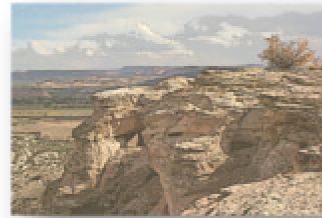
Chapter 7

The Mesaverde Total Petroleum System, Uinta-Piceance Province, Utah and Colorado



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By R.C. Johnson *and* S.B. Roberts

Chapter 7 *of*

Petroleum Systems and Geologic Assessment of Oil and Gas in the Uinta-Piceance Province, Utah and Colorado

By USGS Uinta-Piceance Assessment Team

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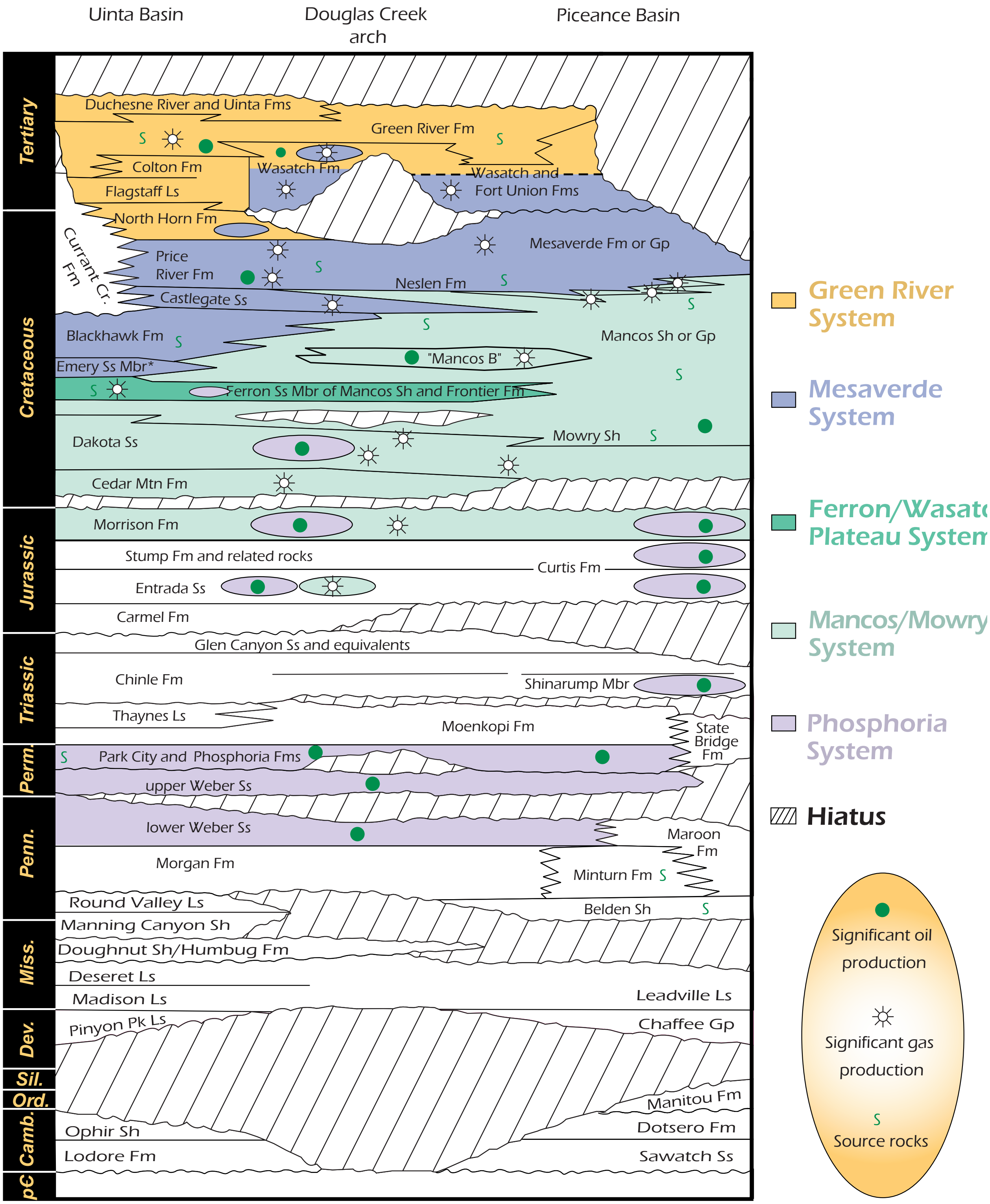
Introduction

The Mesaverde Total Petroleum System (TPS) in the Uinta and Piceance Basins (Uinta-Piceance Province), Utah and Colorado, produces mainly natural gas sourced primarily by coal and associated organic-rich (carbonaceous) strata (for example, shale and siltstone) in the Upper Cretaceous Mesaverde Group (for example, see Pitman and others, 1987; Johnson and Rice, 1990) (fig. 1). The Mesaverde TPS (designated by number 502002) encompasses about 20,000 mi^2. The TPS boundary is defined by the outcrop limits of the Mesaverde Group in the Wasatch Plateau and southern and central Uinta and Piceance Basins; in northern areas of both basins, the boundary is defined by the limits of the Uinta-Piceance province (fig. 2), which generally follow the southern extent of Precambrian exposures in the Uinta Mountains. East of the Uinta Mountains, the boundary generally follows the crest of the Axial Basin anticline. Fields produce gas from the Mesaverde TPS throughout much of the Piceance Basin and the eastern half of the Uinta Basin (fig. 3). The total thickness of stratigraphic units within the Mesaverde TPS ranges from less than 1,500 ft along the Douglas Creek arch, which separates the Uinta and Piceance Basins (fig. 4), to more than 10,000 ft in the deepest part of the Piceance Basin, and to more than 9,000 ft in the deepest part of the Uinta Basin. Maximum depth to the base of the Mesaverde TPS is about 13,000 ft in the Piceance Basin and more than 19,000 ft in the much deeper Uinta Basin (fig. 5).

The Mesaverde Total Petroleum System includes seven gas assessment units: two continuous gas assessment units (50200261 and 50200263), two transitional gas assessment units (50200262 and 50200264), two coalbed methane assessment units (50200281 and 50200282), and one conventional gas assessment unit (50200201). Some oil is also produced, but the amount is so minor compared to the volume of gas that only the gas resources are considered in this study.

Rocks included in the Mesaverde TPS crop out throughout much of the Uinta-Piceance Province (fig. 6). Assignment of stratigraphic units to the system is based on the presence of gas-prone source rocks within the Mesaverde Group, and the presence of reservoirs producing gas that is interpreted to have migrated either vertically or up dip from these source rocks. Based on these criteria, the Mesaverde TPS includes the lowest major coal zone within the Mesaverde Group (considered to be the source rocks), as well as potential reservoirs within overlying units in the Mesaverde Group, and in the North Horn, Colton, Fort Union, and Wasatch Formations. In the Uinta Basin and Wasatch Plateau, the Mesaverde Group includes the Star Point Sandstone (Fisher and others, 1960), the Blackhawk, Price River, Neslen, Farrer, and Tuscher Formations, and the Castlegate and Sego Sandstones (for example, see Fouch and others, 1992) (figs. 7, 8). The Blackhawk and Neslen Formations contain most of the Mesaverde coal in the Uinta Basin. In the Tabby Mountain and Vernal coal fields (fig. 2), the term Mesaverde Formation is applied to coal-bearing units (for example, see Doelling and Graham, 1972) that we consider to be stratigraphically equivalent (in part) to the Blackhawk and Neslen Formations. In the Piceance Basin, the Mesaverde Group includes the Mount Garfield, Hunter Canyon, Iles, and Williams Fork Formations; locally, the term Mesaverde Formation is applied to strata considered to be equivalent (in part) to the Iles and Williams Fork Formations (pls. 1, 2). The Mount Garfield, Mesaverde, and Williams Fork Formations contain coal deposits that are thought to be the source for most of the gas found in the Mesaverde TPS in the Piceance Basin. For ease of discussion, we include all major coal-bearing strata in the lower part of the Mesaverde Group in the Williams Fork Formation, and use this terminology in lieu of Mount Garfield and Mesaverde Formation nomenclature in the Piceance Basin (for example, see Johnson, 1989).

The upper limit of the stratigraphic interval included in the Mesaverde TPS is generally placed at the base of the lowest lacustrine shale bed in the Green River Formation (pl. 1). The base of the Green River is time transgressive and ranges from late Paleocene in the deepest part of the Uinta Basin to possibly middle Eocene on the Douglas Creek arch (pl. 2). Throughout much of the Uinta and Piceance Basins, the lacustrine shales form a potential seal that may inhibit further vertical migration of gas from Mesaverde Group source rocks. Gas produced from reservoirs within the Green River Formation is largely derived from lacustrine source rocks within that formation (Johnson and Rice, 1990; Rice and others, 1992). The base of these lacustrine shales is used as the boundary between the Mesaverde TPS and the overlying Green River TPS.



* Emery Sandstone Member of the Mancos Shale

Figure 1. Generalized stratigraphic column of Uinta-Piceance Province, showing total petroleum systems and intervals of hydrocarbon production and source rocks. Modified from Sanborn (1977) and Spencer and Wilson (1988).

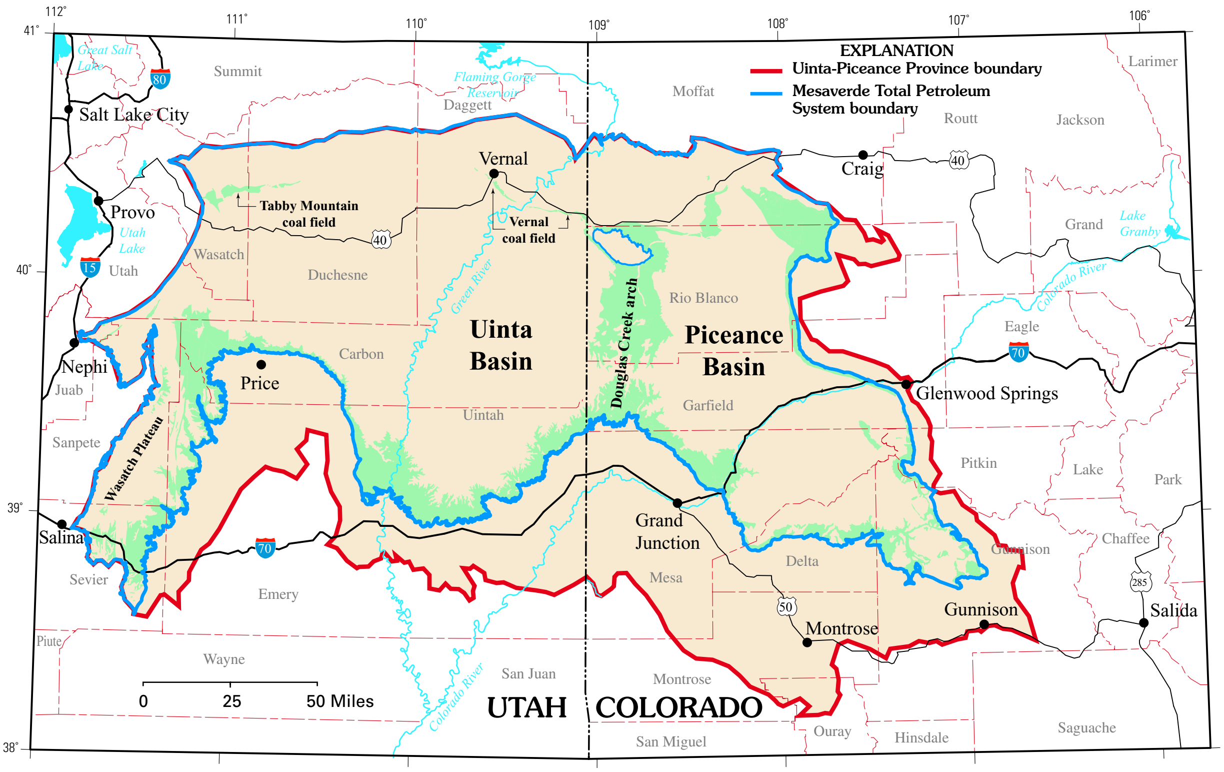


Figure 2. Distribution of Mesaverde Group outcrops (shaded green) and areal extent of Mesaverde Total Petroleum System in Uinta-Piceance Province, Utah and Colorado.

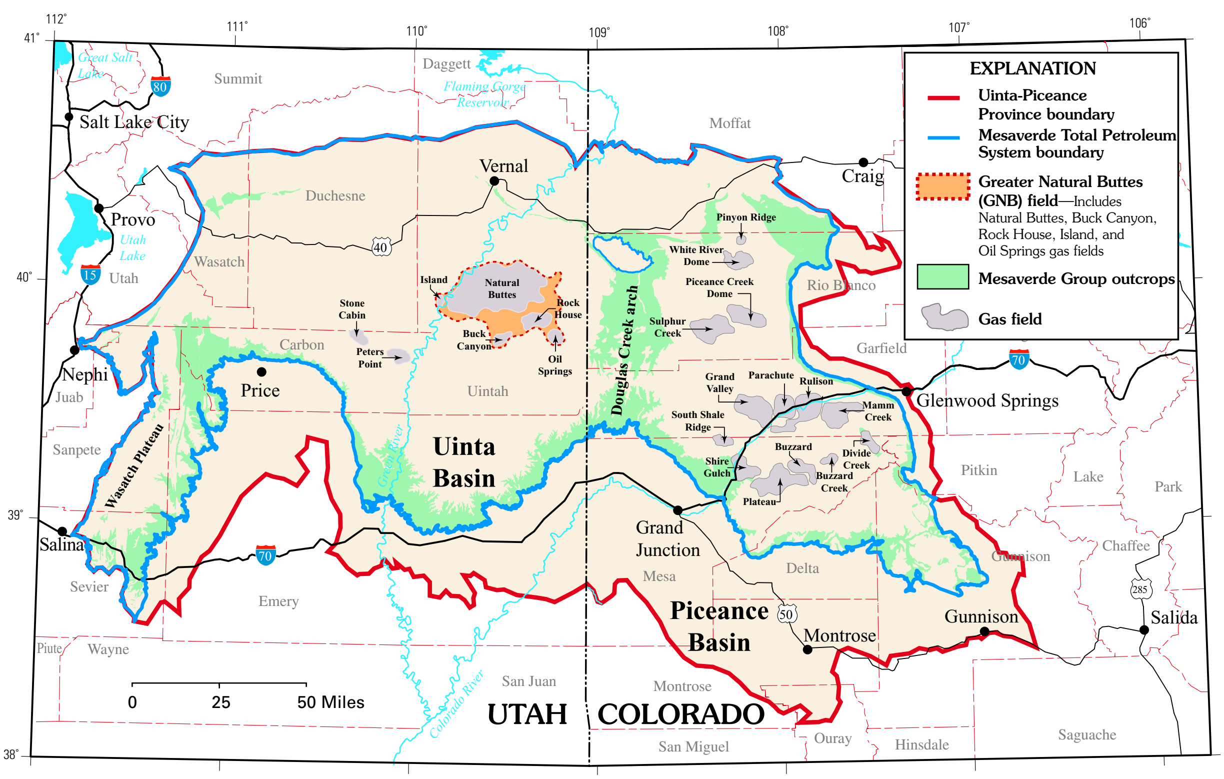


Figure 3. Location of major fields producing gas from reservoirs in Mesaverde Total Petroleum System, Uinta and Piceance Basins, Utah and Colorado. Field designations and areal limits based on Osmond (1992) and Petroleum Information/Dwights LLC (1999).

