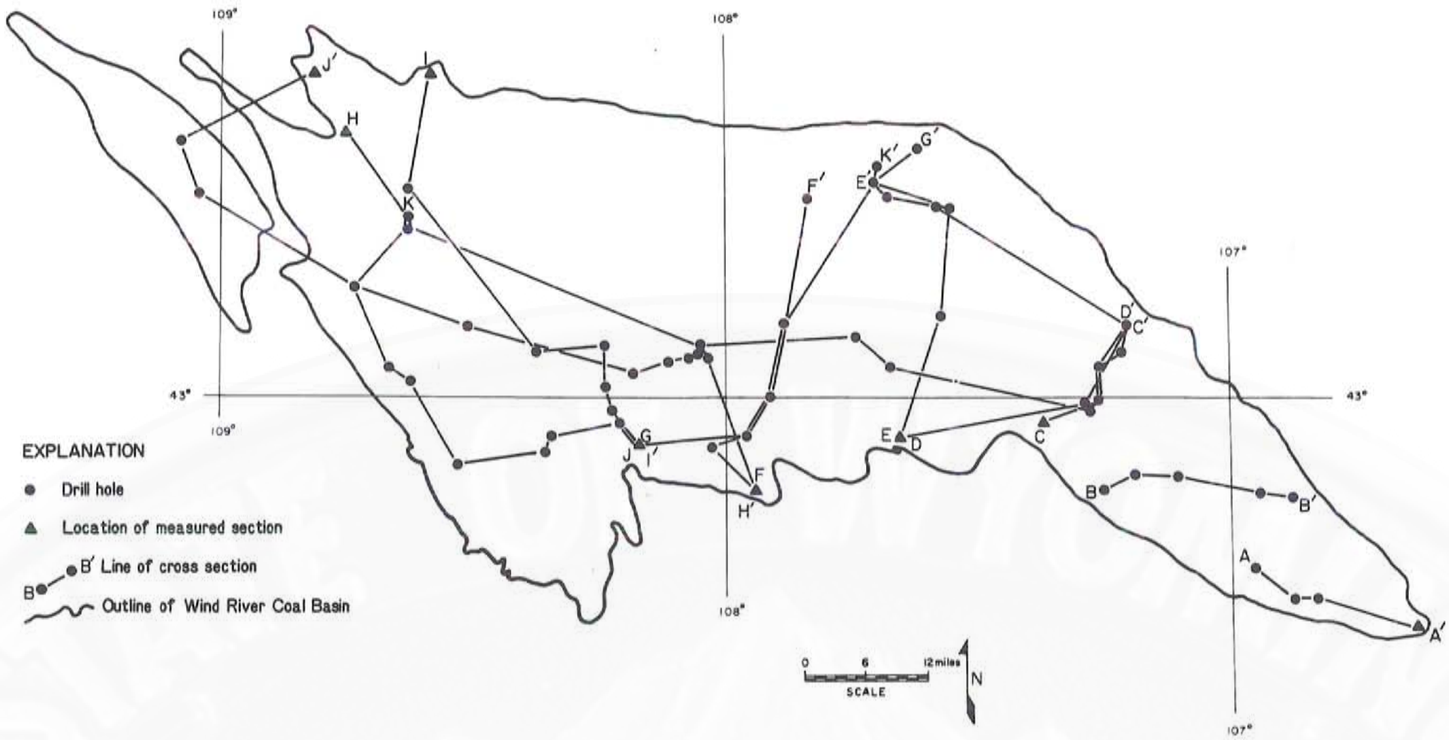


Figure 5. *Location map for cross sections in the Wind River Basin, Wyoming.*

lowest significant coal-bearing formation in the basin. The Mesaverde Formation is conformable throughout the basin with the underlying Cody Shale and can be correlated on the surface and throughout the subsurface of the basin. For a detailed definition, description, lithology, and depositional history of the Mesaverde Formation, the reader is referred to Keefer (1972). The present study uses new data to expand and refine previous subsurface investigations of the Mesaverde in the Wind River Basin.

Previous investigations of the Mesaverde in the Wind River Basin include Asquith (1970), Bartram (1937), Barwin (1959, 1961), Cobban and Reeside (1952), Keefer (1972), Krumbein and Nagel (1953), Lillegraven and McKenna (1986), Love (1948), and Shapurji (1978). The five members defined by Keefer (1972) in the eastern and southeastern parts of the basin are, from oldest to youngest, the Fales member, Wallace Creek Tongue, Parkman Sandstone, an unnamed middle member, and Teapot Sandstone. In the western part of the basin, these members cannot be distinguished and the Mesaverde has never been formally subdivided. Troyer and Keefer (1955) called the uppermost sandstone member in the northwestern part of the basin the white sandstone member and determined that it was stratigraphically equivalent to the Teapot Sandstone member.

All five members of the Mesaverde described by Keefer (1972) can be distinguished in the extreme southeastern part of the basin on subsurface geophysical well logs. However, the Parkman Sandstone member, a stratigraphic term originally defined in the western Powder River Basin by Darton (1907), can be recognized only in the extreme southeastern portion of the basin. Elsewhere in the Wind River Basin, sandstones previously known as Parkman are here included in the unnamed middle member of the Mesaverde Formation. For the most part, the Mesaverde in the eastern half of the basin consists of only four distinct members: the Teapot Sandstone, the unnamed middle member, the Wallace Creek Tongue and the Fales member.

The present structural configuration of the top of the Cody Shale, or base of the Mesaverde Formation (Fig. 4) illustrates the overall great asymmetry of the basin. The Mesaverde Formation crops out at an elevation of 6,000+ ft (1,830 m) above mean sea level along the southern and northwestern parts of the basin. Less than 30 miles (48+ km) to the northeast, the base of the Mesaverde reaches a maximum depth of 14,000 feet (4,270 m) below sea level, a difference of 20,000+ ft (6,100 m) in structural elevation. In the eastern, northeastern, and northern Wind River Basin, both the upper and lower portions (supra- and subthrust) of the thrust plate are contoured. In this area, the Mesaverde Formation and other coal-bearing rocks are overridden in the subthrust and overriding in the hanging wall of the thrust plate. In some cases, the Mesaverde Formation in the subthrust extends several miles beyond the surface exposures in the subthrust.

Comparison of the structure contour map, top of the Cody Shale (Fig. 4, in pocket), with the total thickness of the Mesaverde Formation (Fig. 18) illustrates that deposition of the Mesaverde was, in part, controlled by structural development of the basin. The thick unnamed tongue of Cody Shale in the western part of the basin was not included in the total Mesaverde isopach. The Mesaverde Formation is thickest near the structural lows such as along the present Wind River Basin structural trough and near Shotgun Butte syncline in the northwestern part of the basin where the Mesaverde Formation reaches a maximum thickness of 2,300+ ft (700+ m). Thinning of the Mesaverde in structurally high areas occurs around Alkali Butte, near the southwestern margin of the basin; localized thinning of the Mesaverde Formation can be seen over the subsurface Madden anticline structure in the northeast. Thickness variations of the Mesaverde Formation indicate that the Wind River Basin was developing as early as 78 million years ago.

Cross section A-A' (Fig. 6), in the extreme southeastern part of the basin, illustrates all five members of the Mesaverde Formation in both the subsurface and in the surface measured section at Casper Canal. The uppermost member, the Teapot Sandstone, is conformably overlain by the lower tongue of the marine Lewis Shale.

In cross section B-B' (Fig. 7) north of A-A', the Parkman Sandstone member cannot be distinguished in the subsurface. The Teapot Sandstone is overlain by a thinner, still conformable tongue of Lewis Shale.

In the central portion of the basin west of B-B', the Mesaverde Formation has a very different appearance on the geophysical logs. Cross section F-F' (Fig. 11) illustrates an upper and lower sequence of Mesaverde rocks. For convenience in separating the two sequences, the new informal name Alkali Butte member is used for the lower sequence of Mesaverde rocks. This name is taken from surface exposures at Alkali Butte near the southwest margin of the coal basin. In the southwestern part of the basin the upper Mesaverde Formation and the Alkali Butte member are separated by a major tongue of Cody Shale. The upper section is equivalent to the entire Mesaverde Formation to the east and southeast; the Alkali Butte member is equivalent to marine sandstones in the Cody Shale to the east. The tongue of Cody Shale that separates the upper Mesaverde from the lower Alkali Butte member reaches a maximum thickness of 700+ feet (215 m) in the southwest part of the basin (calculated from Table 1). Maximum thickness for the upper Mesaverde in the southwest part of the basin is 1,000+ ft (305 m). Maximum thickness for the Alkali Butte member is 2,000+ ft (610 m), also in the southwest part of the basin, but not directly underlying the maximum thickness of the upper member. In Figure 11, the Mesaverde Formation is conformably overlain in the subsurface by the Meeteetse Formation; however, at the surface near Conant Creek the Meeteetse is absent and the Mesaverde Formation is unconformably overlain by the Lance Formation.

Cross section H-H' (Fig. 13) shows that farther to the west the intertonguing relationship of the Mesaverde and Cody formations becomes less complex in both the subsurface and surface. At the Armstrong mine measured section the Cody Shale conformably underlies the Mesaverde Formation with no apparent interfingering of the two formations. The Mesaverde reaches a thickness of almost 2,000 ft (610 m) in Hickerson Oil Company Tribal 33x-10.

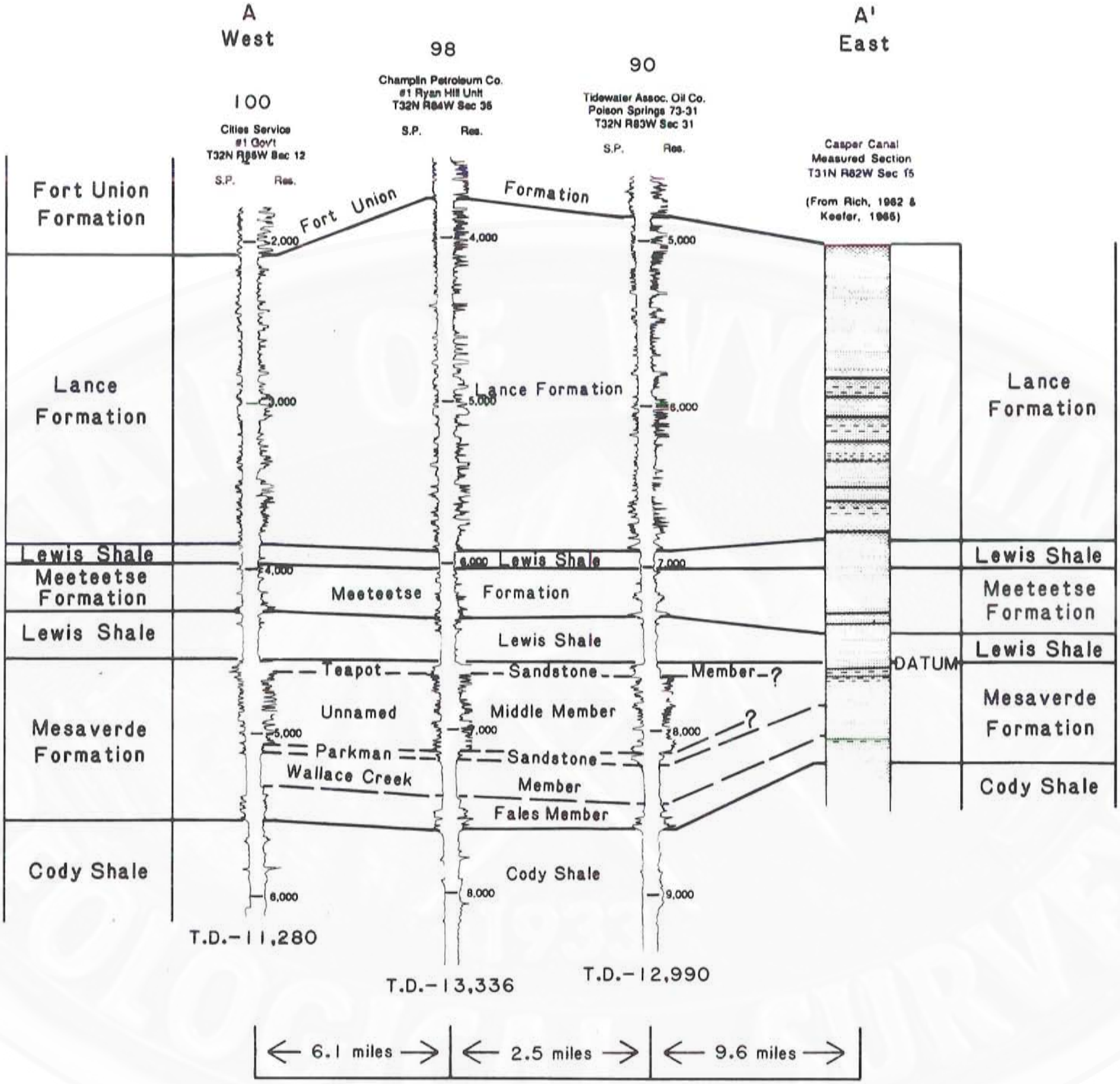
Cross section I-I' (Fig. 14) extends from Alkali Butte in the southeast to West Dry Creek in the northwest. This section includes, in part, the major unconformity between the Cretaceous Mesaverde Formation and the overlying Paleocene Fort Union Formation. Somewhere between Continental Oil Company Tribal 36-#3 and Trigg Drilling Company Trigg-Tribal #1-12, the Meeteetse Formation is preserved in the subsurface and underlies the unconformity which exists to the southeast. The upper part of the Mesaverde Formation is preserved (for the most part) across the line of section; the Alkali Butte member conformably overlies the Cody Shale.