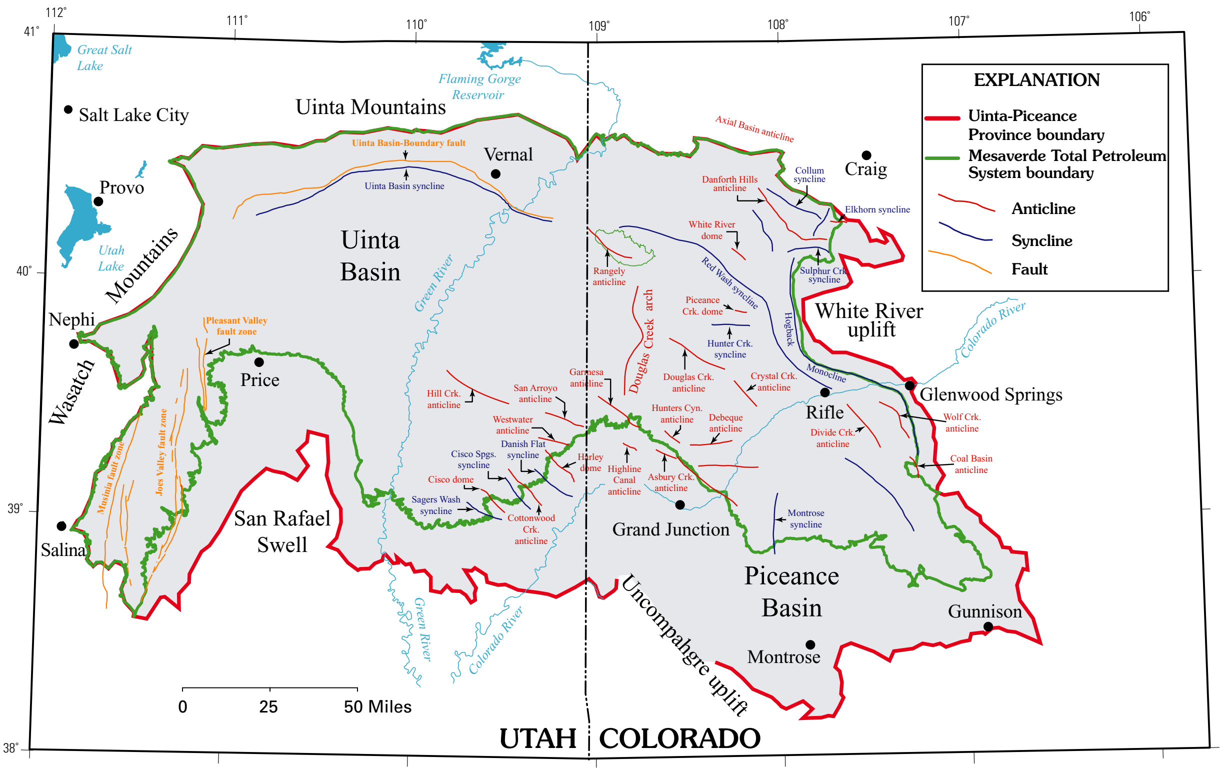


Figure 4. Major anticlines, synclines, and fault zones in Uinta Basin, Douglas Creek arch, and Piceance Basin, Utah and Colorado.

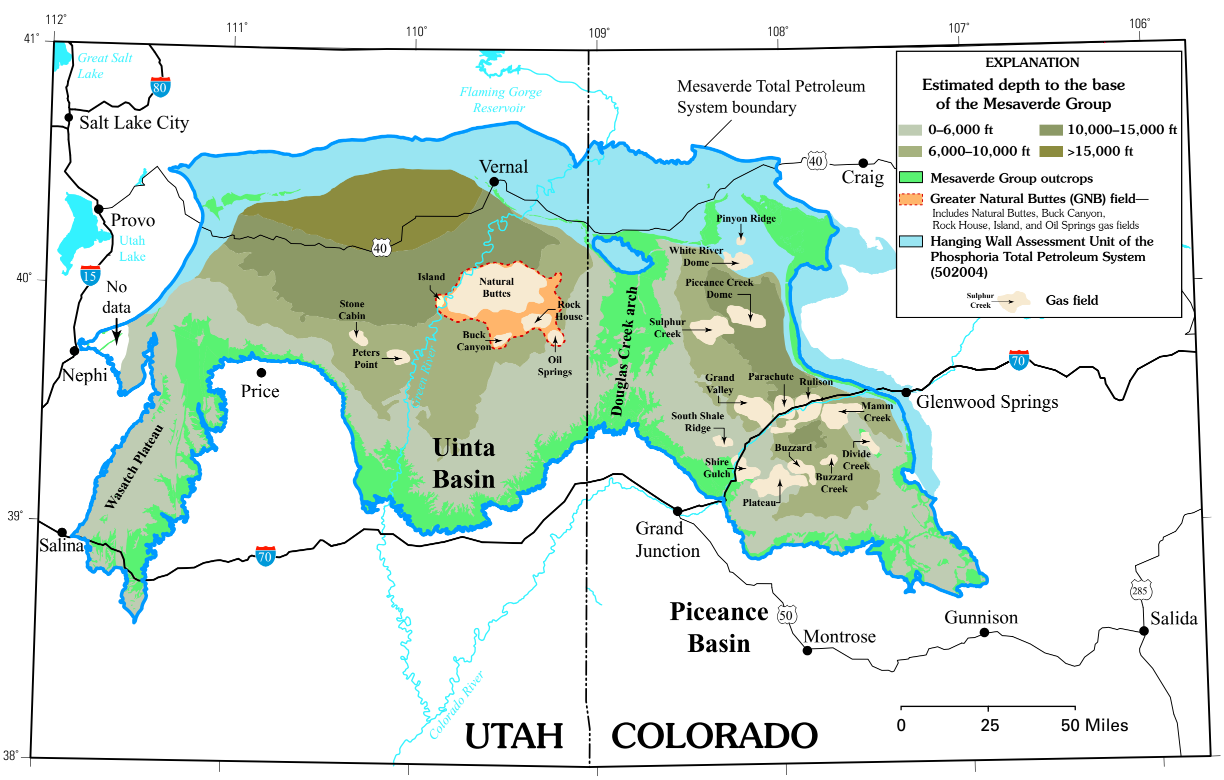


Figure 5. Estimated depths to stratigraphic horizons near base of Mesaverde Total Petroleum System, Uinta and Piceance Basins, Utah and Colorado. Horizons used for depth estimates include the top of the Blackhawk Formation (western Uinta Basin), the top of the lower Castlegate Sandstone (central and eastern Uinta Basin), and the top of the Rollins and Trout Creek Sandstone Members of the Iles Formation in the Piceance Basin.

Click on image below to bring up high-resolution image of plate 1.

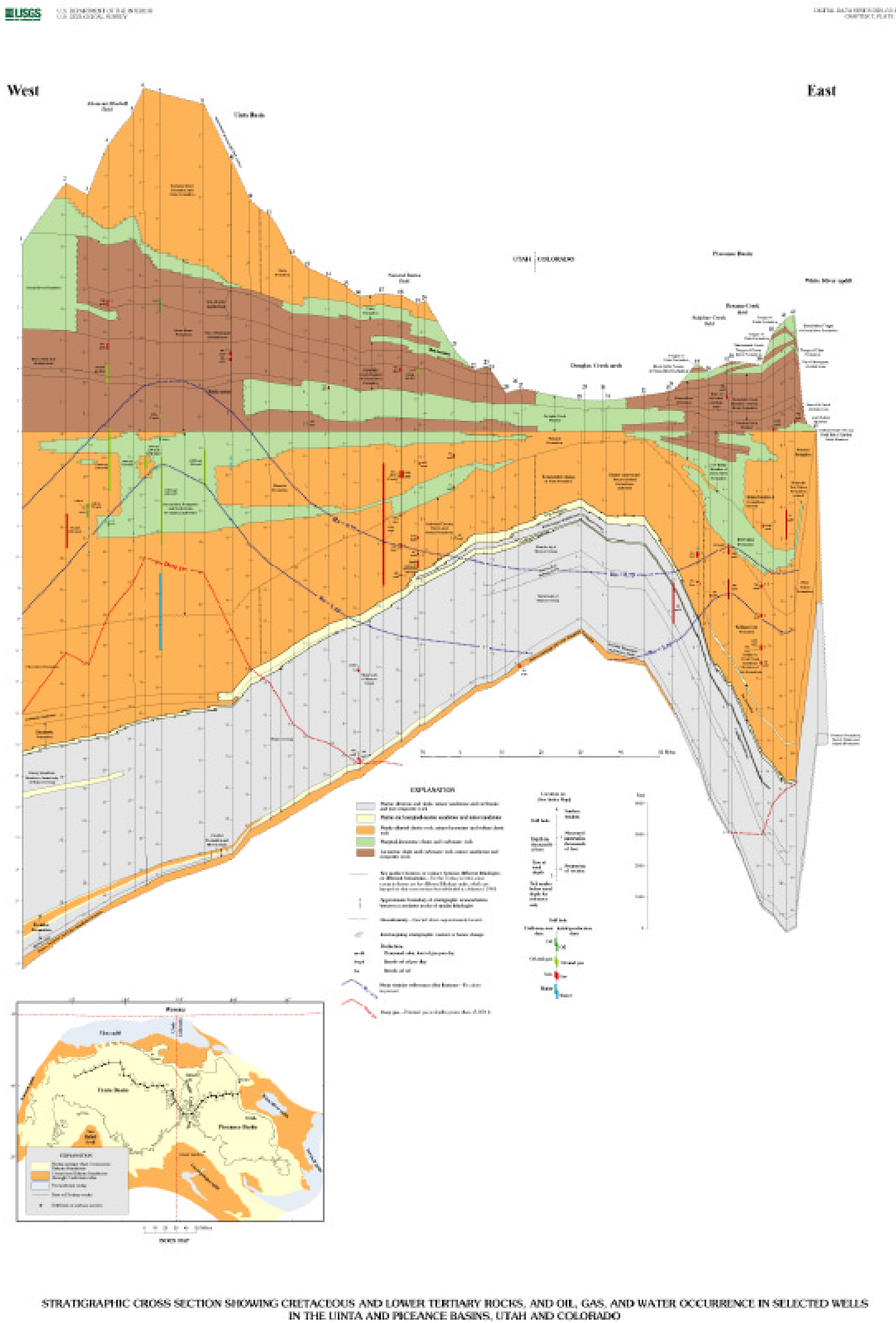


Plate 1. Stratigraphic cross section showing Cretaceous and lower Tertiary rocks, and oil, gas, and water occurrence in selected wells in the Uinta and Piceance Basins, Utah and Colorado.

Click on image below to bring up high-resolution image of plate 2.

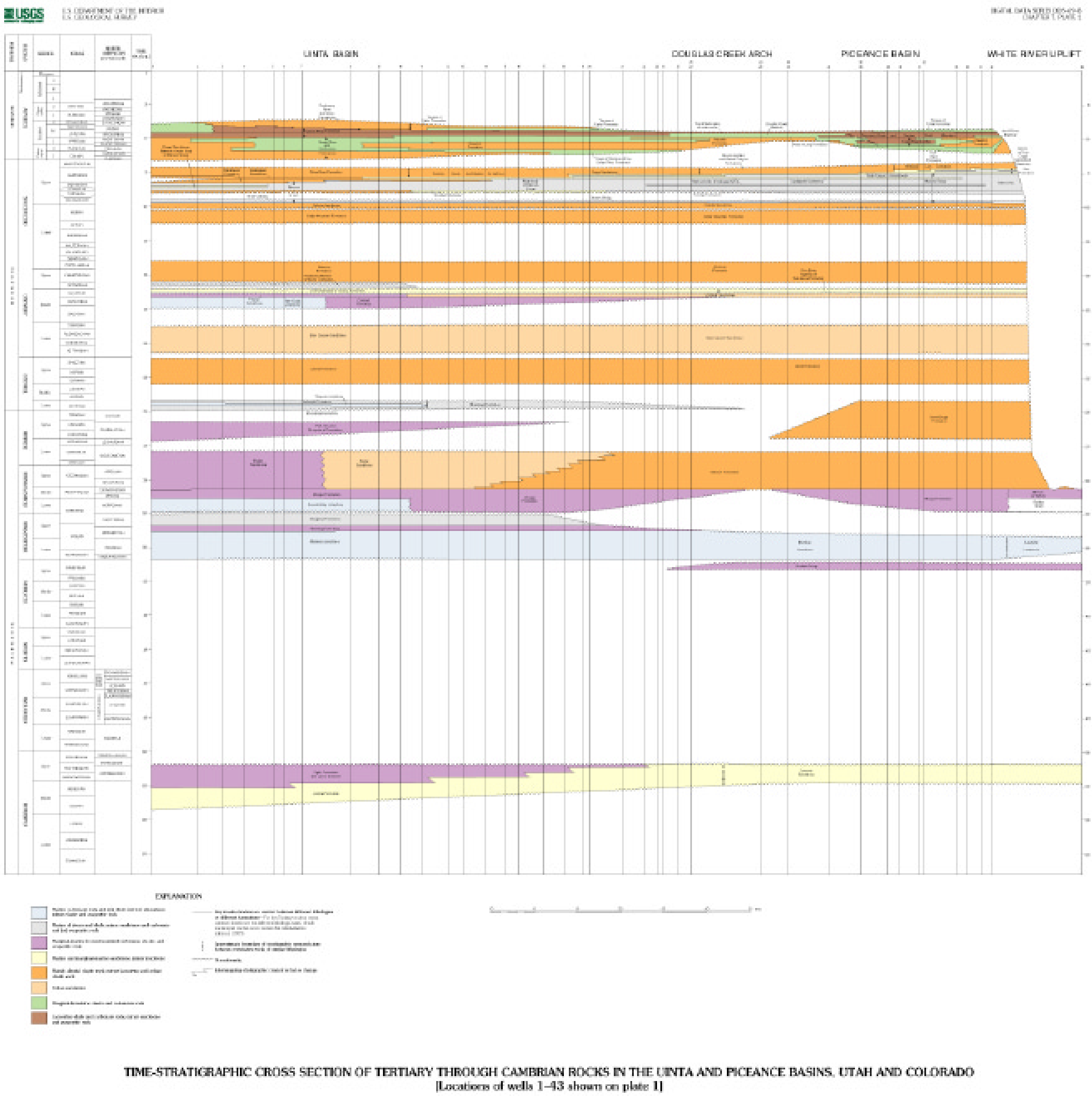


Plate 2. Time-stratigraphic cross section of Tertiary through Cambrian rocks in the Uinta and Piceance Basins, Utah and Colorado.