Cross section J-J' (Fig. 15, in pocket) is the western-most of Mesaverde Formation cross sections. Along the western margin and also in parts of the southwestern Wind River Basin, the upper sequence of the Mesaverde Formation is absent and the Alkali Butte member is unconformably overlain by the Paleocene Fort Union Formation. This major unconformity can be correlated for several miles/kilometers in the subsurface. Drill holes which cross this unconformity are given in Table 1 (in pocket). Surface exposures demonstrate that the Cody Shale tongue and Alkali Butte member are at least partially preserved at Alkali Butte. Across the basin to the northwest a conformable section of rocks is preserved at Welton Mine/Shotgun Butte. The Shotgun Butte syncline probably served as a major trough for sediment accumulation and subsequent preservation. Although the geophysical logs indicate that much of the sedimentary sequence is absent in the western Wind River Basin, a sliver of the upper part of the Mesaverde Formation or a thin section of Meeteetse and/or Lance formations could be present below the unconformity in places where subsurface data are not clearly defined. It is impossible at this time to map in the subsurface, except in a general way, the rocks preserved immediately adjacent to the unconformity. However, based on geophysical log signatures, limited palynology data, outcrops at the extreme western edge of the coal basin, and overall thicknesses of rocks above the Cody Shale, we interpret that in the western part of the Wind River Basin, the Paleocene Fort Union Formation unconformably overlies the Alkali Butte member of the Mesaverde Formation.

Coal beds occur in the Mesaverde Formation throughout the Wind River Basin (Fig. 23) but are thickest and most numerous in the Alkali Butte member in the southwestern part of the basin and in the lower part of the Mesaverde in the northwestern part of the basin. Subbituminous coal was once mined commercially from the Mesaverde Formation in several areas as reported by Glass and Roberts (1978), Thompson and White (1952), and Windolph et al (1986). As many as 15 separate coal beds with cumulative coal thickness of 83 ft (25.3 m) were observed in drill holes at Beaver Creek south of Riverton. Peats that formed these coals were deposited in coastal swamps in and adjacent to deltas prograding eastward into the Cody seaway.

Lewis Shale, Meeteetse, and Lance Formations

The Lewis Shale and Meeteetse Formation are defined and described by Keefer (1965). The contact between the Meeteetse Formation and overlying Lance Formation is difficult to pick on the geophysical logs, particularly in areas where the Lewis Shale is absent and thick sandstones in the Meeteetse are overlain by thick sandstones in the Lance. For this reason, the Lewis and Meeteetse are combined with the Lance Formation for the isopachous map (Fig, 19). The combined thickness of the Lewis, Meeteetse and Lance formations ranges from 0 to 8,000+ ft (0 to



EXPLANATION

S.P. – Spontaneous Potential curve

Res. – Resistivity curve

——— Formation Contact

— — Member Contact (Queried where correlation uncertain)

Number in column is depth below surface in thousands of feet

Number at top of log heading is Reference Number in Table 1

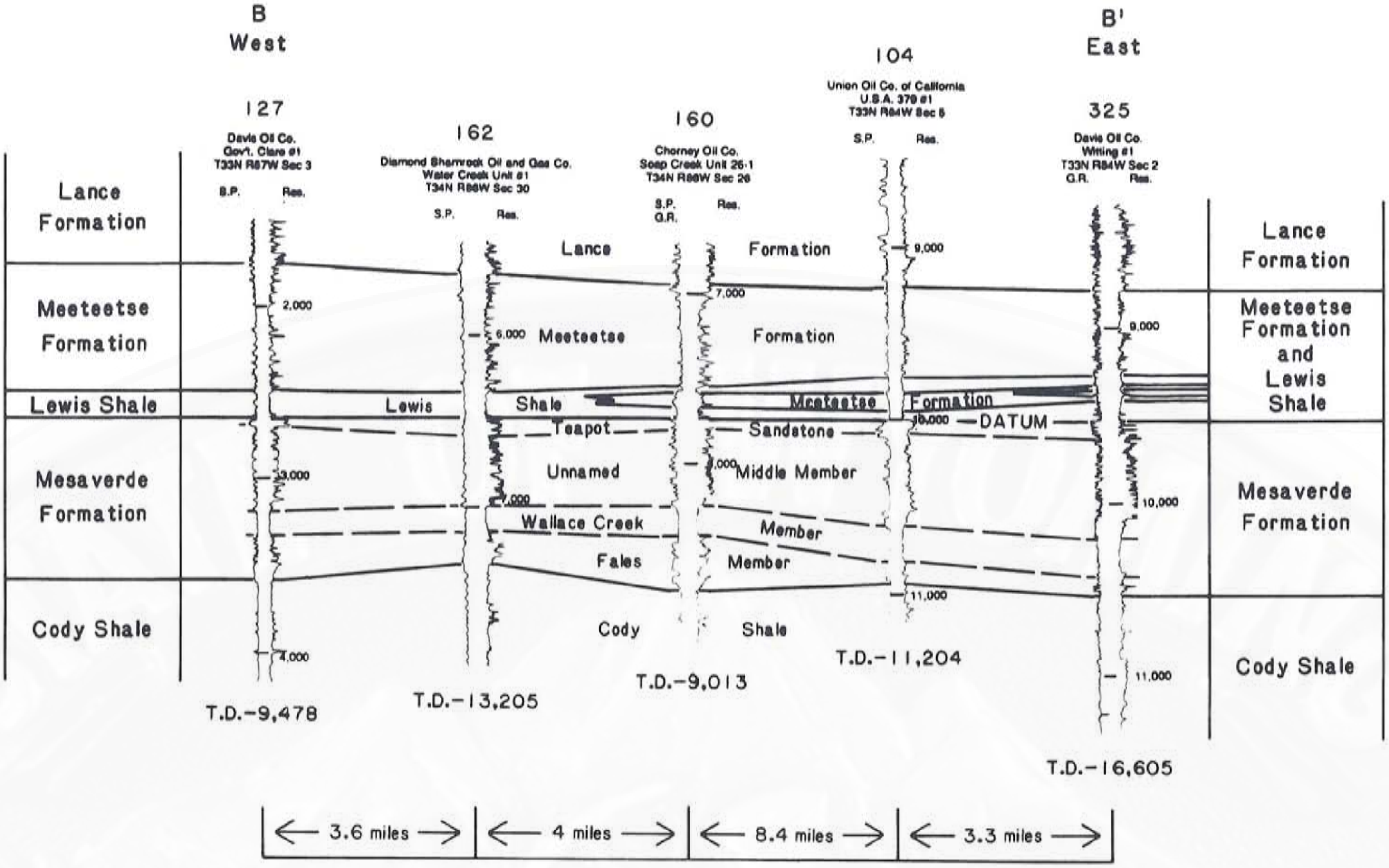
note: subsurface sections not corrected for dip

Vertical scale

800 feet

1"=800'

Figure 6. *Cross section A-A' showing correlations of Upper Cretaceous rocks, Wind River Basin, Wyoming.*



EXPLANATION

S.P. – Spontaneous Potential curve

Res. – Resistivity curve

G.R. – Gamma Ray curve

——— Formation Contact

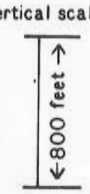
— — Member Contact

Number in column is depth below surface in thousands of feet

Number at top of log heading is Reference Number in Table 1

note: subsurface sections are not corrected for dip

Vertical scale



1″=800′

Figure 7. *Cross section B-B' showing subsurface correlations of Upper Cretaceous rocks, Wind River Basin, Wyoming.*

2,440 m). In the southeastern part of the basin the Lewis Shale reaches a maximum total thickness of 700+ ft (215 m). The Meeteetse Formation reaches a maximum thickness of 1,900+ ft (580 m) in the northeastern part of the basin. Where the Lance can be distinguished from the underlying Meeteetse Formation, it reaches a maximum thickness of 5,100+ ft (1,555 m) in the northeastern part of the basin. Keefer (1965) showed the westward limit of the upper and lower tongues of the Lewis Shale in the subsurface; findings of this study concur with these limits, as is shown in Figure 16. Where the Lewis Shale is absent in the central and western parts of the basin, the isopachous map shows the combined thickness of the nonmarine Meeteetse and Lance formations.

West of the subsurface zero (0) isopachous line along the western portion of the basin (Fig. 19), the Meeteetse and Lance formations were either never deposited or deposited and subsequently eroded. It is our opinion that the latter of the two explanations is correct. Because these formations are so thick in the eastern, northeastern, and northwestern Wind River Basin, it is unlikely that deposition of these sediments did not occur to the west and southwest. The presence of a thick sequence of Mesaverde, Meeteetse and Lance formations at Shotgun Butte in the northwestern part of the basin indicates that sediments were preserved at least as close as the Shotgun Butte syncline. The sedimentary package that was deposited in the western part of the

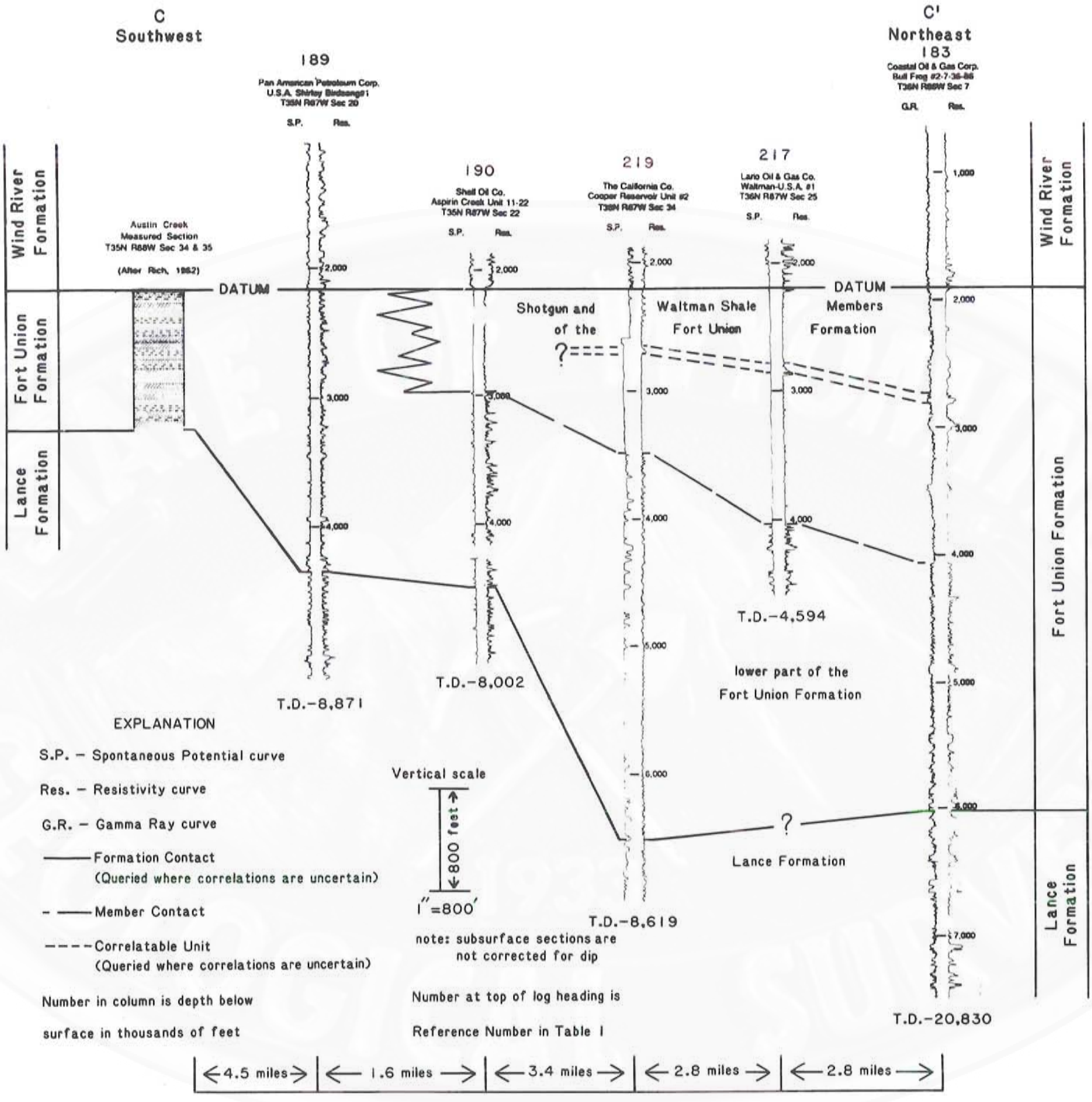


Figure 8. *Cross section C-C' showing correlations of uppermost Cretaceous through lower Eocene rocks, Wind River Basin, Wyoming.*

basin was eroded down to the Alkali Butte member of the Mesaverde Formation at a later time. Surface and subsurface data (Figs. 14 and 15, 16, in pocket) demonstrate that the Paleocene Fort Union Formation unconformably overlies the lower portion of the Cretaceous Mesaverde Formation in the southwestern and westernmost parts of the basin.

Cross section A-A' (Fig. 6) in the extreme southeastern part of the basin shows that two major tongues of Lewis Shale at the Casper Canal measured section can be correlated into the subsurface. Between the two Lewis Shale tongues is a section of Meeteetse Formation approximately 300 ft (90 m) thick. The upper tongue of Lewis Shale is conformably overlain by about 2,000 ft (610 m) of Lance Formation.

Cross section B-B' (Fig. 7) illustrates that two thinner tongues of Lewis Shale merge into one section of Lewis Shale to the west. The Meeteetse Formation has increased in overall

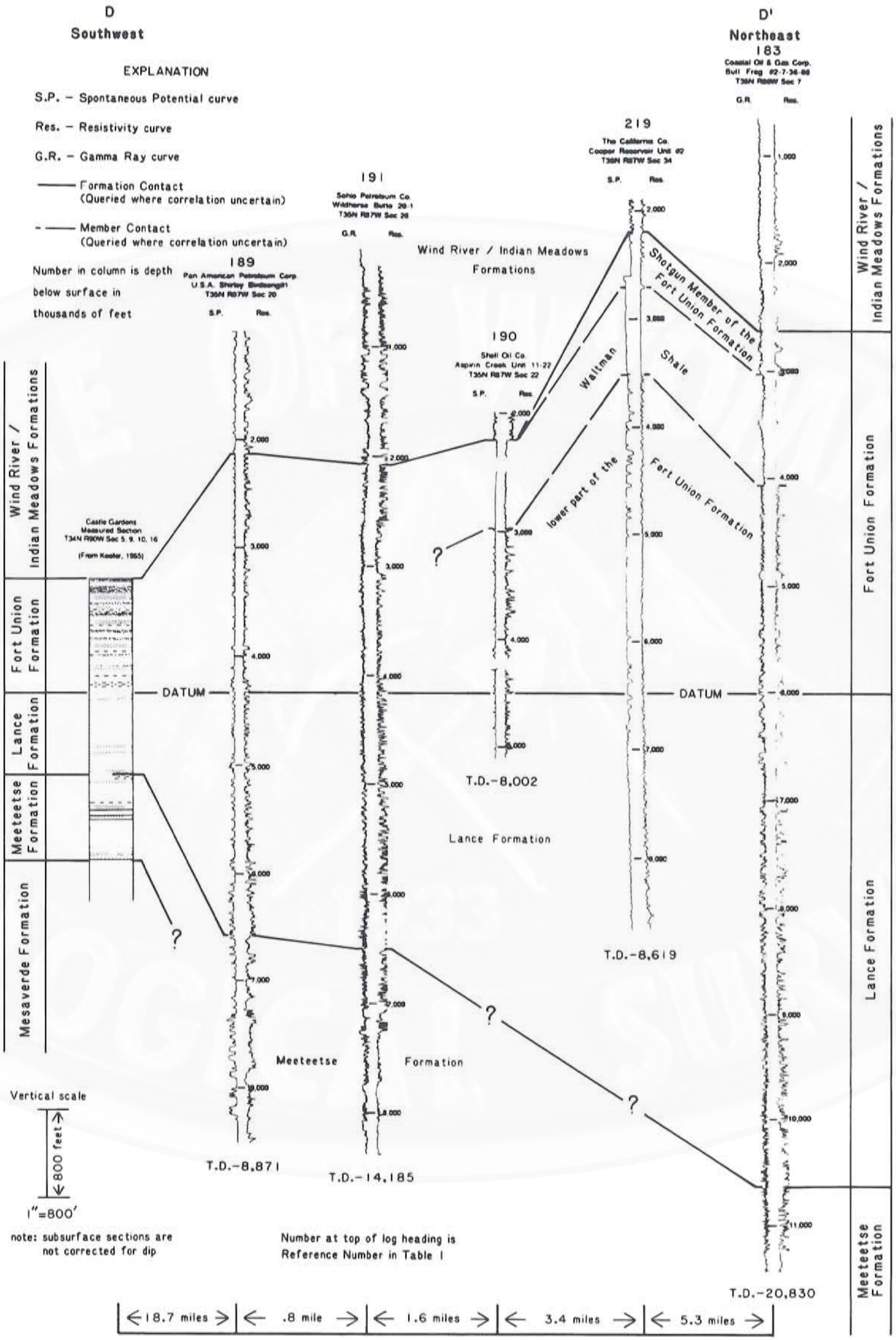


Figure 9. *Cross section D-D' showing correlations of Upper Cretaceous through lower Eocene rocks, Wind River Basin, Wyoming.*

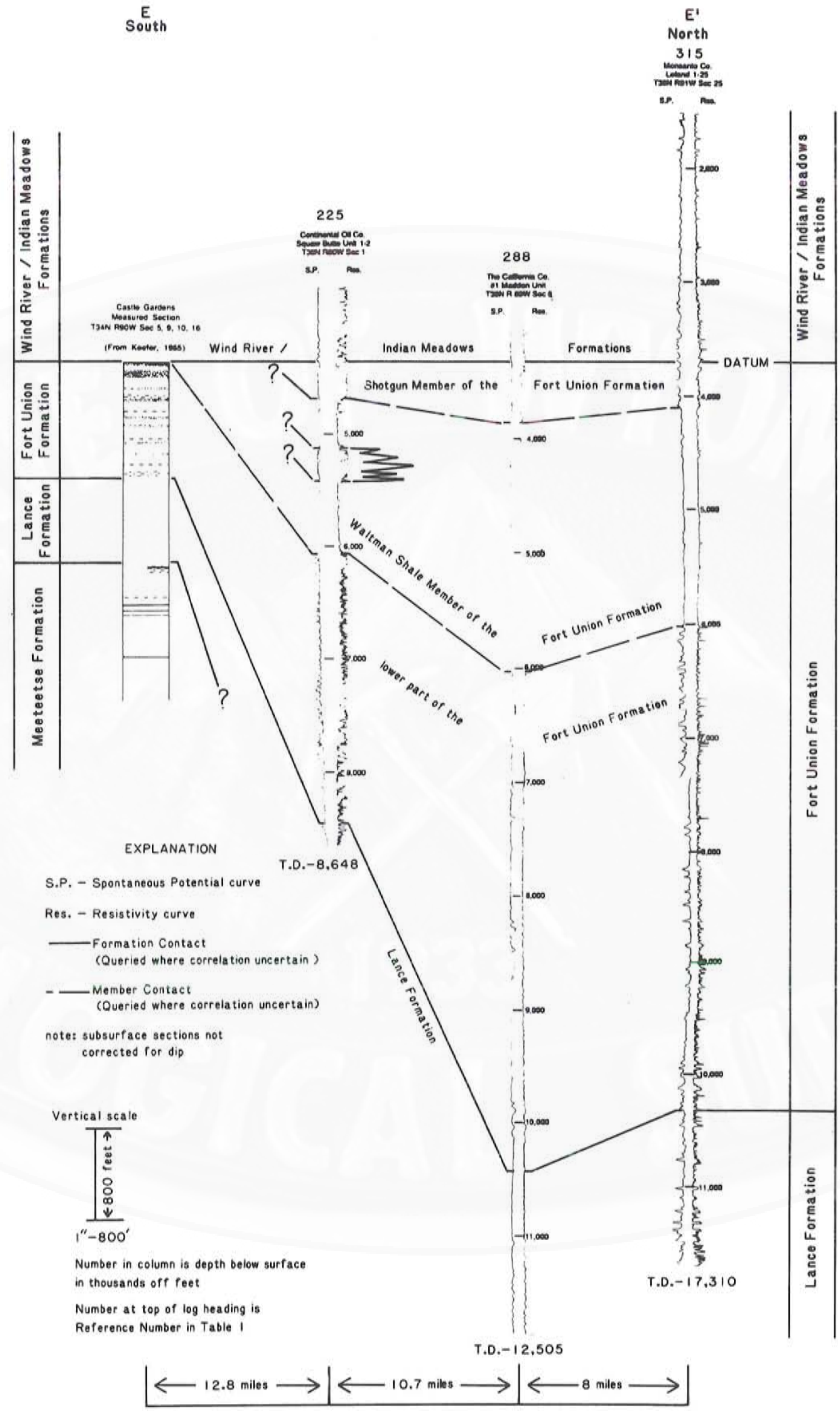
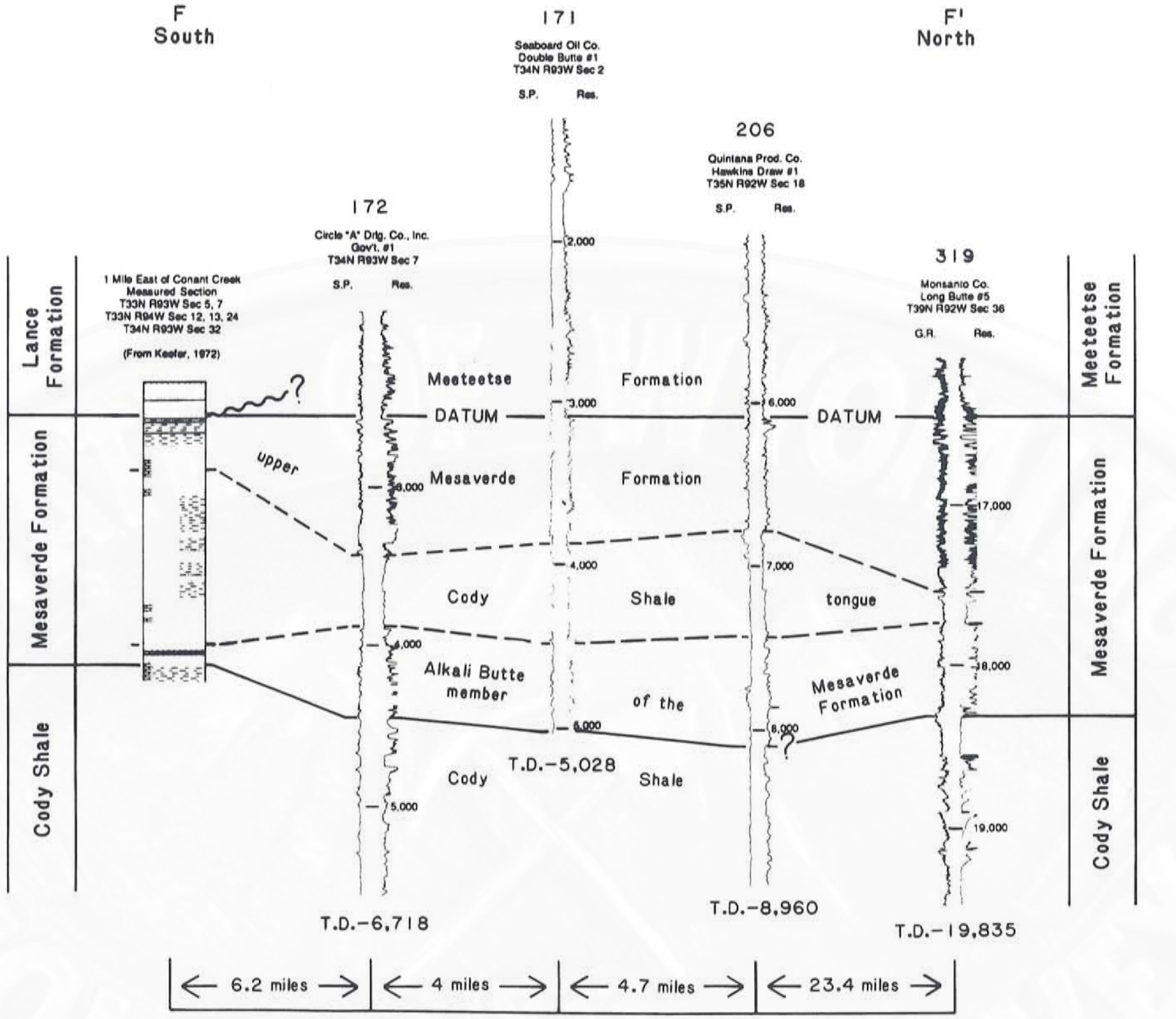