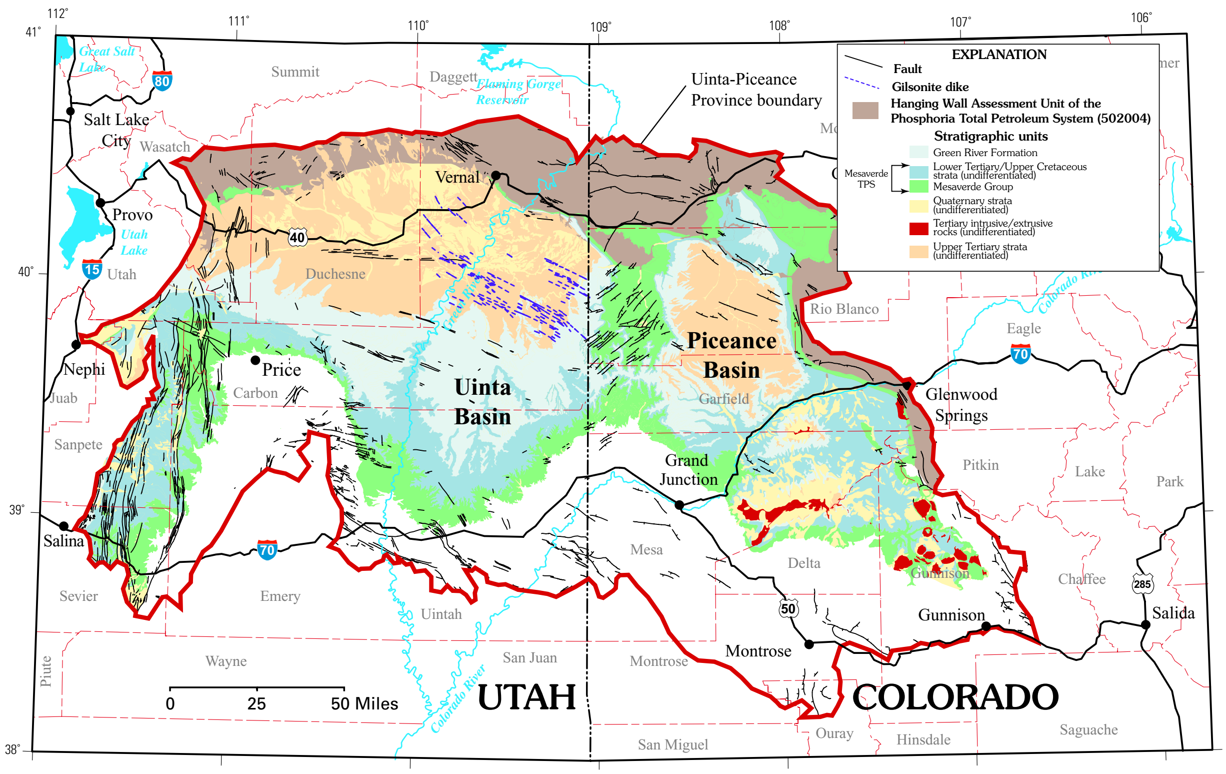


Figure 6. Distribution of stratigraphic units exposed within Mesaverde Total Petroleum System, Uinta and Piceance Basins, Utah and Colorado. Geology based on Green (1992) and Hintze and others (2000). Hanging Wall Assessment Unit is described in Johnson (Chapter 9, this CD-ROM).

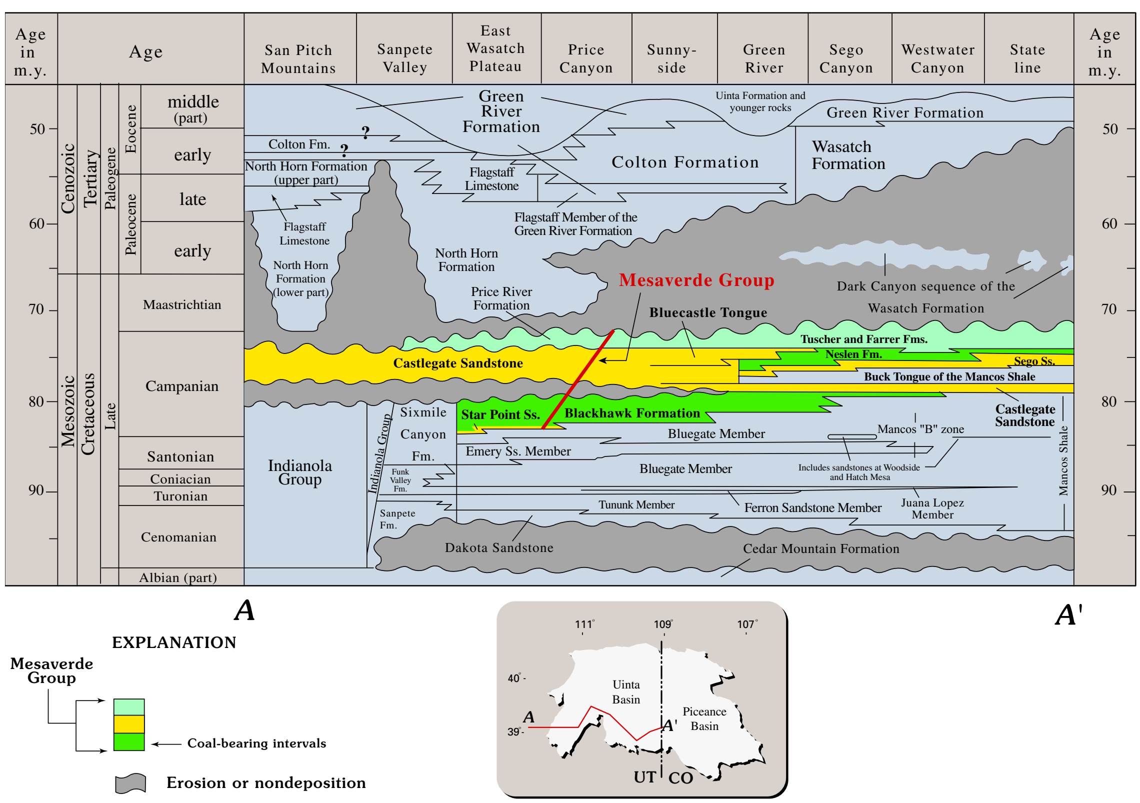


Figure 7. West-east chronostratigraphic chart showing temporal relations of Upper Cretaceous–lower Tertiary rocks in Uinta Basin, Utah. Vertical lines through stratigraphic units indicate a change in nomenclature. Modified from Fouch and others (1992).

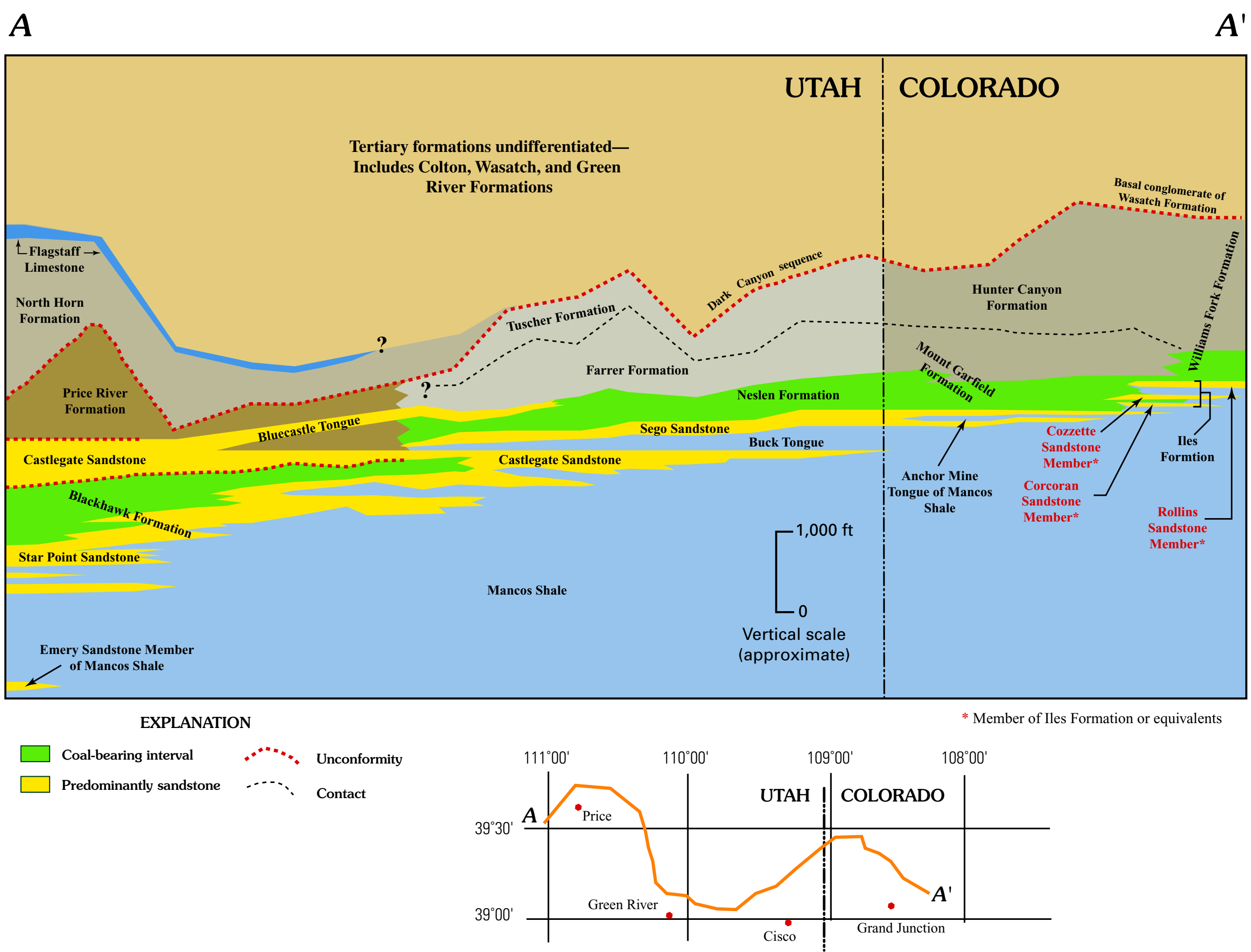


Figure 8. Generalized west-east cross section showing Upper Cretaceous and lower Tertiary stratigraphic units in Uinta Basin and western Piceance Basin, Utah and Colorado. Modified from Fisher and others (1960).

Separation of the Mesaverde TPS from the underlying Mancos/Mowry TPS (fig. 1) is problematic. In many areas, there does not appear to be an effective seal separating the two systems, and gas occurring in reservoirs in the lower part of the Mesaverde Group may have migrated from source rocks in the underlying Mancos Shale. For this reason, that part of the Mesaverde Group below the lowest major coal zone is included in the underlying Mancos/Mowry TPS. Units in the Mesaverde Group assigned to the Mancos/Mowry TPS based on these criteria include marginal-marine sandstones in the Star Point Sandstone and in the lower part of the Blackhawk Formation, the Castlegate (part) and Sego Sandstones, and the Corcoran, Cozzette, Rollins, and Trout Creek Sandstone Members of the Iles Formation (for example, see Johnson, 1989). We believe that the gas within these units migrated primarily from source rocks in the underlying Mancos/Mowry TPS. There is some geochemical evidence to support this interpretation. Johnson and Rice (1990), for example, noted that gas produced in reservoirs below the lowest major coal zone in the Mesaverde Group in the Piceance Basin, and gases produced from reservoirs in the underlying Mancos Shale, tend to be chemically wet and are commonly associated with minor amounts of oil. Their study indicates that the gas was generated by source rocks composed of a mixture of Type II and Type III organic matter typical of the marine Mancos Shale.

In addition, the "blanket-like" geometry that characterizes some of the marginal-marine sandstones below the lowest major coal zone in the Mesaverde Group throughout much of the Piceance Basin and part of the Uinta Basin may have provided a conduit for up-dip migration and leakage of gas derived from the Mancos Shale. An example is the Rollins and Trout Creek Sandstone Members of the Iles Formation, which underlie the lowest major coal zone in the Mesaverde Group throughout most of the Piceance Basin (Johnson, 1989). Although the Rollins and Trout Creek gradually climb stratigraphically towards the southeast, in a regional sense they form a single, unbroken regressive sandstone unit throughout much of the basin (for example, see Hettinger, Chapter 12, this CD-ROM). Unlike the more highly gas saturated, lenticular sandstones within the Mesaverde Group, the sandstone body formed by the Rollins and Trout Creek is unique in that it appears to be predominantly water saturated, even within basin-centered accumulations where little water should be present. Paleogeographic reconstructions by Johnson and Nuccio (1986) and Johnson (1989) indicate that the Rollins and Trout Creek have been exposed on the margins of the Piceance Basin since Eocene time and thus could have acted as a conduit for gas migration and leakage from the deep basin to the surface since the time of peak gas generation in the Mancos Shale during late Paleocene and early Eocene time (Nuccio and Roberts, Chapter 4, this CD-ROM). This conduit, in effect, may have inhibited the migration of gas from Mancos Shale source rocks in down-dip areas of the basin to potential reservoirs higher in the Mesaverde Group and in overlying formations. The Castlegate Sandstone in the east-central and eastern Uinta Basin may be analogous (in part) to the Rollins–Trout Creek body in that this unit forms an extensive sandstone sheet that could also allow for leakage of gas derived from the underlying Mancos Shale. However, limited drill-hole data, coupled with the fact that some gas is being currently produced from the Castlegate Sandstone, preclude determining if this unit is predominantly water saturated, as the Rollins and Trout Creek Sandstone Members seem to be.

Based on the foregoing, we define the stratigraphic base of the Mesaverde TPS as follows: (1) in the western part of the Uinta Basin, the base of the Mesaverde TPS is placed at the base of the lowest coal zone in the Blackhawk Formation or at the base of the Mesaverde Formation in the Tabby Mountain coal field; (2) in the central and eastern part of the Uinta Basin, the base of the Mesaverde TPS is placed at the base of the lowest coal zone in the Neslen Formation (top of Sego Sandstone) and at the base of the Mesaverde Formation in the Vernal coal field; and (3) in the Piceance Basin, the base of the Mesaverde TPS is placed at the base of the lowest coal zone in the Williams Fork Formation (top of Rollins and Trout Creek Sandstone Members).

Source Rocks

Coal and carbonaceous shale source rocks in the Mesaverde Group accumulated in mires, swamps, and marshes associated with deltaic and coastal plain environments in a generally west to east progradational depositional system; the primary coal-bearing intervals become increasingly younger and rise stratigraphically from west to east across the Uinta-Piceance Province (figs. 7, 8; Hettinger and Kirschbaum, Chapter 12, this CD-ROM). Thicker coal accumulations typically overlie marine and marginal-marine sandstone successions in the lower part of the Mesaverde Group.

In the Piceance Basin, the most important coal-bearing interval is the Cameo-Fairfield coal group in the lower part of the Williams Fork Formation (Johnson, 1989); the Cameo-Fairfield coal group is present in the subsurface throughout most of the basin. Some of the more important local designations for part or all of this interval include (in ascending order) the Cameo-Wheeler, South Canyon, and Coal Ridge coal zones (Hettinger and Kirschbaum, Chapter 12, this CD-ROM). Coal-bearing intervals within the Cameo-Fairfield coal zone overlie the regressive Rollins and Trout Creek Sandstone Members of the Iles Formation (pl. 1), and also overlie younger regressive sandstones designated as the middle sandstone and upper sandstone in the Bowie Shale and Paonia Shale Members of the Williams Fork Formation or the Mesaverde Formation (Hettinger and Kirschbaum, Chapter 12, this CD-ROM). Total (cumulative) coal thickness in the Cameo-Fairfield coal group varies from near zero in the extreme southeastern part of the Piceance Basin to greater than 180 ft in the northeastern corner (fig. 9). Throughout most of the basin, however, the zone contains from 20 to 80 ft of total net coal.

West of the pinch out of the Rollins Sandstone Member, in the southwestern Piceance Basin near the Colorado-Utah border, only the lower part of the Cameo-Fairfield coal group (Cameo-Wheeler zone) is present. Additional coal-bearing units within the Mesaverde Group [Anchor, Palisade (Colorado designation), and Chesterfield coal zones] underlie the Cameo-Wheeler coal zone and overlie the Sego Sandstone. In the southwestern part of the Piceance Basin, total net coal thickness in the lower part of the Mesaverde Group decreases to less than 20 ft near the Utah-Colorado border (Hettinger and Kirschbaum, Chapter 12, this CD-ROM).