Figure 10. *Cross section E-E' showing correlations of Upper Cretaceous through lower Eocene rocks, Wind River Basin, Wyoming.*



EXPLANATION

S.P. – Spontaneous Potential curve

Res. – Resistivity curve

G.R. – Gamma Ray curve

——— Formation Contact (Queried where correlations are uncertain)

– – – Correlatable Unit

~~~ Unconformable Contact (Queried where correlations are uncertain)

Number in column is depth below surface in thousands of feet

Number at top of log heading is Reference Number in Table I

Vertical scale

800 feet

1″=800′

note: subsurface sections are not corrected for dip

Figure 11. *Cross section F-F' showing correlations of Upper Cretaceous rocks, Wind River Basin, Wyoming.*
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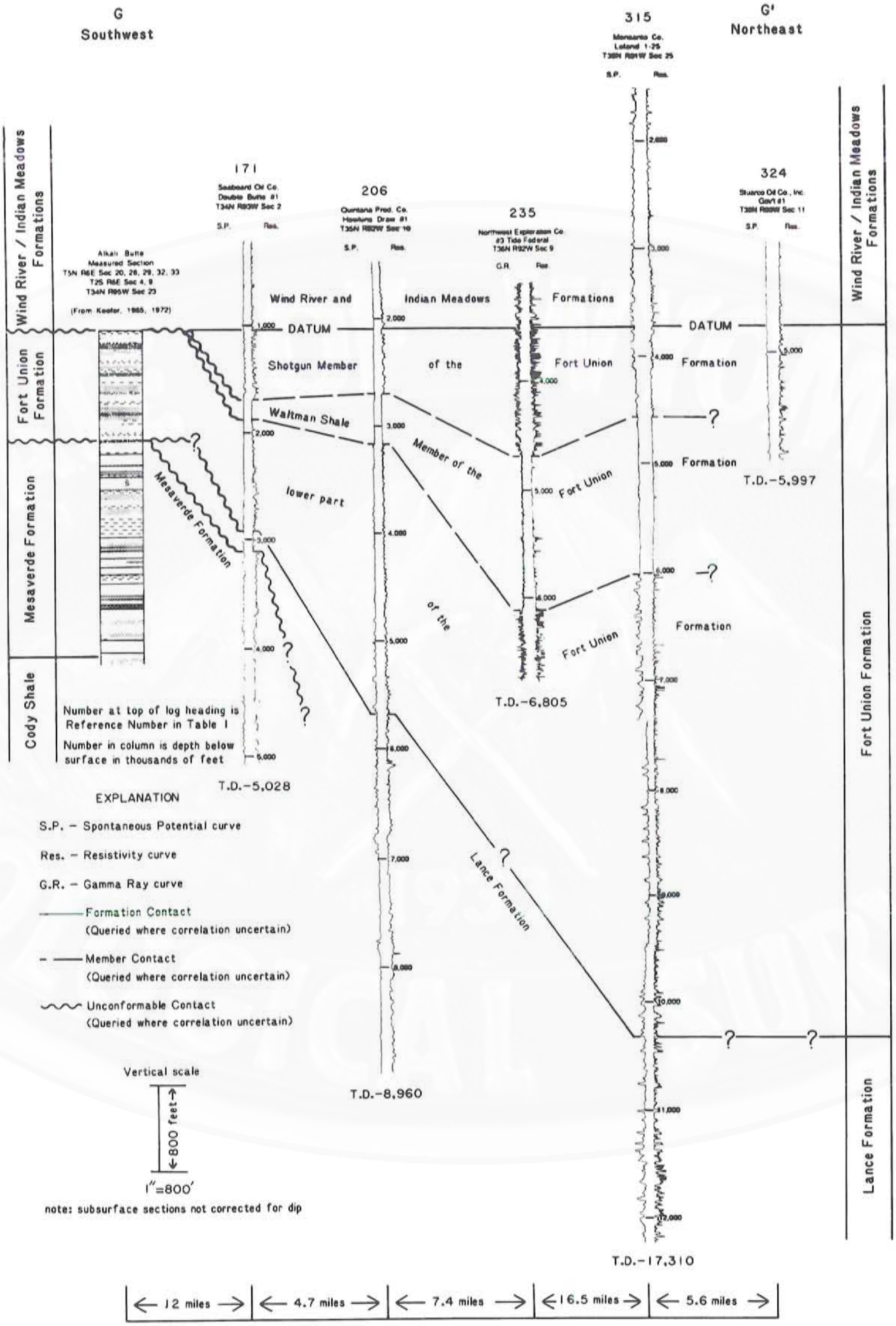

Figure 12. *Cross section G-G' showing correlations of Upper Cretaceous through lower Eocene rocks, Wind River Basin, Wyoming.*

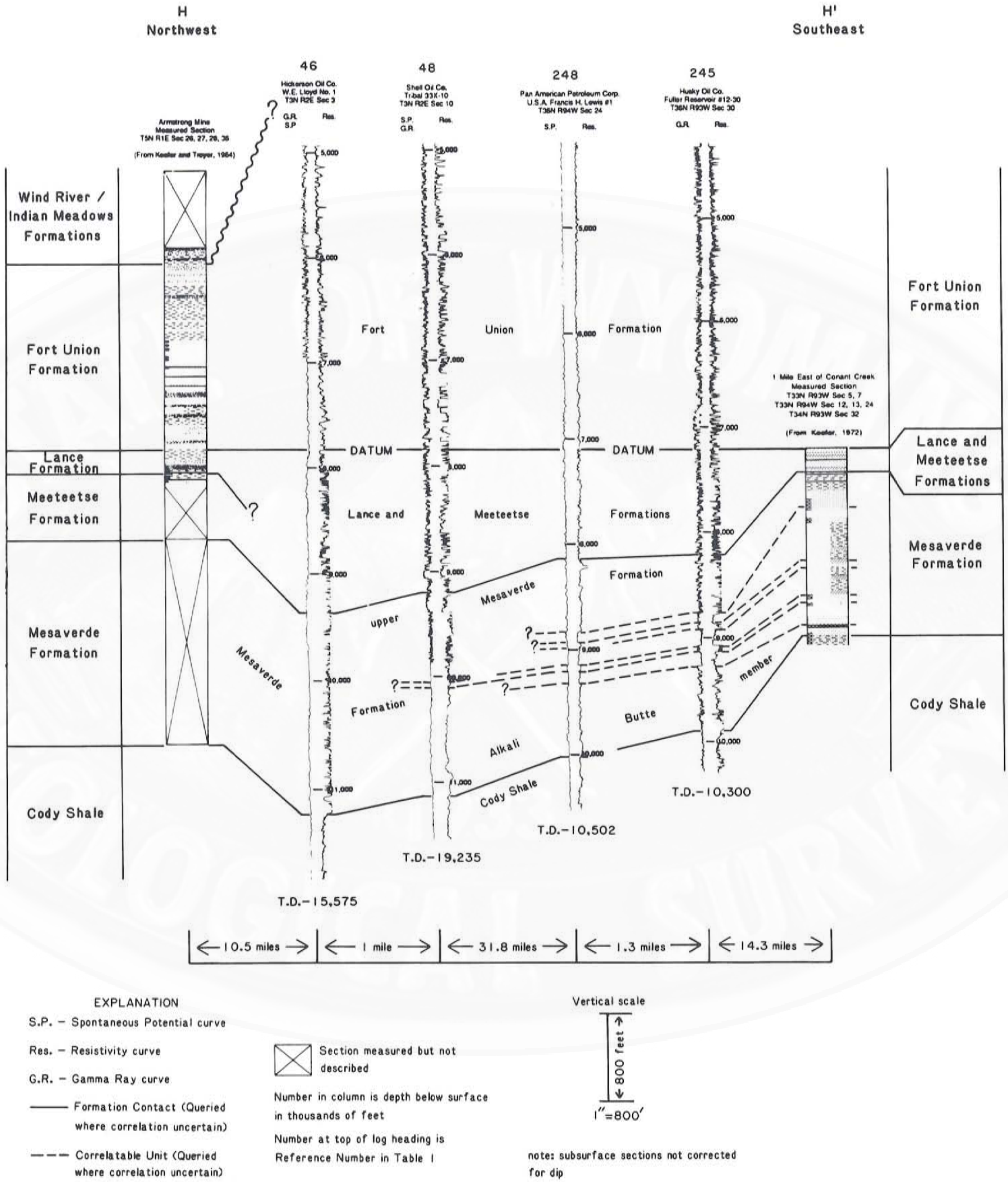

Figure 13. *Cross section H-H' showing correlations of Upper Cretaceous through Paleocene rocks, Wind River Basin, Wyoming.*

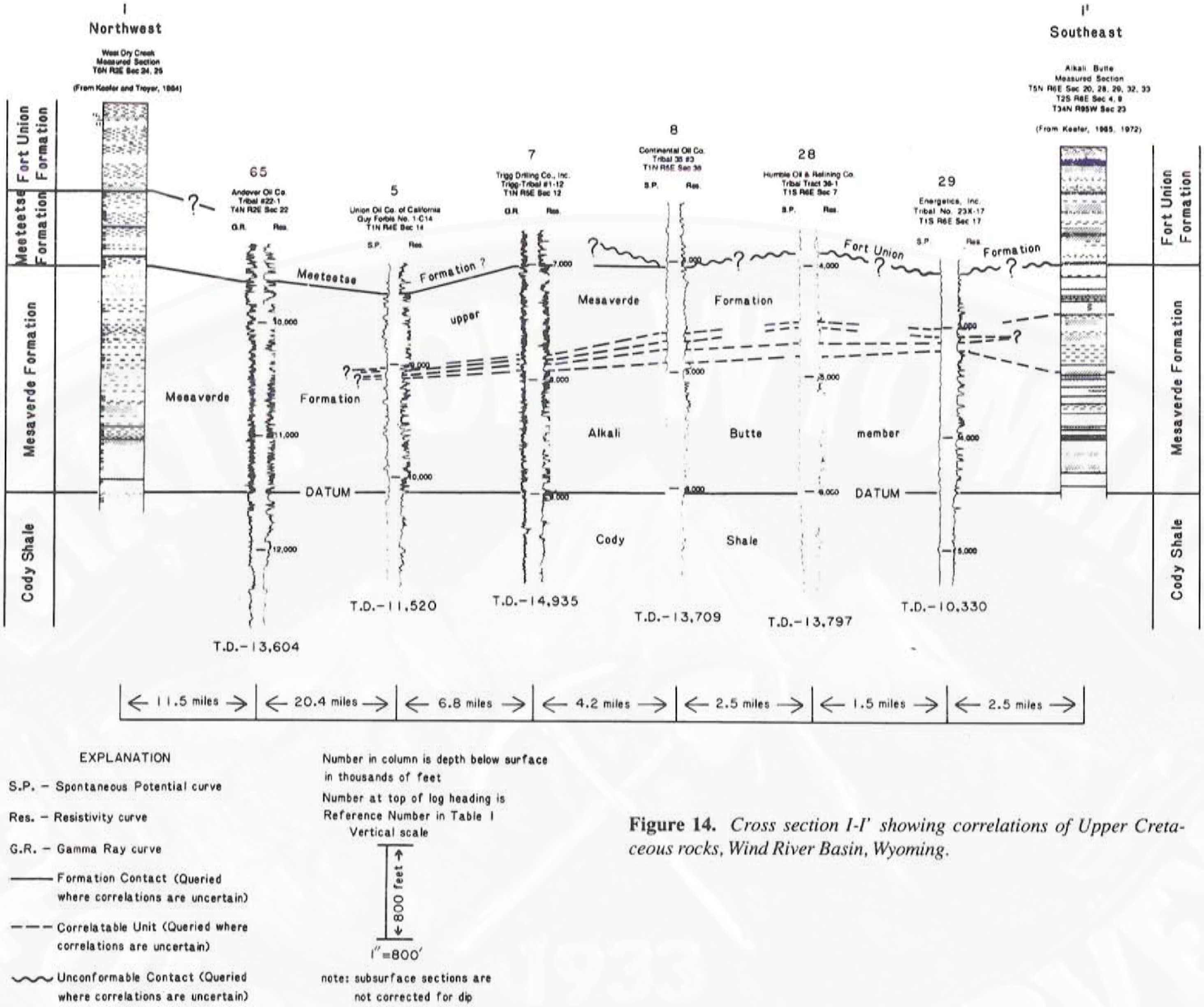

Figure 14. *Cross section I-I' showing correlations of Upper Cretaceous rocks, Wind River Basin, Wyoming.*

thickness and is conformably overlain by the Lance Formation.

Cross section D-D' (Fig. 9) illustrates significant thickening of the Lance Formation from Castle Gardens toward the structural axis of the basin near Coastal Oil Company Bullfrog #2-7-36-86. The Lewis Shale is absent and in the subsurface the Lance Formation is in conformable contact with the underlying Meeteetse Formation and overlying Fort Union Formation.

Cross section H-H' (Fig. 13) shows correlations for the combined Meeteetse and Lance formations across the west-central part of the basin. Much of the stratigraphic section is absent at both the Armstrong Mine and Conant Creek measured sections. However, this stratigraphic sequence appears to be conformable in the subsurface. Here, the Meeteetse and Lance formations have a combined total thickness of nearly 1,500 ft (460 m). Coals in the Meeteetse and Lance formations occur throughout the Wind River Basin (Fig. 24) but only a few areas contain thick, numerous coal beds. Because of the poor resolution for detecting coal beds in the subsurface on many oil and gas geophysical logs, the number of coal beds "picked" is probably underestimated. Also, there is a lack of data in some areas of the basin. A maximum sixteen coal beds were identified in the Meeteetse-Lance interval, primarily in the Meeteetse Formation in the northwestern part of the basin. Here, a single coal bed reaches 16 ft (4.9 m) in thickness (Glass and Roberts, 1978). As many as 13 coal beds, primarily in the Lance Formation, occur in the extreme southeastern part of the basin. The greatest cumulative thickness of coals in the combined Lance and Meeteetse formations is 53 ft (16.2 m).

Fort Union Formation

The Fort Union Formation in the Wind River Basin represents deposition during the Paleocene epoch. Previous published studies of the Fort Union Formation include Courdin and Hubert

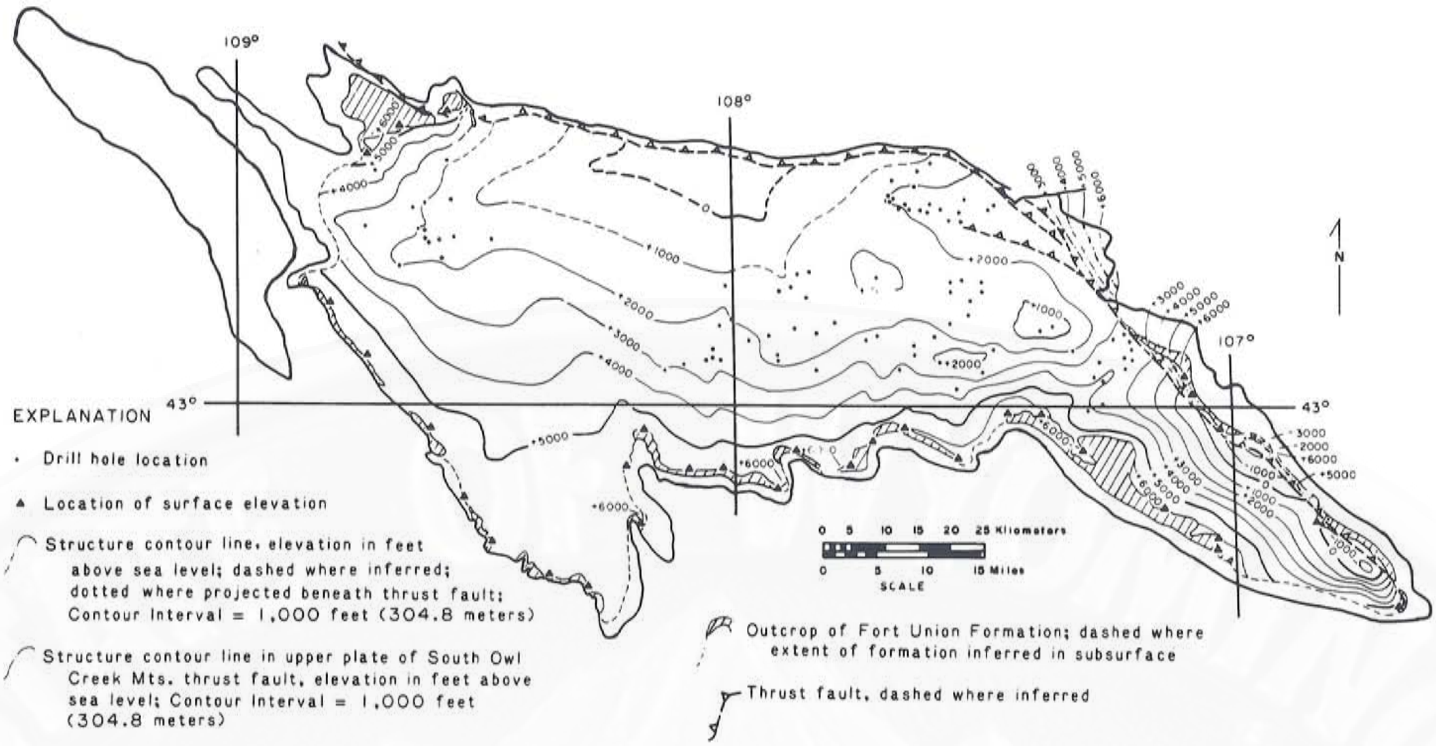

Figure 17. *Structure contour map on top of the Fort Union Formation, Wind River Basin, Wyoming.*

(1969), Emry (1975), Keefer (1965), Phillips (1983), Tourtelot (1946), and Van Houten (1957). Present day structural configuration shows the top of the Fort Union Formation (Fig. 17) ranges in elevation from 6,000+ ft (1,830 m) above mean sea level to 0 ft (0 m) at mean sea level. Figure 17 also illustrates the overall great asymmetry of the basin toward the northeast. The Fort Union Formation occurs in both the upper and lower plates (supra-and subthrust) of the South Owl Creek Mountains thrust fault along the northeastern and eastern margins of the present basin. A sliver of Fort Union occurs in the upper plate of the thrust and is steeply dipping or overturned in this area. Total thickness for the Fort Union Formation (Fig. 20) ranges from 0 to 7,000+ ft (0 to 2,140+ m). The Fort Union is thickest in the northeastern part of the basin and corresponds with the structural low that is found there. In much of the eastern half of the basin, the Fort Union Formation consists of three distinct members: the lower part of the Fort Union, the Waltman Shale member, and the Shotgun member. When the Waltman Shale member, a very distinct unit on geophysical logs, is present, subsurface correlations are more easily determined. Another aid in subsurface correlation of the Fort Union Formation is the frequent occurrence of multiple coal beds throughout the lower part. Although the upper part of the Lance Formation may contain some coal beds, in contrast, the lower part of the Fort Union Formation of Paleocene age (as confirmed by palynological data) has a section where multiple coal beds are present and show characteristic "kicks" on the resistivity and gamma ray logs. Data adjacent to sites where multiple coal beds occur are widely scattered and not quantitative enough to generate maps for basin-wide coal occurrences.

Cross sections (Figs. 8, 9, 10, and 12) depict a thick sequence of the Waltman Shale member that can be correlated throughout much of the eastern Wind River Basin. The Waltman is a sequence of as much as 2,800 ft (850+ m) of mostly organic-rich shales, as shown on the isopachous map (Fig. 21). This map illustrates (in greater detail than previous publications) the areal extent and configuration of sediments deposited in Waltman Lake. Although no conclusive evidence has yet been presented as to whether Waltman Lake was marine or nonmarine in nature, the areal extent and lithology of this member indicate that the lake was an extensive body of water in the basin during the Paleocene (Keefer, 1961, 1965; Newman, 1965; Nichols and Ott, 1978; and Phillips, 1982, 1983).

In the western half of the basin, no distinct members of the Fort Union Formation have been recognized. Cross sections H-H', I-I', and J-J' (Fig. 13, 14, and 15, in pocket) however, show that in the western area, several individual stratigraphic units near the base of the Fort Union can be correlated in the subsurface.

Indian Meadows and Wind River Formations

Fossil-rich and well exposed, lower Eocene rocks in the Wind River Basin have been investigated by many scientists, including Keefer (1965, 1970), Love (1939), Seeland (1978), Soister (1968), Stucky et al (1987), and Winterfeld and Conard (1983). The Indian Meadows Formation is stratigraphically below the Wind River Formation and is composed of red to variegated claystone, sandstone, algal-ball(?) limestone and some beds of large Paleozoic boulders and detachment masses of Paleozoic and Mesozoic rocks (Love and Christiansen, 1985). The Wind River Formation is composed of variegated claystone and sandstone and lenticular conglomerate (Love and Christiansen, 1985).

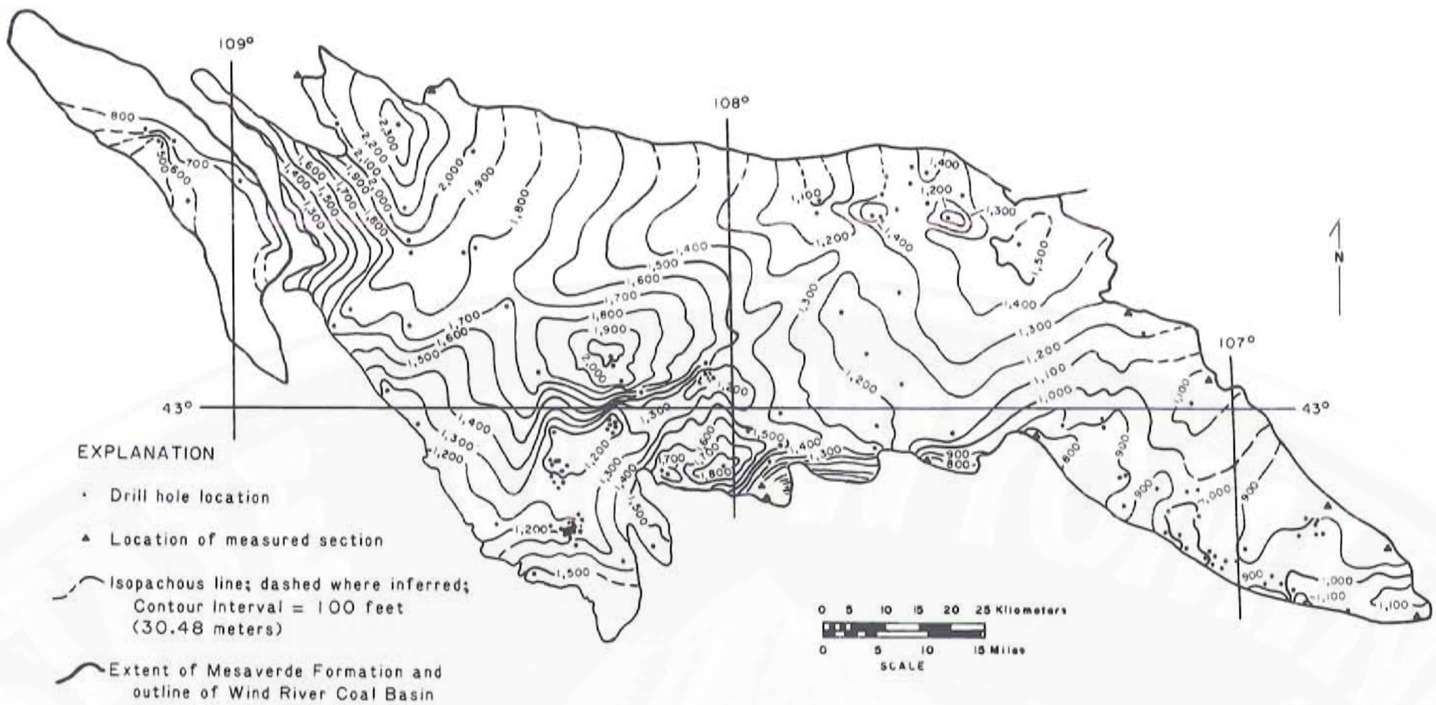

Figure 18. *Isopachous map of the Mesaverde Formation, Wind River Basin, Wyoming.*

The Early Eocene Indian Meadows is Wasatchian in age while the Wind River Formation is middle Early to early Middle Eocene, Wasatchian, and Bridgerian in age. A major angular unconformity between the Indian Meadows and Wind River formations is exposed at the surface around the margins of the basin. The Indian Meadows is overridden by the South Owl Creek Mountains thrust, whereas the Wind River Formation is not. However, away from the basin margins in the subsurface, the two formations are indistinguishable (Love, 1939, 1970). Keefer (1965) stated correctly that the extent of the Indian Meadows in the subsurface is unknown and "it seems likely that strata equivalent to the Indian Meadows are an indistinguishable part of a continuous depositional sequence of lower Eocene rocks...." For this reason, the Indian Meadows and Wind River formations were combined on the isopachous map and in the cross sections.

Post-Wind River strata are still preserved only along the north and south margins of the Wind River Basin. In the remainder of the basin, the top of the formation is the present topographic land surface. Therefore, the isopach thickness is a minimum throughout the basin. The total isopachous map of the Indian Meadows/Wind River formations (Fig. 22) shows combined thickness from between 0 to 5,500+ ft (0 -1,680 m). Total thickness of this unit is greatest in the northern and northeastern parts of the basin, illustrating that the basin continued to downdrop and develop through early Middle Eocene time.

Coal beds, lignite beds, and carbonaceous shale units occur in the Wind River Formation, particularly along the northern margin of the basin. These coal beds and other rock units have been mapped by Thaden (1978, 1979, 1980a-e, 1981). Individual coal beds are for the most part lenticular. One mapped coal bed in the northeastern Wind River Basin was approximately 20 ft (6.4 m) thick. The coals are evidently limited in extent in that they cannot be seen or correlated in the subsurface for any appreciable distance. However, a carbonaceous shale unit, approximately 5 ft (1.5 m) thick can be followed on the surface from Moneta to near Bonneville, a distance of almost 20 miles (32+ km) (Stucky, 1990, personal communication).

Summary Cross Section