In the central and eastern parts of the Uinta Basin, coal and carbonaceous shale beds are present in the Neslen Formation (fig. 10), a unit that for the most part is older than the Cameo-Fairfield coal group (Fisher and others, 1960). The Neslen Formation extends into the deep subsurface of the Uinta Basin, and equivalent coal-bearing strata in the Mesaverde Formation crop out in the Vernal coal field (fig. 2) north of the Uinta Basin boundary fault (fig. 4). Thickness of the Neslen ranges from 250 to 500 ft in southern and eastern-central areas of the basin (Fisher and others, 1960; Fouch and Cashion, 1979; Hettinger and Kirschbaum, Chapter 12, this CD-ROM). West of the Green River, the formation grades laterally into fluvial units of the Castlegate Sandstone (Fouch and others, 1992; figs. 7, 8). Coal zones within the Neslen Formation in the south-central and southeastern Uinta Basin include (in ascending order) the Palisade (Utah designation), Ballard, Chesterfield, and Cameo-Carbonera coal zones. The Palisade coal zone is equivalent (in part) to the Anchor coal zone in the Piceance Basin, and the Cameo-Carbonera coal zone is equivalent (in part) to the Cameo-Wheeler coal zone (Hettinger and Kirschbaum, Chapter 12, this CD-ROM). Coal beds in the Neslen Formation decrease in abundance and thin toward the west, and only carbonaceous shale and minor coal occurs in the formation about 15 mi east of the Green River (for example, see Hettinger and Kirschbaum, Chapter 12, this CD-ROM). Total net coal thickness in the formation in the south-central and southeastern parts of the Uinta Basin ranges from 0 to as much as 29 ft near the Utah-Colorado border (D. Tabet, Utah Geological Survey, written commun., 1999).

The Blackhawk Formation, which is older than the Neslen Formation (fig. 7), is the dominant coal-bearing unit in

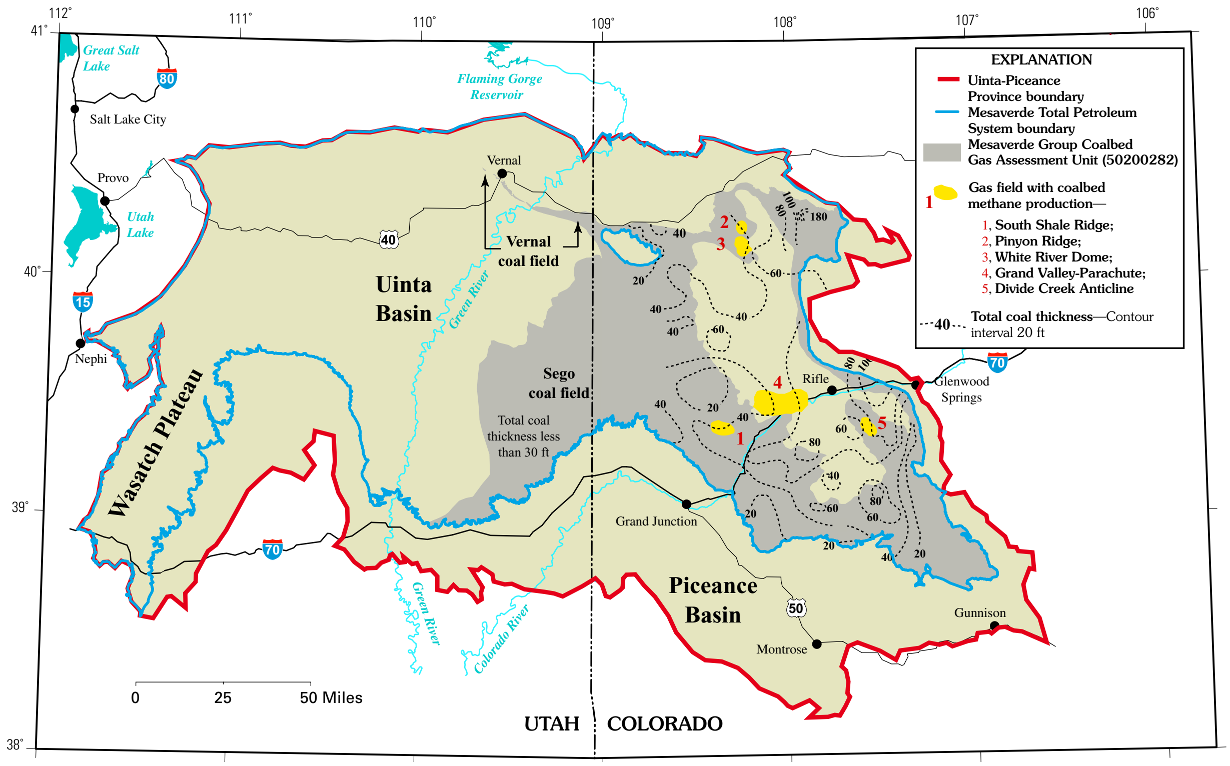


Figure 9. Total net coal thickness in Cameo-Fairfield coal group, Williams Fork Formation, Piceance Basin, Colorado. Modified from Johnson (1989).

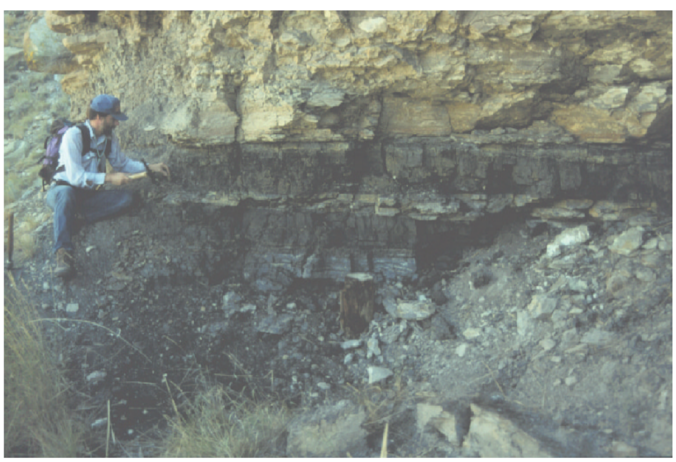


Figure 10. Coal beds in Neslen Formation, Sego coal field area, Uinta Basin, Utah.

the Mesaverde Group in the western part of the Uinta Basin and the Wasatch Plateau. The formation is more than 900 ft thick in the southwestern part of the Uinta Basin and northern Wasatch Plateau (Fisher and others, 1960), and thins eastward to a depositional pinch out near the Utah-Colorado border (fig. 8; Hettinger and Kirschbaum, Chapter 12, this CD-ROM). Coal beds are present throughout most of the Blackhawk, although thicker coal is generally restricted to the lower 500 ft or less of the formation. Named coal beds in the area north of Price, Utah (fig. 2), include the Subseams 1-3, Castlegate A-E, Kenilworth, Gilson, Fish Creek, Rock Canyon, and Sunnyside coal beds (Gloyn and Sommer, 1993; fig. 11). The formation extends into the deep subsurface of the Uinta Basin, and equivalent coal-bearing strata in the Mesaverde Formation crop out in the Tabby Mountain coal field (fig. 2) north of the Uinta Basin boundary fault (fig. 4). Because of sparse drill-hole data in the western part of the Uinta Basin, the physical character of the Blackhawk Formation in the deep subsurface is not well known. Total net coal thickness in the formation is as much as 80 ft in the subsurface north of Price, Utah (D. Tabet, Utah Geological Survey, written commun., 2000), and decreases to less than 40 ft in the southern part of the Wasatch Plateau (Dubiel and others, 2000).

Coal beds in the Emery Sandstone Member of the Mancos Shale may be a source for coalbed gas in the western Wasatch Plateau, and potential coalbed methane resources in the Emery are included as part of the Mesaverde TPS gas assessment. The Emery Sandstone Member underlies the Blackhawk Formation, and includes as many as nine coal beds in an interval ranging from 600 to 800 ft thick. Based on limited subsurface data, the total net coal thickness may be as much as 32 ft.

Maturation Summary

Thermal maturities based on vitrinite reflectance (Ro) values in the coaly intervals in the Mesaverde Group range

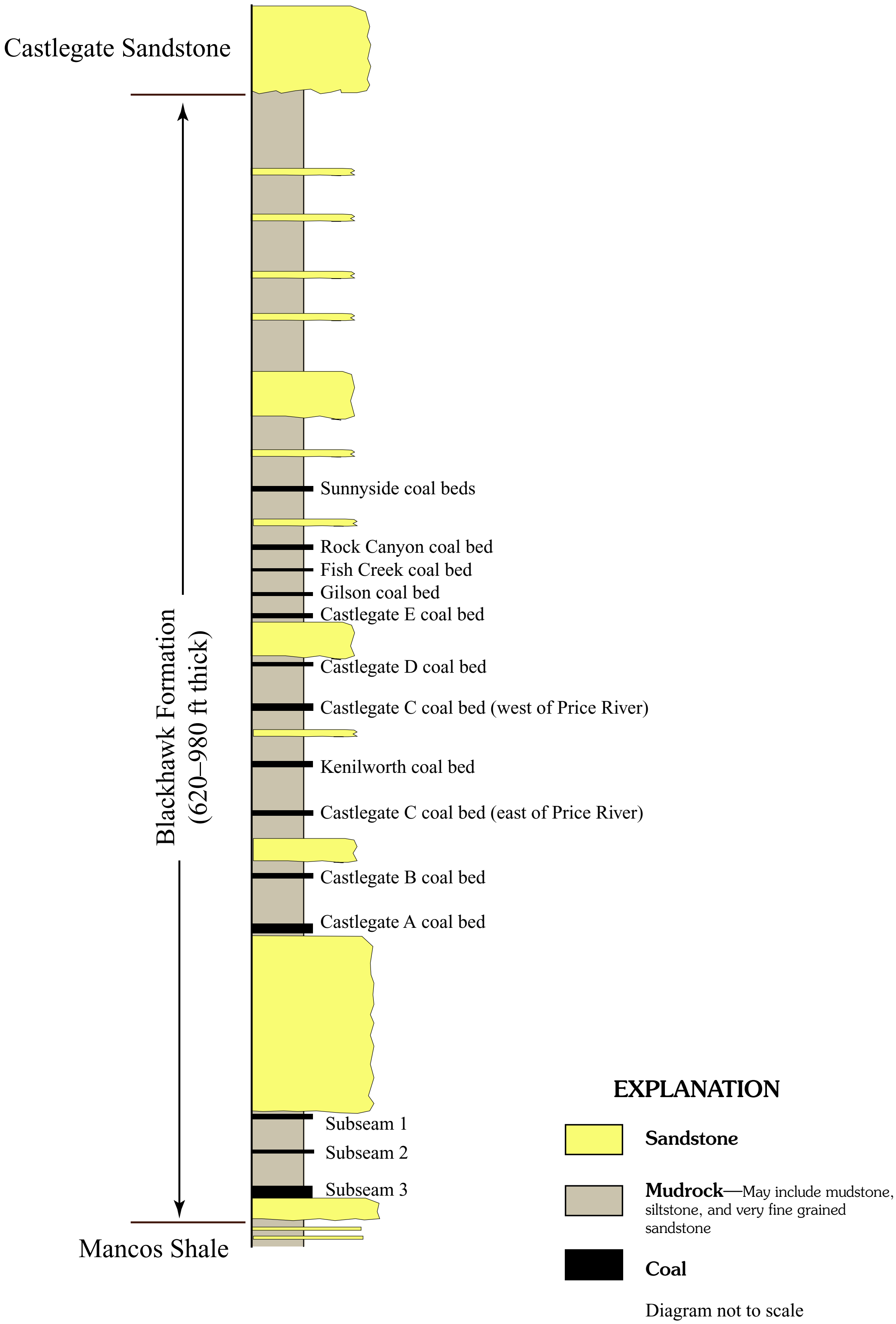


Figure 11. Schematic stratigraphic column showing coal beds in lower part of Blackhawk Formation, Book Cliffs coal field, Uinta Basin, Utah. Modified from Gloyn and Sommer (1993).

from an Ro of 0.60 percent or less in outcrops around the margins of the two basins to Ro values exceeding 1.35 percent in deeper basinal areas (fig. 12). Maximum Ro values are about 2.1 percent in the deep trough of the Piceance Basin, and about 1.8 percent along the deep trough of the Uinta Basin. The onset of thermogenic gas generation occurs at an Ro of about 0.73–0.75 percent (for example, see Johnson, 1989); coal-bearing zones in the basal part of the Mesaverde Group have exceeded this level of thermal maturity throughout much of the Uinta and Piceance Basins (fig. 13).

Charts summarizing the timing of source-rock gas generation for assessment units in the Mesaverde TPS are shown in figures 14–18. In the Uinta Basin, the onset of thermogenic gas generation in the coaly intervals began about 42 million years ago (Ma) in the deep-basin trough, with peak gas generation occurring between 26 and 17 Ma (fig. 14). Coal in the Emery Sandstone Member of the Mancos Shale in the Wasatch Plateau may have begun to generate gas as early as 68 Ma (fig. 17). In the Piceance Basin, the onset of gas generation along the deep-basin trough may have begun as early as 55 Ma, with peak generation occurring between 47 and 39 Ma (fig. 15). The difference in timing for gas generation in the two basins is related to their respective thermal and burial histories. During the Cretaceous, both basins were part of a much larger foreland basin that formed primarily as a result of thrust loading along the Sevier orogenic belt, which impinges on the west margin of the Uinta Basin. From latest Cretaceous through Eocene time, the foreland basin was separated into several smaller structural and sedimentary basins by rising Laramide uplifts. The Laramide Piceance Basin began to subside in Late Cretaceous (late Campanian) time, and subsidence ended during the middle Eocene (Johnson and Finn, 1986; Johnson, 1990). The Laramide Uinta Basin, in contrast, did not begin to subside until sometime during the Paleocene, with subsidence continuing into the late Eocene and possible early Oligocene time (Johnson and Finn, 1986). Cooling, as a result of downcutting during the last 10 m.y., has greatly reduced the rate of gas generation in both basins, but some gas generation may still be occurring where present-day subsurface temperatures in Mesaverde Group coal-bearing intervals exceed about 200°F (Law, 1984; Spencer, 1987).

Migration Summary

Coal has a substantial capacity to store gas in micropores and cleats, and as adsorbed gas within its molecular structure. Thus, much of the gas generated during the early stages of thermogenic gas generation remains within the coal beds. Only after the coal is saturated with gas does significant expulsion of gas occur. The ability of coal to store gas decreases with increasing rank (Juntgen and Karweil, 1966; Meissner, 1984); also, increasing pressure increases the storage capacity, whereas increasing temperature decreases storage capacity (Meissner, 1984; Wyman, 1984). Coal beds generally start to expel appreciable amounts of gas at medium-volatile bituminous ranks and higher (Ro=1.1 percent or greater) (Rice, 1993). The capacity for dispersed organic matter, such as that found in carbonaceous shale, to store methane is less well understood, and it is possible that carbonaceous shale expels gas at lower levels of thermal maturity (Ro<0.75 percent). Johnson and Rice (1990) found that coalbed gases in the Piceance Basin were distinctly different from gases in adjacent sandstone reservoirs. They suggested that sandstones in the basin-centered accumulation might contain gas generated from dispersed Type III organic matter in carbonaceous shales as well as gas generated from coals.

Gas expelled from coals and carbonaceous shales in the Uinta and Piceance Basins migrated into nearby, low-permeability sandstone beds in the Mesaverde Group, initiating the development of basin-centered gas accumulations in both basins. Migration from the source rocks into sandstone beds probably occurred along fractures that formed as pressures increased and eventually exceeded fracture gradients during active gas generation. These accumulations probably began to form during peak gas generation, which occurred about 26 Ma in the Uinta Basin (fig. 14) and 47 Ma in the Piceance Basin (fig. 15). As nearby sandstone reservoir rocks became largely gas saturated, gas derived from coal and carbonaceous shale in the lower part of the Mesaverde Group began to migrate vertically, expanding the basin-centered accumulations into the overlying less organically rich part of the Mesaverde Group as well as into overlying lower Tertiary rocks at places such as the Greater Natural Buttes (GNB) field in the Uinta Basin. Some Mesaverde gas also escaped vertically into shallow, conventional-type sandstone reservoirs in both basins (Johnson and Rice, 1990; Rice and others, 1992; Johnson and others, 1994). The vertical migration of gas from Mesaverde Group source rocks through faults and major fractures may best be evidenced in the GNB field, which coincides in large part with a major fault-fracture trend (figs. 5, 6). Many of the fractures are filled with gilsonite, a solid hydrocarbon derived from oil shale in the Green River Formation.