Stratigraphic cross section K-K' (Fig. 16, in pocket) summarizes correlations for Upper Cretaceous through lower Eocene rocks in an east-west direction across 125+ mi (200+ km) of the Wind River Basin. In the northeastern portion of the basin near K' (in several Madden deep wells), the Mesaverde, Meeteetse, Lance, Fort Union and Wind River formations are 18,000 ft (5,486 m) thick. The lithologies of the Mesaverde, Meeteetse, and Lance formations are predominantly sandstones and siltstones, with thicknesses of 1,500 ft (455+ m), 1,900+ ft (580 m), and 5,100 ft (1,555 m), respectively. The only significant shale unit in this thick section is the Waltman Shale member of the Paleocene Fort Union Formation. The Waltman reaches a maximum thickness of 2,800 ft (850+ m) in the northeastern part of the basin. South of T35N, the Waltman Shale is absent. The lower Eocene Wind River Formation occurs at the surface everywhere along K-K'. The combined Wind River and Indian Meadows formations average between 2,500 ft (762 m) and 3,500 ft (1,067 m) thick on section K-K' and reach a maximum combined thickness of 5,500+ ft (1,676 m) in the eastern part of the basin (see Fig. 22). South of the Madden deep wells, in Coastal Oil Bullfrog 2-7-36-86, the entire Upper Cretaceous and lower Tertiary section remains very thick near the structurally low part of the basin adjacent to the South Owl Creek Mountains thrust.

In the east-central part of the basin, four distinct members of the Mesaverde Formation can be delineated on the geophysical

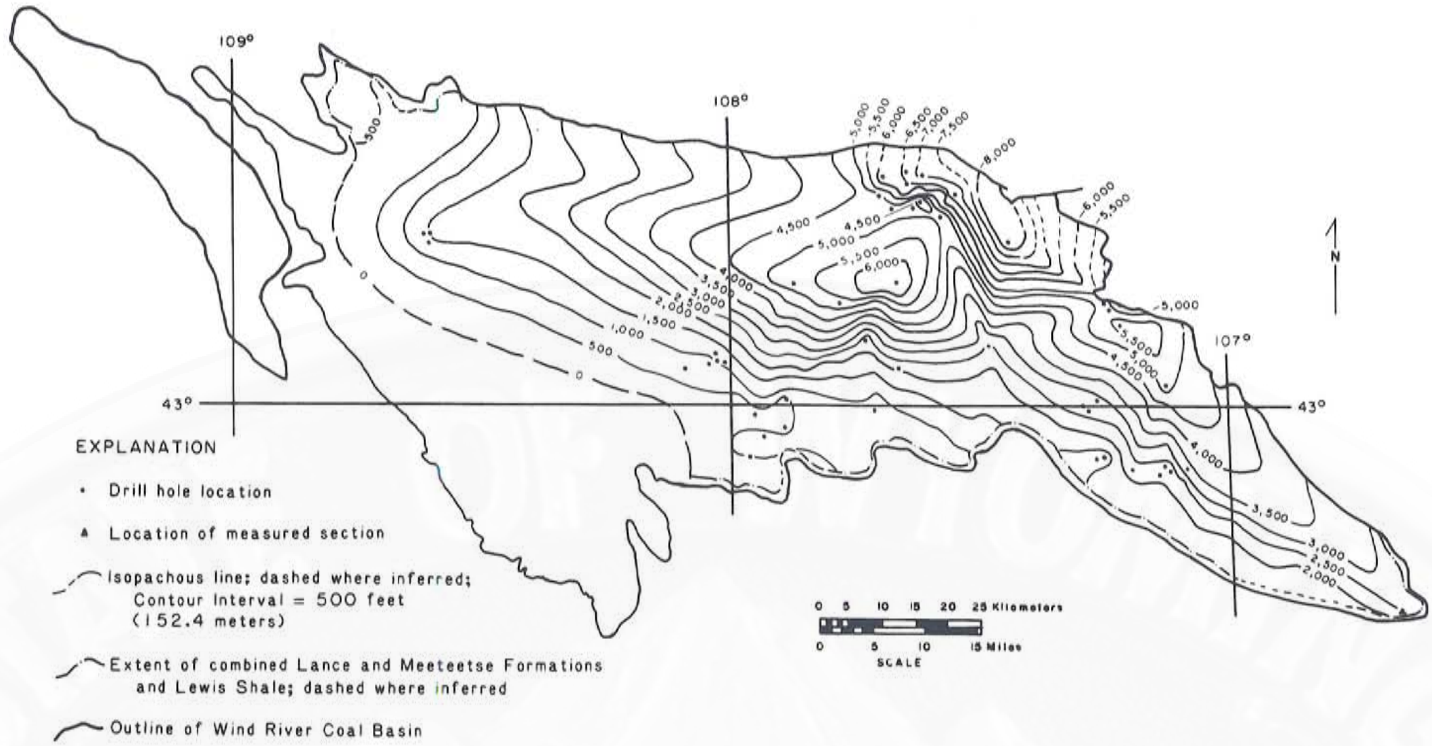

Figure 19. *Isopachous map of combined Lewis Shale, Lance and Meeteetse formations, Wind River Basin, Wyoming.*

logs. These are the Fales member, an unnamed middle member, the Wallace Creek Tongue, and the Teapot Sandstone. The Wallace Creek Tongue is a major tongue of the Cody Shale and reaches a maximum thickness of 345+ ft (105+ m) in the southeastern part of the basin. The Lewis Shale, a marine equivalent of the Meeteetse Formation, is also recognized on geophysical logs in the southeastern quadrant of the basin. Often described as having two distinct shale tongues, the Lewis obtains a maximum thickness of 700+ feet (215 m).

In the central portion of cross section K-K', the overall stratigraphic picture changes. Between Inexco Oil Federal Hanagan #1-15 and Pan American Petroleum Fuller Reservoir Unit #22-25, the upper section of marine Cody Shale correlates westward with the coal-bearing, nonmarine Mesaverde Formation. This lower coal-bearing member of the Mesaverde Formation, the Alkali Butte member, lies stratigraphically below the entire section of Mesaverde Formation to the east, southeast, and northeast. Between the Alkali Butte member and the upper section of the Mesaverde Formation is a tongue of Cody Shale as much as 700+ ft (215 m) thick. Overlying the Mesaverde Formation, the Meeteetse Formation has thinned to zero (0) and the Lance Formation is about 1,000 ft (305 m) thick.

West and southwest of the central part of the basin between W.C. McBride No. 1 Government-Croft Ranch and Shell Oil Company Tribal 33X-10, the Meeteetse and Lance formations are absent. Here, a major unconformity separates the Mesaverde Formation from the overlying Fort Union Formation. This unconformity can be traced for many miles in the subsurface. Most of the Mesaverde is present below the unconformity, but is locally eroded down to the Alkali Butte member. The intertonguing Cody Shale is present in the McBride well but absent to the west in Impel Energy Corporation Tribal #9-34. The absence of the intertonguing Cody Shale in the southwestern part of the basin is due to local erosion; in the west-central and northwestern Wind River Basin, the tongue is absent due to nondeposition of the marine shale and the contemporaneous deposition of nonmarine rocks in the Mesaverde Formation.

At K in the northwestern part of the basin, the entire Upper Cretaceous through lower Eocene rock sequence is again represented.

SUMMARY OF DEPOSITIONAL AND TECTONIC EVENTS

The depositional and tectonic activity that occurred in the Wind River Basin from Late Cretaceous through early Eocene is summarized below by a continuum of inter-related events. An event is defined here as a depositional or tectonic incident (or series of incidents) that is evidenced in the geologic record. The following summary discusses both the incident or event and the evidence, implications, or results of the event in the Wind River Basin.

Depositional Event 1: Mesaverde Formation (Upper Cretaceous). This formation interfingers, in part, with the upper part of the marine Cody Shale. It was deposited in fluvial, deltaic and near shore environments adjacent to the Cody seaway. In the eastern half of the basin the Mesaverde is comprised of four members: the Fales member, Wallace Creek Tongue, unnamed middle member, and Teapot Sandstone. The Wallace Creek member is a major tongue of the Cody Shale and reaches a maximum thickness of 345 ft (105+ m). In the southwestern part of the basin the Mesaverde consists of an upper sequence of rocks

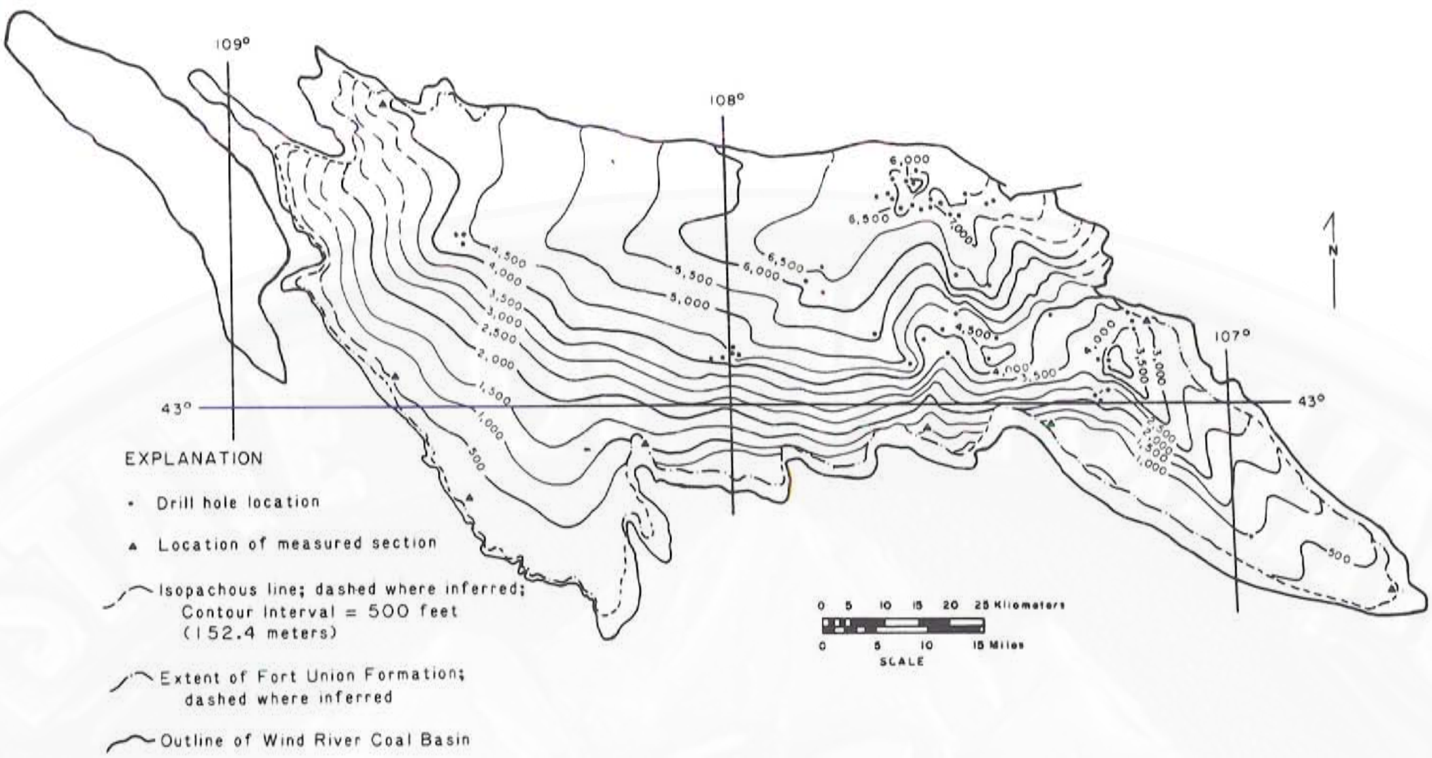

Figure 20. *Isopachous map of the Fort Union Formation, Wind River Basin, Wyoming.*

stratigraphically equivalent to the four members to the east plus a lower sequence of coal-bearing rocks as much as 2,000 ft (610 m) thick known here as the Alkali Butte member. These two sequences are separated by a major unnamed tongue of the Cody Shale which has a maximum thickness of 700+ ft (215 m). No significant intertonguing of the Mesaverde Formation and Cody Shale exists in the northwestern part of the basin where the Mesaverde reaches its maximum overall thickness of 2,300+ ft (700+ m).

Tectonic Event 1. As early as 78 million years ago, development of structural features was contemporaneous with deposition of the Mesaverde Formation and controlled, in part, the depositional thicknesses of the formation. The Mesaverde is thickest in structurally low areas where synorogenic deposition occurred, such as in the major basin trough area and near Shotgun Butte syncline. Thinning of the Mesaverde from either nondeposition or erosion occurred over structurally high areas such as near Alkali Butte and at Madden anticline.

Depositional Event 2: Lewis Shale and Meeteetse Formation (Upper Cretaceous). The Lewis Shale was deposited in the southeastern part of the basin and is the marine equivalent of the nonmarine Meeteetse Formation. The Lewis is comprised of one to several tongues of shale, with a maximum combined thickness of 700+ ft (215 m). The Meeteetse Formation is difficult to distinguish from the overlying Lance Formation in the subsurface but where the formation can be distinguished, the Meeteetse has a maximum thickness of 1,900+ ft (580 m) in the northeastern part of the basin.

Depositional Event 3: Lance Formation (Upper Cretaceous). The non-marine Lance Formation was deposited throughout much of the Wind River Basin. It varies in thickness from 0 in the southwestern part of the basin, where it has since been completely eroded, to over 5,100 ft (1,555 m) in the northeastern part of the basin.

Tectonic Event 2. Major overall structural development of the basin began during the latest Cretaceous as is evidenced by the extreme thickening of sedimentary rocks (the Lance Formation) along the present day northern and eastern edges of the basin. Downdropping of the basin continued into early Eocene time. Pulses of tectonic activity resulted in erosion or nondeposition, especially in the western part of the basin, while subsidence and deposition continued in other areas of the basin.

Depositional Event 4: Fort Union Formation (Paleocene). Continuous deposition occurred throughout most of the basin across the Cretaceous-Tertiary boundary. Because the rocks are so similar lithologically, the differentiation between the lowermost Paleocene and uppermost Cretaceous can best be determined using palynological data. The Fort Union Formation consists of three members in the eastern half of the basin. The Waltman Shale member has a maximum thickness of 2,800 ft (850+ m) and was deposited during a period of major ponding in much of the basin during Paleocene time. Including the Waltman

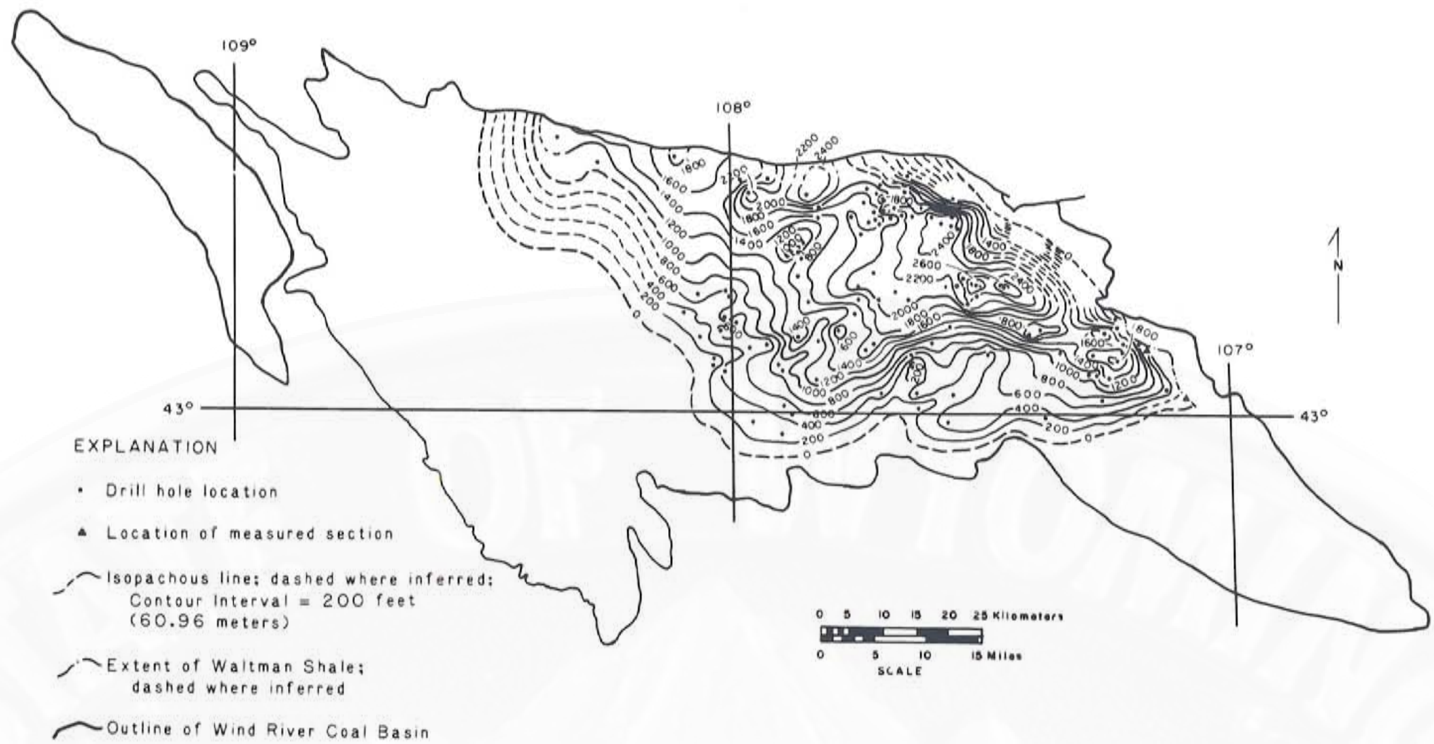

Figure 21. *Isopachous map of the Waltman Shale Member of the Fort Union Formation, Wind River Basin, Wyoming.*

Shale, the maximum overall thickness for the three members of the Fort Union is 7,000+ ft (2,140 m) in the northeastern part of the basin. In the western half of the basin the Fort Union consists of as much as 4,500 ft (1,372 m) of continuous sandstones, siltstones, carbonaceous shales and coals, and has not been subdivided into members.

Tectonic Event 3. After deposition of the Fort Union Formation, major thrusting along the South Owl Creek Mountains thrust fault began. An unconformity on top of the Fort Union, especially along the basin margins, resulted when conglomerates shed off the upper plate of the thrust were deposited on top of the tilted Fort Union Formation.

Depositional Event 5: Indian Meadows Formation (lower Eocene). This formation was deposited during, and is the product of, major tectonic activity in and around the basin at this time. The Indian Meadows is, for the most part, unconformable with the rocks both above and below it. Predominantly conglomeratic, the Indian Meadows is extremely difficult to distinguish from the overlying Wind River Formation using geophysical well logs.