Vertical migration of gas has been documented by studying variations in carbon isotopic ratios in hydrocarbon gases. At GNB field in the Uinta Basin, isotopically similar gases are produced from sandstone reservoirs throughout the entire Mesaverde TPS at depths ranging from 4,210 to 9,332 ft (Rice and others, 1992). In the Piceance Basin, Johnson and Rice (1993) found that gases in the Molina Member of the Wasatch Formation at depths of from 1,100 to 2,300 ft (Rulison and Grand Valley fields, fig. 3) are indistinguishable isotopically from gases in the underlying Mesaverde Formation. The top of the Cameo-Fairfield coal group, which is the most likely source for this gas, occurs at depths of from 5,500 to 8,500 ft in this area. At the Piceance Creek Dome field in the central part of the Piceance Basin (fig. 3), gas from a sandstone reservoir in the lowermost part of the Eocene Green River Formation (depths from 2,300 to 2,700 ft) also appears to be derived largely from Mesaverde Group coal and carbonaceous shale. There, the Cameo-Fairfield coal group occurs at depths

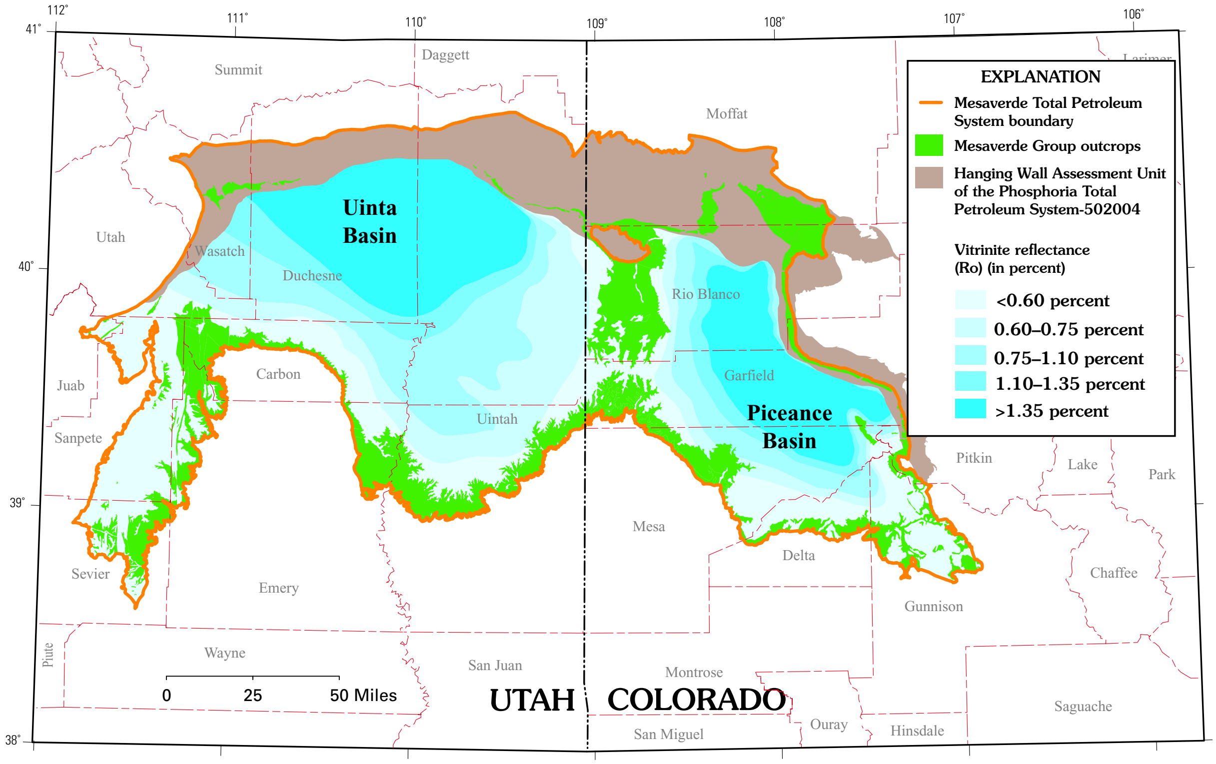


Figure 12. Variations in thermal maturities based primarily on vitrinite reflectance (Ro) for coal or carbonaceous shale beds in the lower part of the Mesaverde Group, Uinta and Piceance Basins, Utah and Colorado. Maturity data compiled primarily from Nuccio and Johnson (1984, 1986); map is based on Nuccio and Roberts (Chapter 4, this CD-ROM).

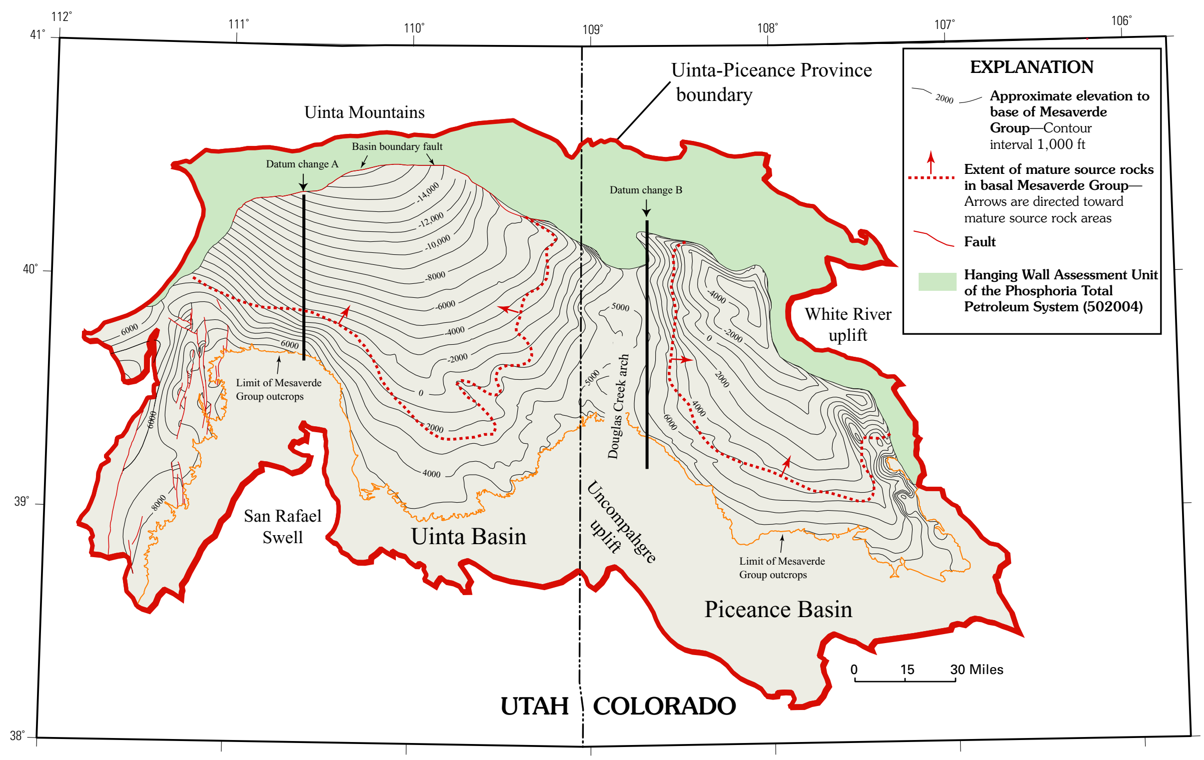


Figure 13. Structure contour map drawn on horizons near base of Mesaverde Group (base of the Mesaverde Total Petroleum System). Contours drawn on the top of the Blackhawk Formation in the western part of the Uinta Basin (west of datum change A), on the top of the lower Castlegate Sandstone in the central and eastern parts of the Uinta Basin (between datum changes A and B), and on the top of the Rollins and Trout Creek Sandstone Members of the Iles Formation in the Piceance Basin (east of datum change B). Contours on the lower Castlegate modified from Johnson (1986); contours on the Rollins and Trout Creek modified from Johnson (1983).

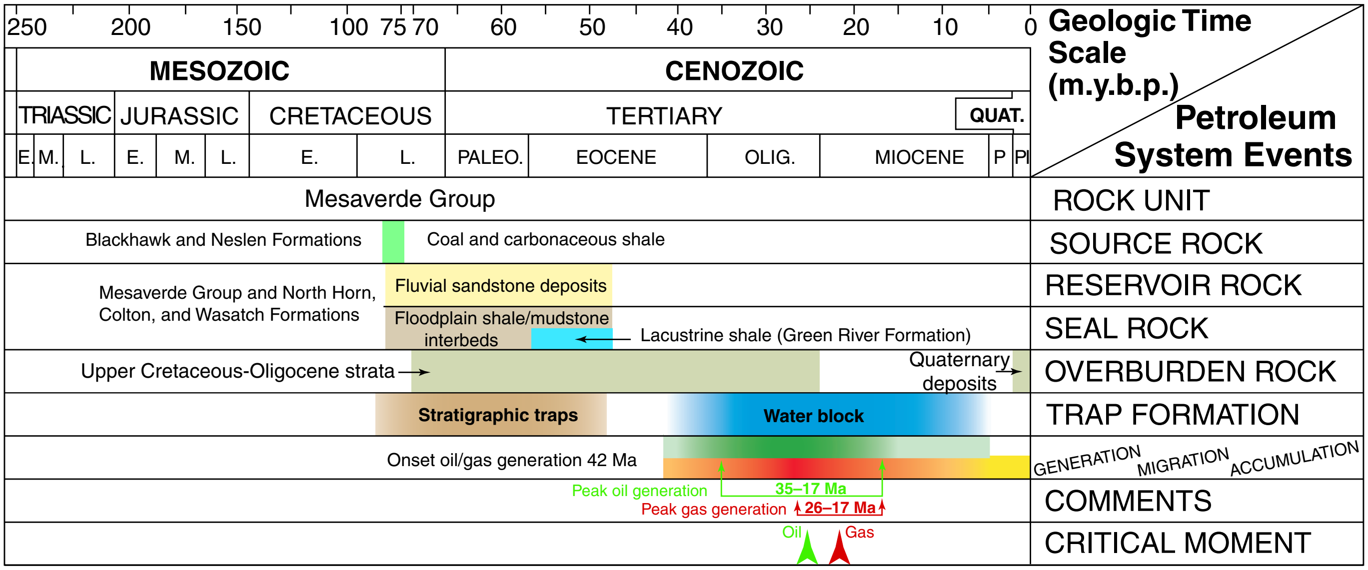


Figure 14. Petroleum system events chart showing interpreted timing of elements and processes related to hydrocarbon generation and accumulation in Uinta Basin Continuous Gas Assessment Unit (AU 50200261) and Uinta Basin Transitional Gas Assessment Unit (AU 50200262), Mesaverde Total Petroleum System. Water block refers to hydrocarbon trapping by capillary seal. Onset of hydrocarbon generation and timing of peak generation are from Nuccio and Roberts (Chapter 4, this CD-ROM). Peak generation refers to maximum depth of burial. Events chart format modified from Magoon and Dow (1994).

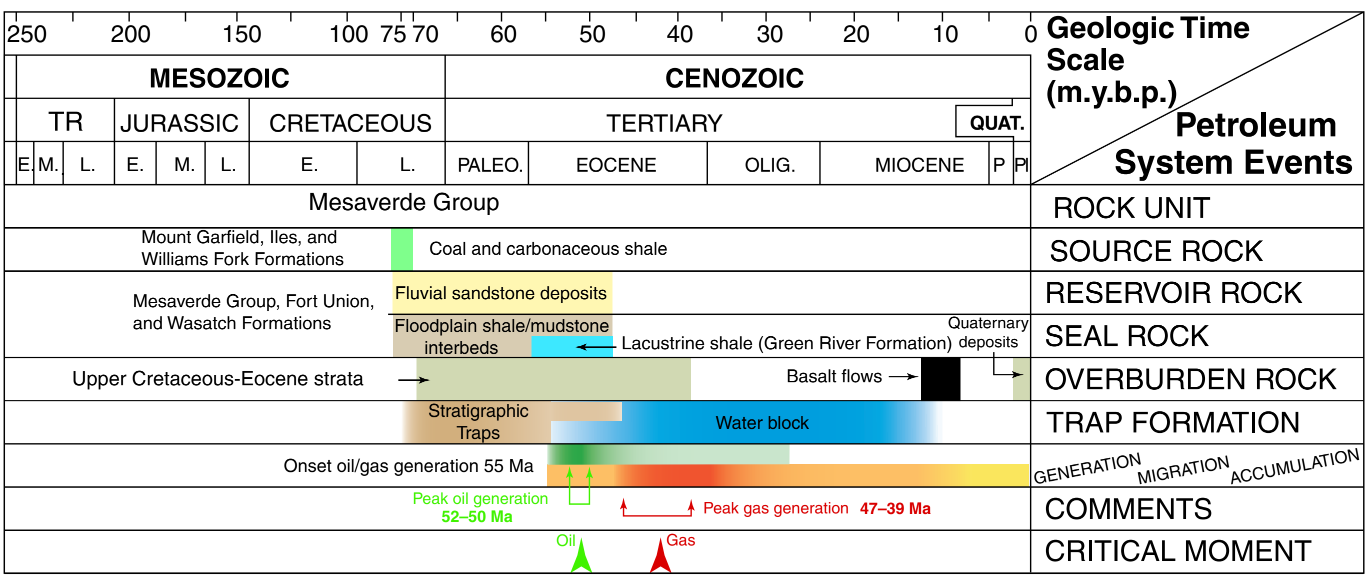


Figure 15. Petroleum system events chart showing interpreted timing of elements and processes related to hydrocarbon generation and accumulation in Piceance Basin Continuous Gas Assessment Unit (AU 50200263) and Piceance Basin Transitional Gas Assessment Unit (AU 50200264), Mesaverde Total Petroleum System. Water block refers to hydrocarbon trapping by capillary seal. Onset of hydrocarbon generation and timing of peak generation are from Nuccio and Roberts (Chapter 4, this CD-ROM). Peak generation refers to maximum depth of burial. Events chart format modified from Magoon and Dow (1994).

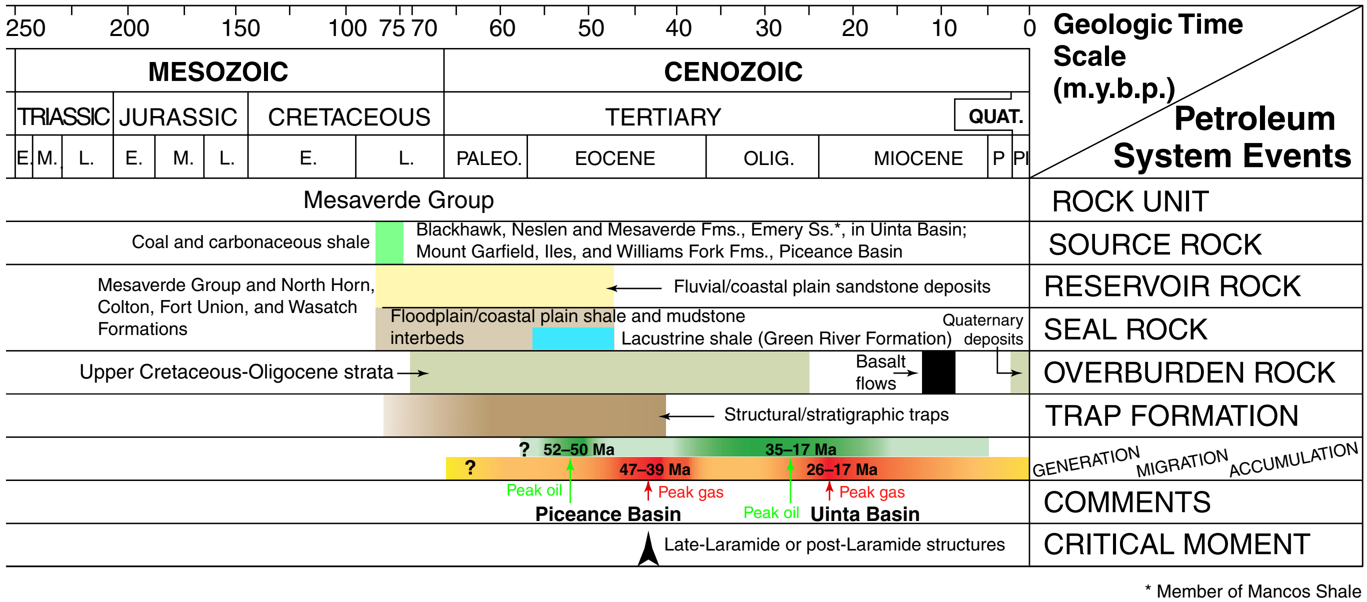


Figure 16. Petroleum system events chart showing interpreted timing of elements and processes related to hydrocarbon generation and accumulation in Uinta-Piceance Basin Conventional Gas Assessment Unit (AU 50200201), Mesaverde Total Petroleum System. Onset of hydrocarbon generation and timing of peak generation are from Nuccio and Roberts (Chapter 4, this CD-ROM). Peak generation refers to maximum depth of burial. Events chart format modified from Magoon and Dow (1994).

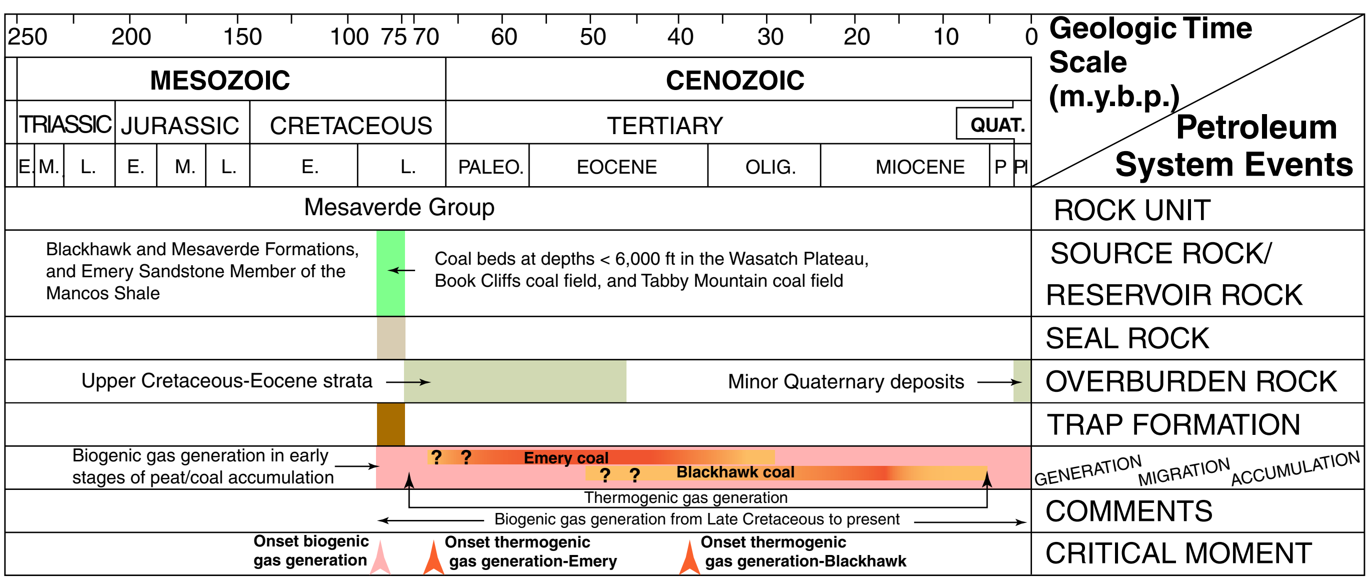


Figure 17. Petroleum system events chart showing interpreted timing of elements and processes related to gas generation and accumulation in Uinta Basin Blackhawk Coalbed Gas Assessment Unit (AU 50200281), Mesaverde Total Petroleum System. Onset of biogenic and thermogenic gas generation, and timing of peak generation are from Nuccio and Roberts (Chapter 4, this CD-ROM). Events chart format modified from Magoon and Dow (1994).

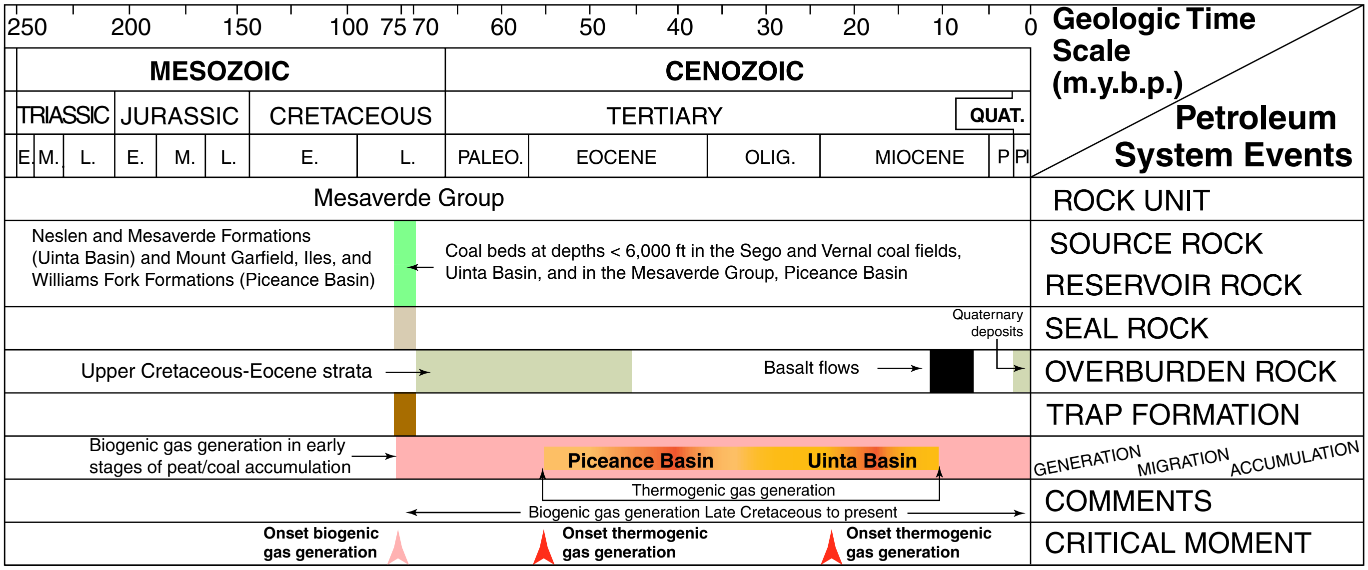


Figure 18. Petroleum system events chart showing interpreted timing of elements and processes related to gas generation and accumulation in Mesaverde Group Coalbed Gas Assessment Unit (AU 50200282), Mesaverde Total Petroleum System. Onset of biogenic and thermogenic gas generation, and timing of peak generation are from Nuccio and Roberts (Chapter 4, this CD-ROM). Events chart format modified from Magoon and Dow (1994).

ranging from 8,000 to 12,000 ft. At the White River Dome field in the northern part of the basin (fig. 3), an old, unplugged gas well, completed in Wasatch Formation sandstone at a depth of 955 ft, is still producing small amounts of gas that is isotopically similar to gases in the underlying Mesaverde Group. Depth to the Cameo-Fairfield coal group at that locality is about 5,500–6,500 ft.

Isotopic evidence also supports the concept that vertical migration of gases was more important than lateral migration. Gases are isotopically distinctive in each of the three different areas of the Piceance Basin mentioned above. The differences are related primarily to variations in thermal maturity in the underlying Cameo-Fairfield group, the likely source for gas in all three areas. Long-term lateral migration would tend to eliminate the distinctiveness of the gases in the three areas and eliminate the close correlation between isotopic compositions and thermal maturities in the underlying source rocks. Furthermore, lateral migration would likely be inhibited by the lenticular nature of the predominantly fluvial sandstone reservoirs in the Mesaverde TPS.

Reservoir Rocks

Producing and potential reservoir rocks are primarily fluvial channel sandstone beds in the Upper Cretaceous Mesaverde Group, and overlying lower Tertiary units including the Fort Union and Wasatch Formations in the Piceance Basin, the Wasatch Formation in the eastern part of the Uinta Basin, and the Upper Cretaceous–Paleocene North Horn Formation and the Paleocene and Eocene Colton Formation in the western part of the Uinta Basin (pls. 1, 2). Fluvial sandstone reservoir units are predominantly lenticular, and were deposited by various streams that flowed into the Uinta-Piceance Province during the Late Cretaceous and early Tertiary.

The bulk of gas production in the Mesaverde TPS is from sandstone reservoirs in the Mesaverde Group and Wasatch Formation. In most of the Piceance Basin, Mesaverde Group reservoirs range from 20 to 60 ft thick (Tremain, 1993), and have porosities varying from less than 5 percent to greater than 8 percent (Spencer, 1996). Mesaverde Group reservoirs are classified as tight, with permeabilities generally ranging from 0.01 to 0.1 millidarcies (mD) (Pitman and Spencer, 1984); locally, permeability may be as low as 0.0006 mD (for example, see Johnson, 1989). In the eastern Uinta Basin (Greater Natural Buttes field), Mesaverde Group sandstone reservoirs may be as thick as 70 ft, with porosities ranging to 18 percent; typical porosities vary from 8 to 12 percent. Reservoir permeability is usually less than 0.1 mD (Osmond, 1992).

Fluvial sandstone reservoirs in the Wasatch Formation of the Uinta Basin generally have porosities ranging from less than 5 percent to greater than 9 percent (Spencer, 1996). In the Greater Natural Buttes area, Wasatch sandstones are also considered to be tight, and typically have permeabilities of less than 0.1 mD (Osmond, 1992). The sandstone reservoirs are as thick as 40 ft, and have porosities generally ranging from 10 to 14 percent; locally, the porosity may be as high as 18 percent (Osmond, 1992). Given the tight nature of gas-producing reservoirs in the Mesaverde TPS, enhanced permeability from natural fractures is often critical to successful gas production.

Sandstone reservoirs in the Upper Cretaceous Mesaverde Group were deposited by meandering to braided stream systems in coastal plain and alluvial plain settings (figs. 19–21).

The thickness of Upper Cretaceous rocks in the Mesaverde TPS varies from about 1,500 to 2,500 ft throughout most of the Uinta Basin, the Douglas Creek arch area, and the westernmost part of the Piceance Basin. The interval thickens to over 4,500 ft along the deep trough of the Piceance Basin (Johnson and others, 1987). Total net sandstone thickness in beds 10 ft thick or greater in the Upper Cretaceous interval in the Piceance Basin varies from less than 500 ft along the west margin of the Piceance Basin to more than 1,900 ft along the deep basin trough (fig. 22). Reinecke and others (1991), in a study of the Grand Valley field in the south-central part of the Piceance Basin (fig. 3), estimated that a typical drill hole encounters approximately 30 discrete sandstone units within the Upper Cretaceous interval. The total net thickness of such sandstone units in Grand Valley field varies from about 1,050 to 1,150 ft; individual sandstone beds average about 37 ft in thickness.

Paleocene and Eocene strata are separated from the underlying Mesaverde Group over much of the Uinta and Piceance Basins by an unconformity. Sandstones in the uppermost part of the Mesaverde Group are typically kaolinized as a result of extended exposure to surface weathering processes (Johnson and May, 1978, 1980). These sandstone beds form a distinctive white zone that can be recognized in outcrop (figs. 23, 24). Late Paleocene fossils have been collected above the unconformity throughout the western part of the Piceance Basin, the Douglas Creek arch area, and the eastern part of the Uinta Basin (Johnson and May, 1978, 1980; Francyzk and Hanley, 1987; Francyzk and others, 1990). Continuous deposition between the Mesaverde Group and overlying lower Tertiary strata may have occurred in the central and western part of the Uinta Basin (Fouch and others, 1983).

The marked thinning of the Mesaverde Group over the Douglas Creek arch and eastern part of the Uinta Basin was originally thought to be caused largely by truncation prior to deposition of the overlying Paleocene and Eocene strata (Johnson and May, 1978, 1980). Isopach maps of time-stratigraphic intervals within the Mesaverde Group, however, indicate that much of this thinning is probably due to original variations in subsidence rates (Johnson, 1990; Chapter 10, this CD-ROM). Pollen collected from a conglomeratic unit, the Dark Canyon sequence of the Wasatch Formation (fig. 7), just above the Mesaverde Group in the eastern Uinta Basin has been dated as late early Paleocene in age (Francyzk and others, 1990), which indicates that at least some deposition occurred during the time gap represented by the unconformity. In addition, detailed mapping along the northeastern part of the Douglas Creek arch found that sandstones in the upper 350–600 ft of the Mesaverde Group were kaolinized only in their upper parts, indicating several periods of weathering during deposition rather than during a single period of deep weathering after deposition (Johnson and Smith, 1993). Thus thinning of the Mesaverde Group over the Douglas Creek arch and eastern part of the Uinta Basin may be largely due to declining rates of subsidence in latest Cretaceous time.

The thickness of reservoir-bearing strata in the lower Paleocene and Eocene part of the Mesaverde TPS varies from less than 500 ft along the Douglas Creek arch to more than 5,000 ft in some of the deeper areas of the Uinta and Piceance Basins. Sandstone beds in the lower Tertiary interval were deposited in an alluvial plain setting that developed around extensive lakes that were present in the Uinta and Piceance Basins throughout much of early Tertiary time. Figure 25 shows some of the major stream depocenters in the Uinta and Piceance Basins during Paleocene and Eocene time. The Douglas Creek arch appears to have acted as a drainage divide throughout much of the Paleocene and Eocene, although some stream connection between the two basins probably existed between the north end of the Douglas Creek arch and the Rangely anticline (fig. 4) at various times (Johnson, 1985). One of the largest and longest lasting fluvial systems in early Tertiary time flowed northward into the south-central part of the Uinta Basin between the San Rafael Swell on the west and the Douglas Creek arch on the east (fig. 25). The oldest Tertiary rocks deposited by fluvial systems in this area of the Uinta Basin are the late-early Paleocene Dark Canyon sequence of the Wasatch Formation (fig. 7). Crossbeds from these conglomerates, observed directly above the Cretaceous-Tertiary unconformity in the eastern part of the Uinta Basin, indicate deposition by north-flowing streams (Francyzk and Pitman, 1987). The overlying upper Paleocene and lower Eocene Wasatch and Colton Formations contain abundant fluvial channel sandstones deposited by north-flowing rivers as well (Chapman, 1982; Zawiskie and others, 1982; Dickinson and others, 1986). Paleogeographic reconstructions by Ryder and others (1976) show that an extensive, sandy alluvial facies was deposited continuously in this area from middle Paleocene through early Eocene time. These north-flowing rivers deposited the gas-productive lower Tertiary sandstone reservoirs at the Greater Natural Buttes field in the southeastern part of the Uinta Basin.

In the Piceance Basin, a major early Tertiary fluvial system flowed northwestward into the southeastern part of the basin during Paleocene time (fig. 25). This river system deposited andesitic conglomerates and sandstone beds that are present within a 1,000-ft-thick interval overlying the Mesaverde Group throughout the southeastern part of the basin (Johnson and others, 1979a, 1979b, 1979c). There is no known hydrocarbon production from these conglomeratic sandstone units, although gas is produced from sandstone in the underlying Mesaverde Group and from nonandesitic sandstone reservoirs in the overlying Wasatch Formation. The conglomeratic strata are overlain throughout much of the Piceance Basin by dark-colored, predominantly carbonaceous mudstones that were deposited in a paludal environment during late Paleocene time (Johnson, 1985).