Tectonic Event 4. During deposition of the Indian Meadows and before deposition of the Lysite Member of the Wind River Formation, major thrusting continued along the South Owl Creek Mountains thrust fault. The Owl Creek Mountains and Casper Arch were thrust southward and westward up to (and possibly over) the structural axis of the basin. Erosion and structural deformation of the Indian Meadows and older rocks continued sporadically in the basin and an unconformity on top of the Indian Meadows was formed prior to deposition of the Wind River Formation.

Depositional Event 6: Wind River Formation (early Eocene). Large amounts of clastic debris, ranging from conglomerates to mudstones, began to accumulate as the Wind River Formation was deposited. This formation consists of two members: the lower Lysite member and the upper Lost Cabin member. In many surface exposures the members are separated by an angular unconformity; this unconformity most likely disappears in the subsurface. The combined maximum thickness for the Indian Meadows and Wind River formations is 5,500+ ft (1,680 m) in the northern part of the basin.

Tectonic Event 5. Widespread normal faulting occurred sometime post- Wind River Formation deposition. Evidence for this exists in many areas of the basin, but the Cedar Ridge fault in the Badwater area, north-central Wind River Basin, is particularly well documented (Love, 1978).

OIL AND GAS POTENTIAL BELOW THE OWL CREEK MOUNTAINS THRUST PLATE

Trumbull (1914) described oil seeping from fractures in Precambrian granite at Copper Mountain, northeast of the Wind River Basin. The extent that the Owl Creek Mountains and Casper Arch overrode the basin is relatively unknown except for geophysical profiles and data from the Waltman and Tepee Creek fields. Gries (1983) described the Moncrief 16-1 well (T37N, R86W, sec. 16) which drilled through the Precambrian in the Casper Arch and into the overridden sedimentary rocks beneath the thrust, and produced 6 to 7 MCFGD from Cretaceous rocks. In the northeast part of the basin, only two to three miles south of the fault, the Madden field alone has produced more than 253 billion cubic feet of gas from Upper Cretaceous through lower Eocene rocks (Wyoming Oil and Gas Conservation Commission, 1988).

Two-dimensional views, as expressed by structure contour and isopachous maps for Upper Cretaceous through lower

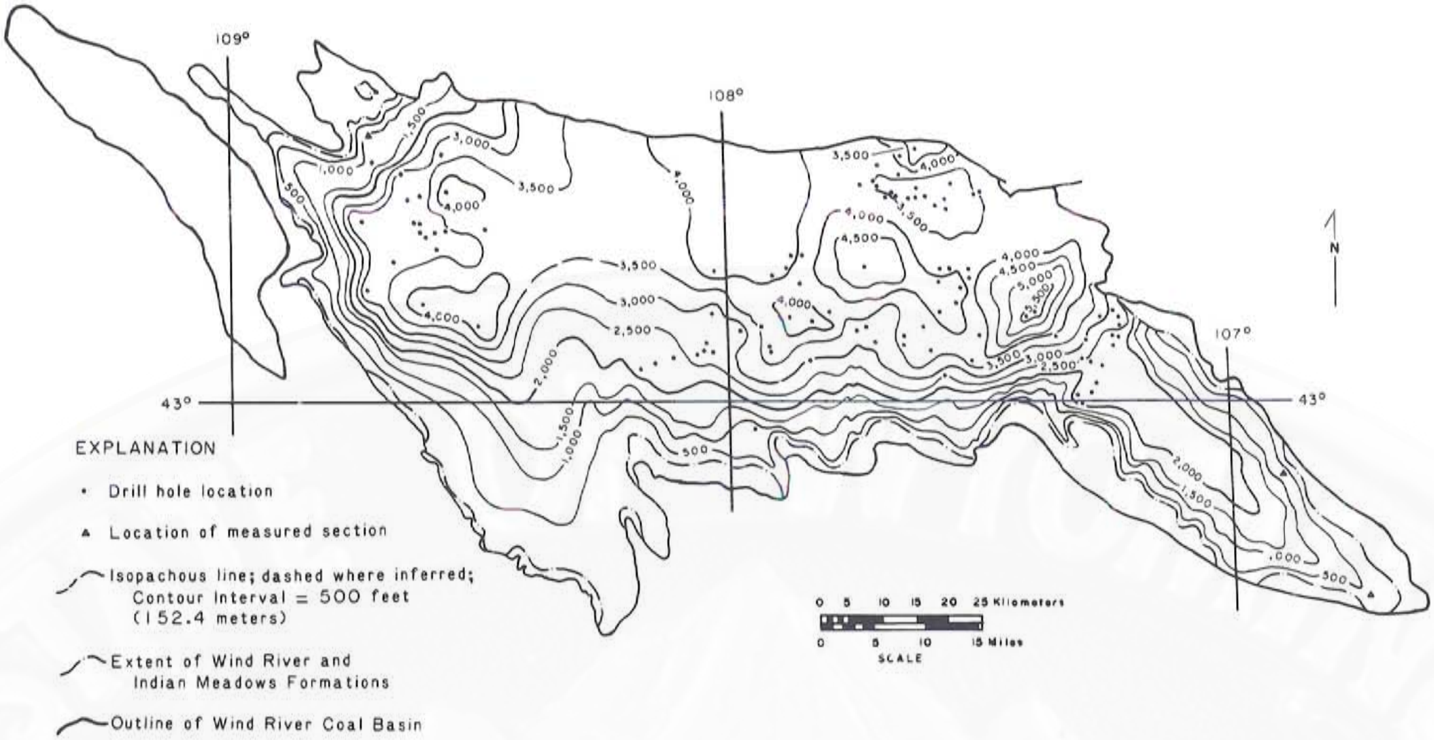

Figure 22. *Isopachous map of the combined Wind River and Indian Meadows formations, Wind River Basin, Wyoming.*

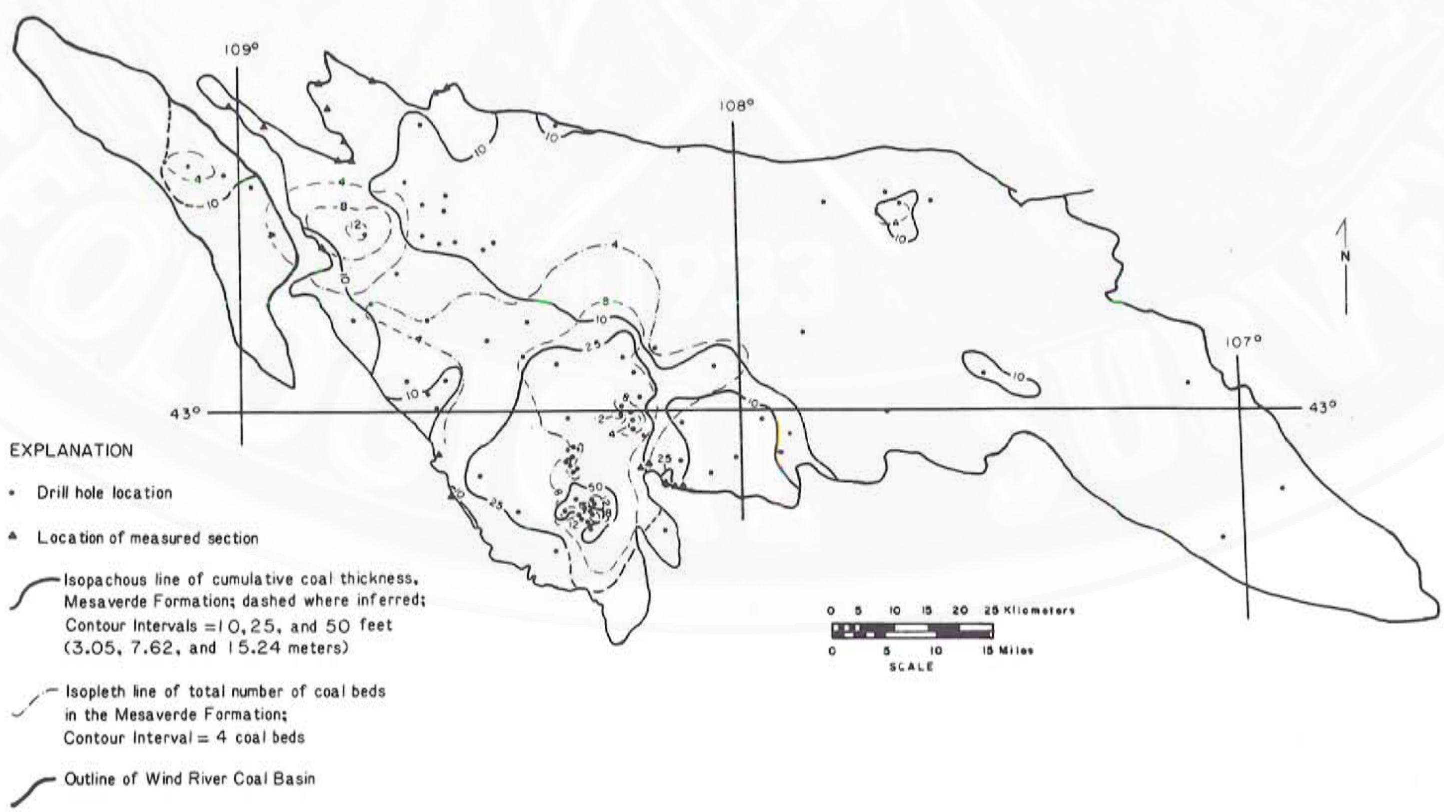

Figure 23. *Isopachous map of total coal and isopleth map of number of coal beds in the Mesaverde Formation, Wind River Basin, Wyoming.*

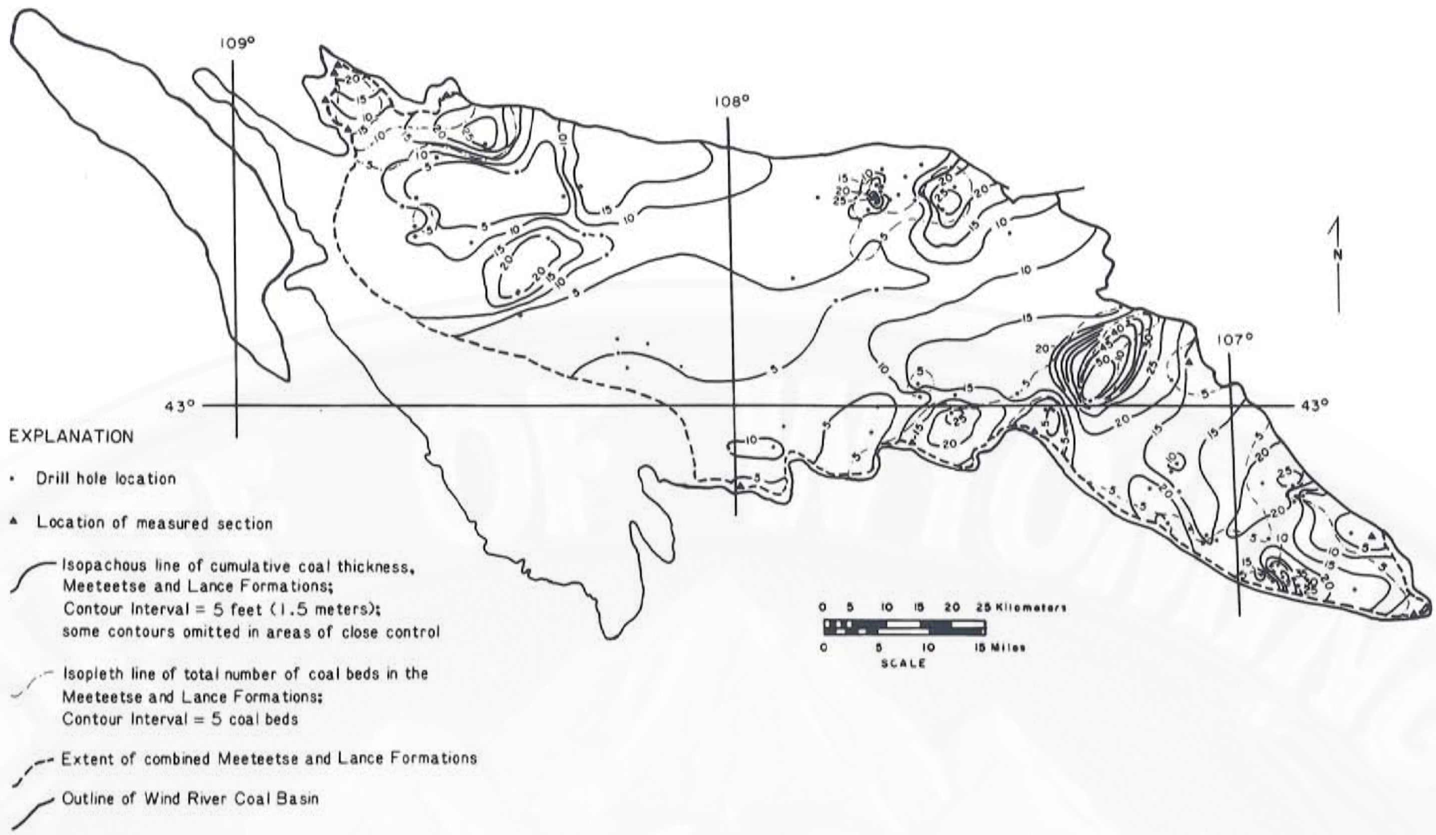

Figure 24. *Isopachous map of total coal and isopleth map of number of coal beds in the Lance and Meeteetse formations, Wind River Basin, Wyoming.*

Eocene rocks (Figs. 4, in pocket, 17, 18, 19, 20, 21, and 22) illustrate dramatically the great thickness of sedimentary rock directly adjacent to the surface trace of the South Owl Creek Mountains fault. Exploration beneath the fault into Eocene, Paleocene, and Upper Cretaceous rocks is minimal, particularly along the northern margin of the basin. At this time, one can only speculate on the existence of hydrocarbons and the presence of facies and fault traps in most of the subthrust half of the structural basin. However, it is possible, and we believe probable, that major hydrocarbon reserves exist in the sedimentary package beneath the South Owl Creek Mountains thrust fault.

CONCLUSIONS

This study demonstrates that as much as 20,000 feet (6,000 m) of predominantly fine-grained sedimentary rocks underlie (to the north and east) the South Owl Creek Mountains thrust fault. The question of exactly what the nature and extent of the thick sequence of sedimentary rocks is beneath the thrust in the eastern Wind River Basin has yet to be determined.

It has been well documented that the Wind River Basin is a major source of hydrocarbons (Benner, 1972; Brown and Shannon, 1989; Dunleavy and Gilbertson, 1986; Hodges and Knutson, 1980; Hubley, 1948; Jenkins, 1957; Keefer, 1969; Pirner, 1978; Ray, 1982; Rieke, 1981; Robertson, 1983; and Stauffer, 1971). Continued exploration will certainly discover significant additional hydrocarbons in the basin.

A refined and detailed three-dimensional stratigraphic framework for Upper Cretaceous through lower Eocene rocks is here established. This framework has economic significance: hydrocarbons produced today in the Wind River Basin are directly related to stratigraphic traps in these rocks. Future potential for hydrocarbon production lies in untested areas, subthrust areas, areas of possible coalbed methane production, and ultra-deep areas. The stratigraphic framework outlined here should contribute to further understanding and future exploration of Wind River Basin mineral resources.

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