A major northeast-flowing fluvial system developed in the southwestern part of the Piceance Basin during latest Paleocene–earliest Eocene time (fig. 25), in an area where only very minor streams existed previously. Fluvial sandstone units deposited by this system extend as far east as the Hogback monocline (fig. 4), along the eastern margin of the basin (Donnell, 1969). Sandstone and conglomeratic sandstone units

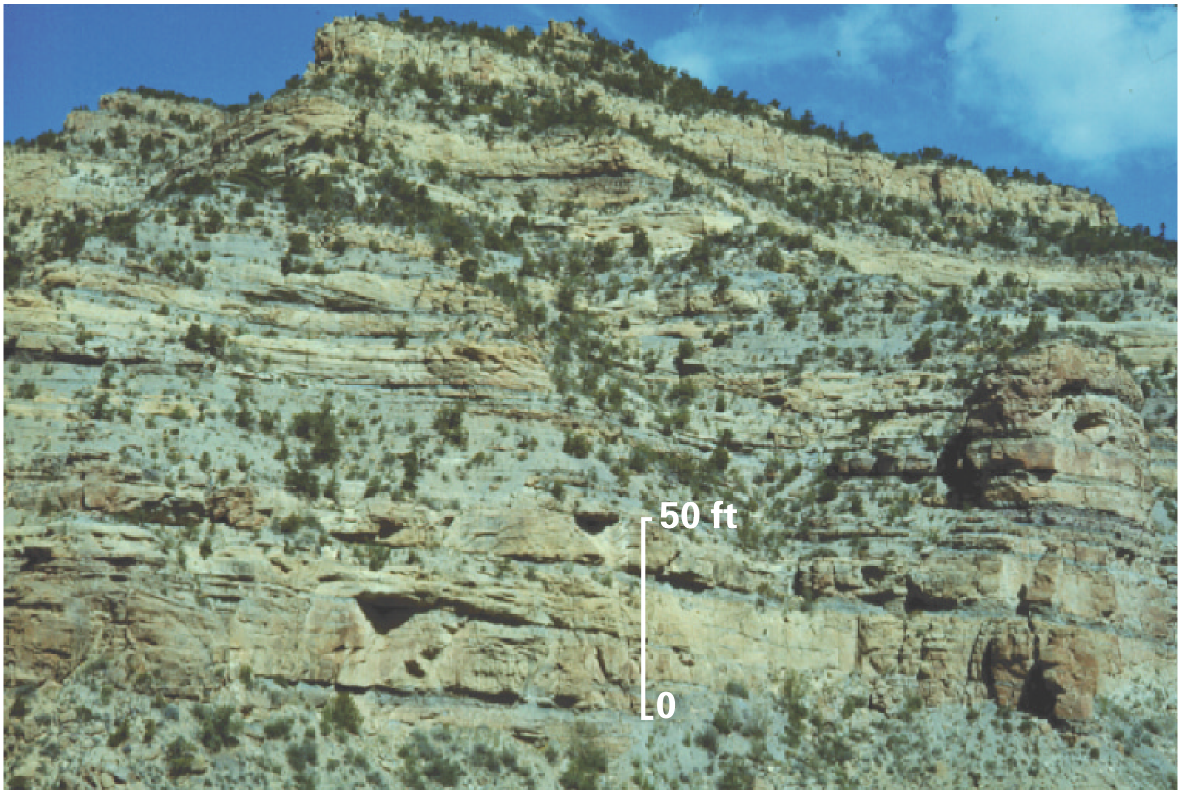


Figure 19. Fluvial channel sandstones in Mesaverde Group at Hunter Canyon in southwestern part of Piceance Basin, Colorado.

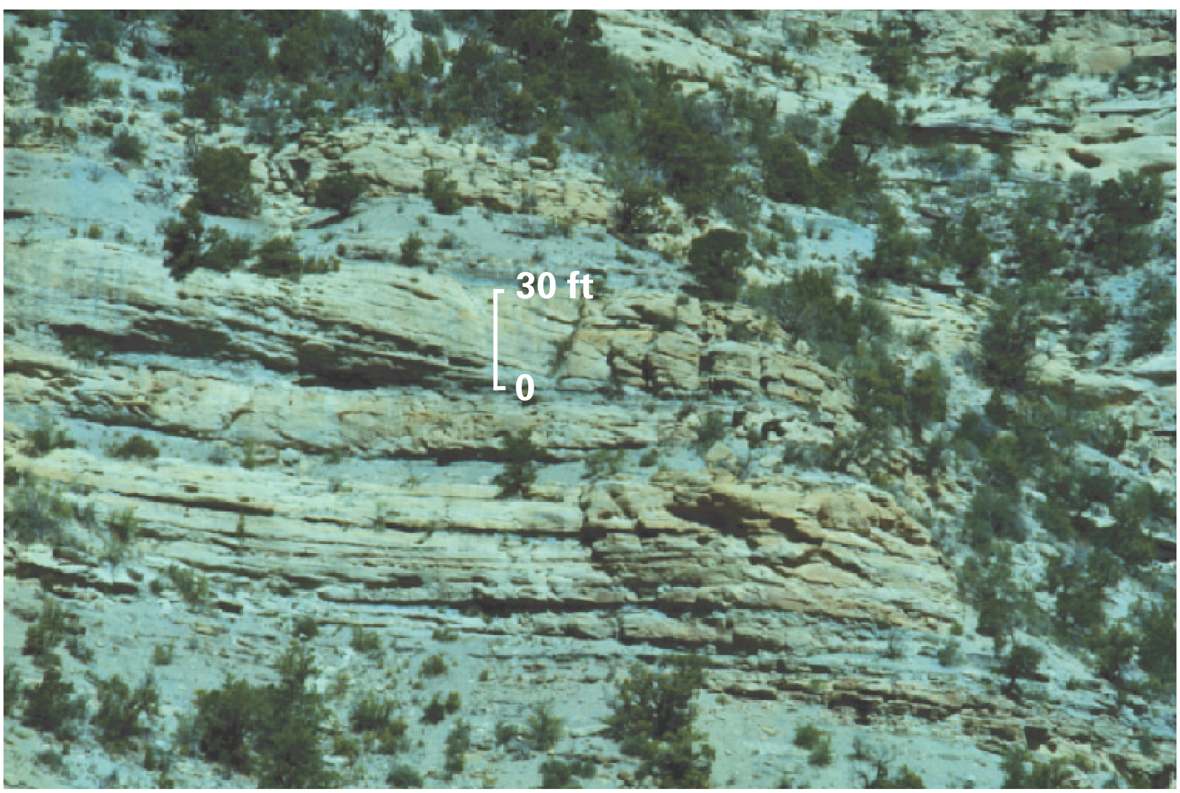


Figure 20. Fluvial channel sandstone displaying lateral accretion in Mesaverde Group at Hunter Canyon in southwestern part of Piceance Basin, Colorado.

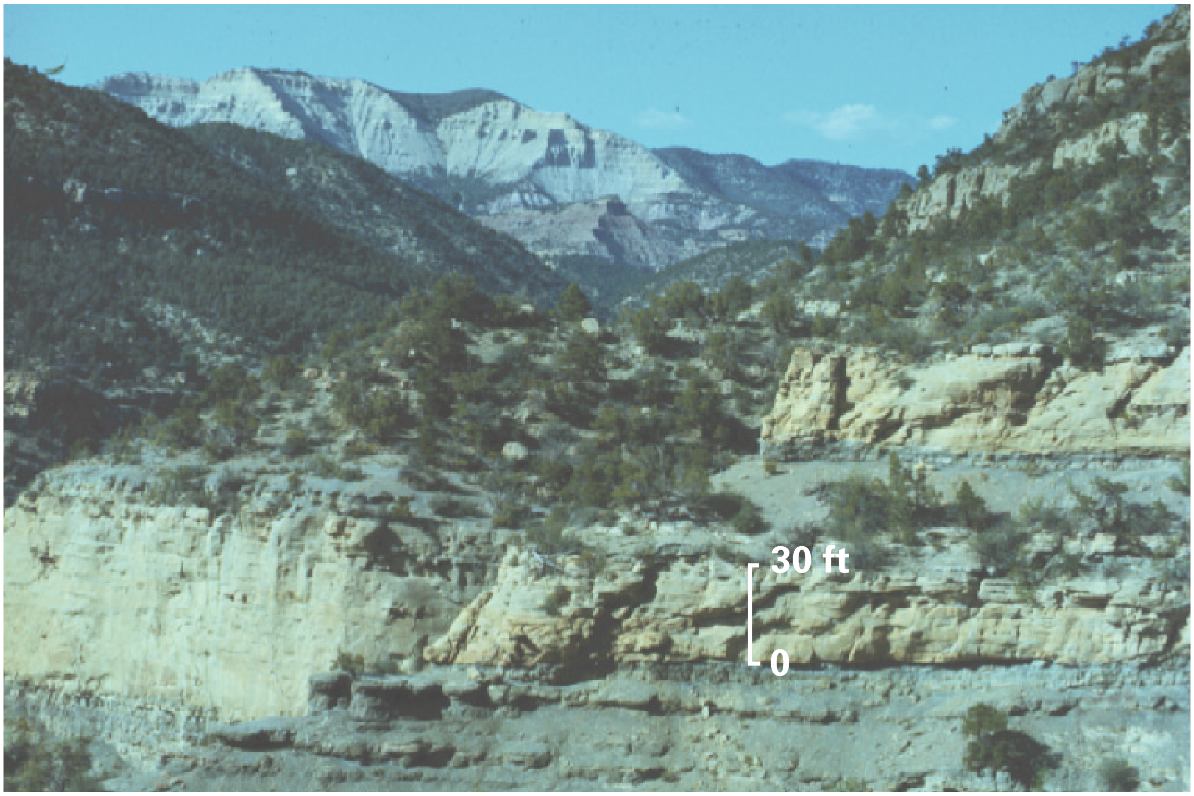


Figure 21. Two lenticular, fluvial channel sandstones in Mesaverde Group at Hunter Canyon in southwestern part of Piceance Basin, Colorado.

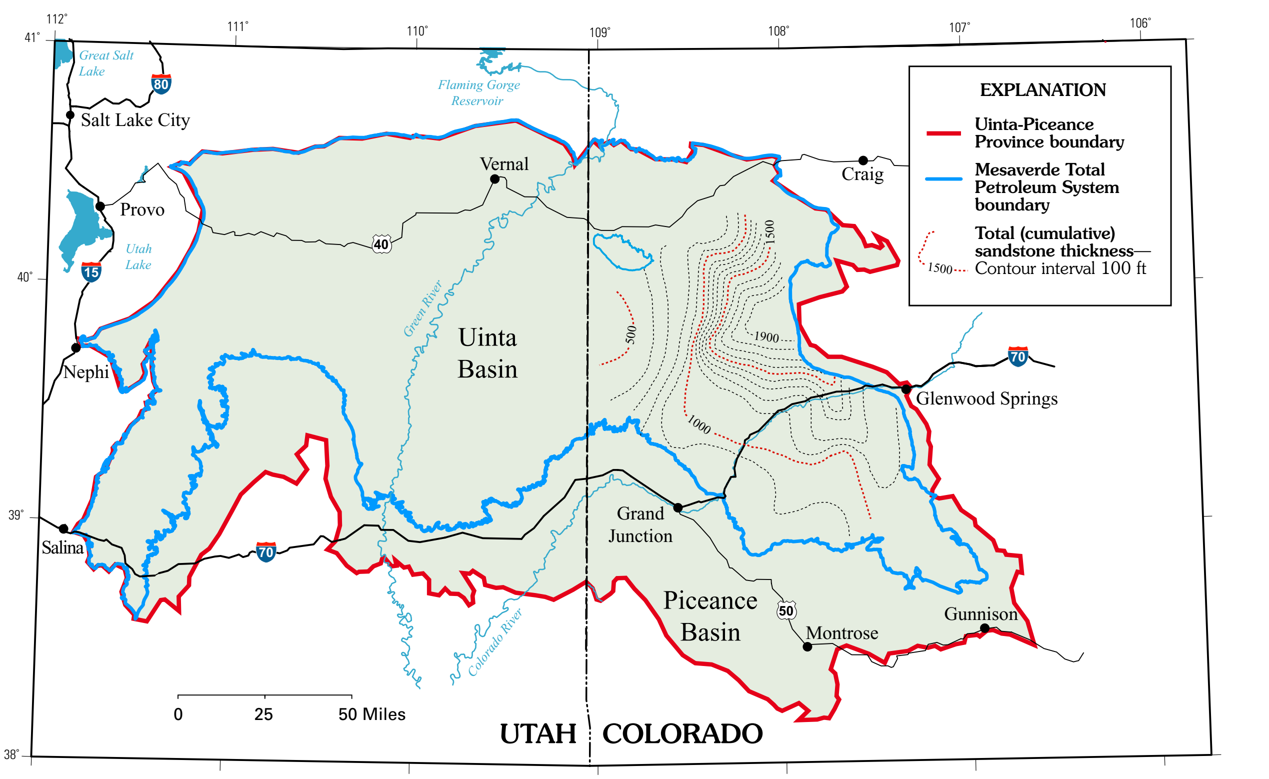


Figure 22. Cumulative thickness of sandstones greater than 10 ft thick in Williams Fork Formation, Mesaverde Group, Piceance Basin, Colorado. Modified from Johnson and others (1987).

Figure 23. White-weathering zone in uppermost part of Mesaverde Group, southwestern Piceance Basin, Colorado. Variegated mudstone succession above weathered zone is late Paleocene in age, and is within the Wasatch Formation.

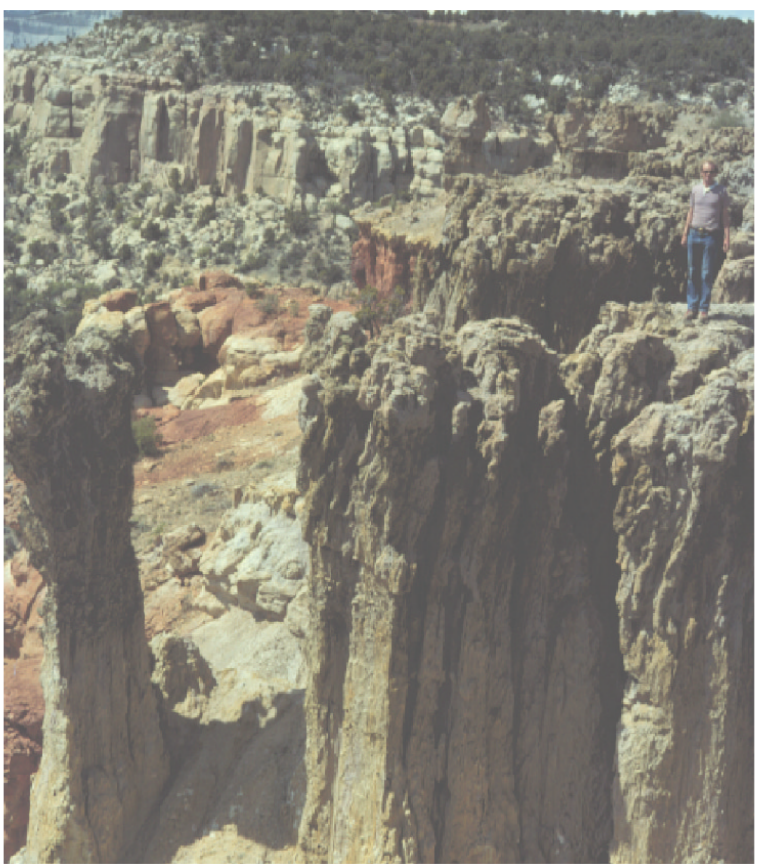


Figure 24. Thick sequence of paleosols preserved at top of Mesaverde Group, southwestern Piceance Basin, Colorado.

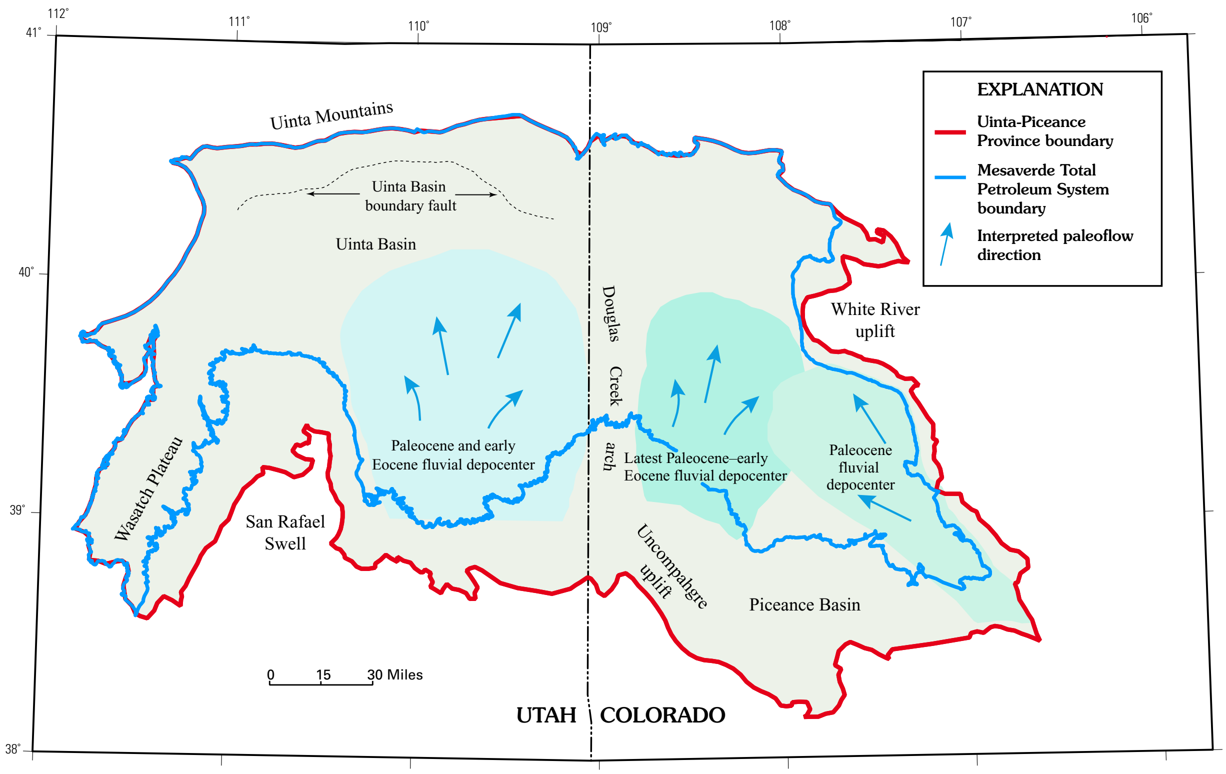


Figure 25. Locations of major fluvial (river) depocenters during Paleocene and Eocene time in Uinta and Piceance Basins, Utah and Colorado.

deposited at that time directly overlie the dark-colored mudstone and carbonaceous mudstone throughout most of the southern half of the Piceance Basin. This sandy/conglomeratic interval, the Molina Member of the Wasatch Formation (Donnell, 1969), and the equivalent "Wasatch G" interval in the subsurface in the central part of the basin, are as much as 500 ft thick in some areas. The sandstone and conglomeratic units in this interval have been interpreted as being deposited by braided streams (Johnson and May, 1978), and are in sharp contact with the underlying paludal mudstone. The cause of this abrupt shift in environments from paludal to braided streams is uncertain. Pebbles in the sandstone units are composed primarily of chert and quartzite in contrast to the abundant andesitic pebbles found in sandstone beds underlying the Molina/Wasatch G interval (Johnson, 1982). The Molina Member and "Wasatch G" sandstone reservoirs produce gas at Piceance Creek Dome and Sulphur Creek fields in the central part of the Piceance Basin, and at Parachute and Rulison fields in the southern part of the basin (fig. 3).

The Molina Member and "Wasatch G" interval in the Piceance Basin grade upward into an interval of variegated mudstone and lenticular fluvial sandstone beds that are less persistent laterally. This variegated interval grades laterally into lacustrine rocks of the Green River Formation toward the central part of the basin (pl. 1). Minor gas has been produced at shallow depths from thin, lenticular sandstone reservoirs in the interval above the Molina/Wasatch G interval at White River dome and DeBeque anticline (fig. 4). Most of this production was from the early 1900's, and poorly documented.

In summary, there are significant differences in the distribution of sandstone reservoirs in the Mesaverde TPS between the Uinta and Piceance Basins. The Upper Cretaceous interval is much thicker and contains more sandstone reservoirs in the Piceance Basin than in the Uinta Basin. In contrast, the Uinta Basin contains more lower Tertiary sandstone reservoirs than the Piceance Basin, primarily because of major, long-lived river systems that flowed northward into the basin. Lower Tertiary sandstone reservoirs in the Uinta Basin typically occur directly above the Upper Cretaceous Mesaverde Group, and it is difficult to distinguish Upper Cretaceous reservoirs from lower Tertiary reservoirs in the subsurface without identifying the bleached, kaolinized zone that marks the top of the Mesaverde Group. The only major, lower Tertiary sandstone reservoir identified thus far in the Piceance Basin is the Molina Member and equivalent units in the Wasatch Formation; these reservoirs are confined to a relatively thin stratigraphic interval. Certain differences are also reflected in gas production in the two basins. In the Greater Natural Buttes field in the eastern Uinta Basin (fig. 3), gas production has been established through a nearly continuous interval starting in the Mesaverde Group and extending upward through much of the overlying Wasatch Formation. The majority of production thus far has been from sandstone reservoirs in the Wasatch Formation. In the Piceance Basin, however, the majority of gas production is from sandstone reservoirs in the Mesaverde Group, with comparatively minor production from the Molina Member and equivalent units in the Wasatch Formation.

Traps/Seals

The overall trapping mechanism for basin-centered gas accumulations in low-permeability sandstone reservoirs such as those of the Mesaverde Group in the Uinta and Piceance Basins is thought to be a capillary seal or water block (Masters, 1979). Trapping is generally also aided by the complex, discontinuous nature of sandstone reservoirs in most basin-centered accumulations. Water blocks probably began to form sometime after gas generation began and prior to peak gas generation (figs. 14, 15). Additional gas accumulated within closed structural traps in conventional reservoirs. Within the basin-centered accumulations, including both continuous and transitional categories (see definitions in next section), gas-charged sandstone reservoirs are typically subdivided into relatively small isolated "compartments" with little or no communication between adjacent compartments. Compartmentalization is aided by lateral facies changes, small fault offsets, and variations in diagenesis. Locally, this compartmentalization has necessitated decreased well spacing (<20 acres) to effectively drain the majority of the gas-charged sandstone reservoirs. Trapping for conventional sandstone reservoirs in the Mesaverde TPS is both structural and stratigraphic.

Lacustrine shale units in the Green River Formation overlying Mesaverde TPS reservoir-bearing strata (pl. 1) appear to have acted as regional seals inhibiting the continued vertical migration of Mesaverde-sourced gas into Eocene-age and younger rocks throughout much of the Uinta and Piceance Basins. Gases produced above the lowest thick lacustrine shale are isotopically different than gases in the underlying Mesaverde TPS. In the Sulphur Creek field in the central part of the Piceance Basin, Johnson and Rice (1990) reported that gases from the Green River Formation were isotopically lighter than gases in the underlying Wasatch Formation and Mesaverde Group. Similar results have been reported in the Uinta Basin (Rice and others, 1992; Johnson and others, 1994). In the Wind River Basin of Wyoming, the lacustrine Waltman Shale Member of the Paleocene Fort Union Formation also appears to have acted as a seal prohibiting the vertical migration of gas (Johnson and Rice, 1993; Johnson and others, 1994; Johnson and Keighin, 1998).

Assessment Units in the Mesaverde Total Petroleum System (502002)

The Mesaverde Total Petroleum System (502002) includes seven gas assessment units. Some oil is also produced but the amount is so minor compared to the volume of gas that only gas resources are considered in this study. The assessment units comprise two continuous gas assessment units (50200261 and 50200263), two transitional gas assessment units (50200262 and 50200264), two coalbed methane assessment units (50200281 and 50200282), and one conventional gas assessment unit (50200201).

Continuous and Transitional Gas Assessment Units

As we define them here, continuous and transitional gas assessment units in the Mesaverde TPS (fig. 26) include and overlie Mesaverde source rocks where thermal maturity (vitrinite reflectance, Ro) values exceed 0.75 percent. Assessment unit boundaries are primarily based on the upward, vertical projection to the surface of vitrinite reflectance (Ro) contours from coal in the lower part of the Mesaverde Group (Nuccio and Roberts, Chapter 4, this CD-ROM). Continuous gas assessment units (50200261 and 50200263) are considered to be basin-centered gas accumulations, and are characterized by a predominance of gas-saturated sandstone reservoirs. Transitional assessment units (50200262 and 50200264) represent a "transition zone" surrounding the basin-centered (continuous) accumulations, and these are characterized primarily by a combination of gas-saturated reservoirs and water-wet reservoirs (Johnson and other, 1987; Johnson and others, 1996). Subtle variations from these general criteria will be addressed for each assessment unit in the following discussions.

Uinta Basin Continuous Gas Assessment Unit (AU 50200261)

Assessment Unit 50200261 is generally defined as that area of the Uinta Basin where a continuous gas accumulation developed from the generation and predominantly vertical migration of gas from thermally mature coal and carbonaceous shale source rocks in the lower part of the Mesaverde Group. The median estimated area of the assessment unit is about 2,050,000 acres (3,200 mi^2) (Appendix B; table B-1) in the north-central part of the Uinta Basin (fig. 26), and includes and overlies source rocks in the basal part of the Mesaverde Group with Ro values greater than or equal to 1.10 percent (Nuccio and Roberts, Chapter 4, this CD-ROM). In the eastern part of the assessment unit, in the Greater Natural Buttes (GNB) gas field (fig. 3), the boundary deviates from the projected Ro=1.10 percent line to include additional areas of interpreted continuous-type gas production in eastern and northeastern areas of the field. In the south-central and southwestern areas, where there is little or no gas production, the boundary is defined solely by the position of the Ro=1.10 percent line (fig. 26). The northern limit extends 2 mi north and northwest of the projected trace of the Uinta Basin boundary thrust fault (fig. 4) (for example, see Campbell, 1975; Fouch and others, 1992) to account for potential gas accumulation in subthrust areas beyond the surface projection of the fault. Variability in the estimated area (minimum-maximum extent; Appendix B; table B-1) relates primarily to uncertainty as to the extent of

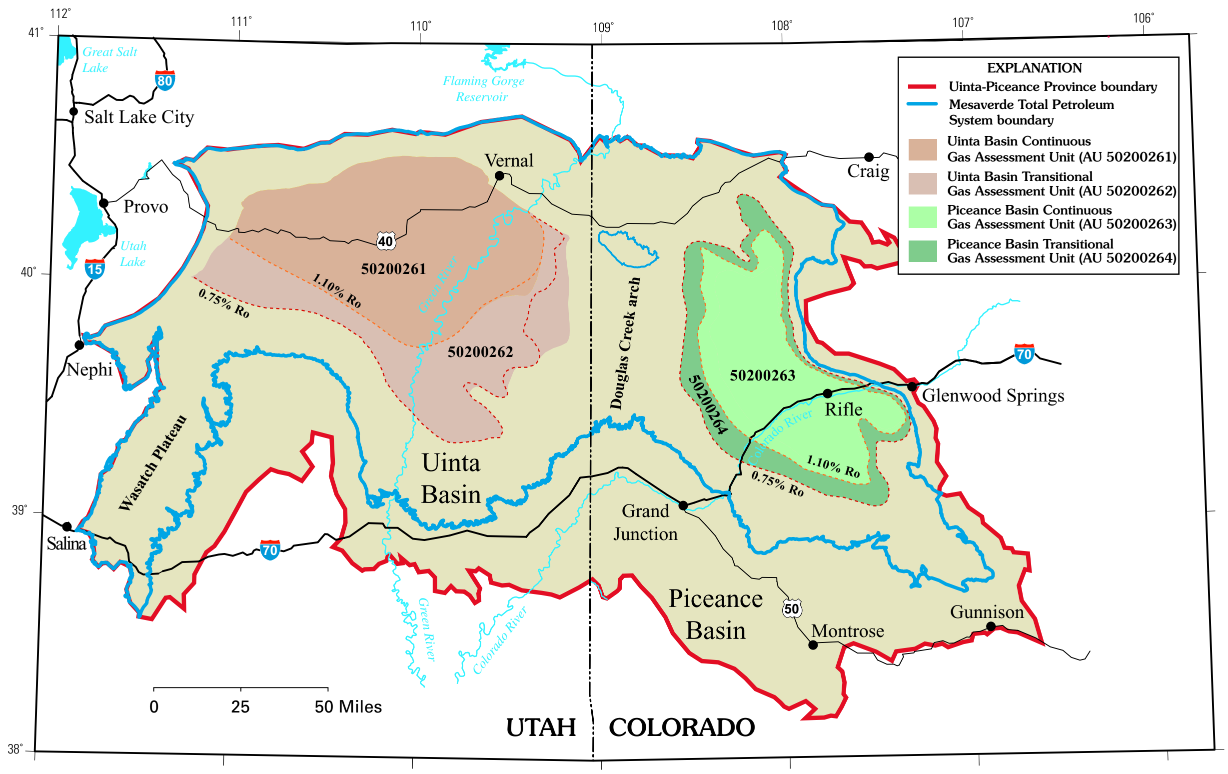


Figure 26. Continuous and transitional gas assessment units in Mesaverde Total Petroleum System, Uinta and Piceance Basins, Utah and Colorado. Levels of thermal maturity (vitrinite reflectance values), which were used to help define the assessment units, are from Nuccio and Roberts (Chapter 4, this CD-ROM).

the subthrust area along the northern boundary of the assessment unit.

Stratigraphically, Assessment Unit 50200261 extends vertically from the base of the lowest coal zone in the Mesaverde Group to the base of the Green River Formation. The base of the Neslen Formation marks the base of the lowest coal zone in the eastern part of the assessment unit, whereas in the western part the lowest coal zone occurs in the Blackhawk Formation (figs. 7, 8). Lenticular, fluvial channel sandstone units in the Wasatch Formation and Mesaverde Group are the primary gas reservoirs. Gas accumulations are confined (sealed) by relatively impermeable mudrock that surrounds many of the sandstones, and by the process of capillary seal (water block) within the overall basin-centered accumulation (for example, see Law and Dickinson, 1985). With respect to hydrostatic pressure at reservoir depth, reservoir pressures vary from being significantly overpressured in the lower strata to normally pressured or underpressured in the upper strata. Although the assessment unit is considered to represent a continuous gas accumulation, it includes an increasing number of water-saturated sandstones in upper stratigraphic levels. Gas-producing reservoirs in the upper strata may have similar characteristics with regard to water saturation as gas reservoirs in the adjacent Uinta Basin Transitional Gas Assessment Unit (AU 50200262) (fig. 26). Additionally, individual sandstone reservoirs in the upper part of Assessment Unit 50200261 may have conventional permeability (>0.1 mD) and apparent gas/water contacts (Osmond, 1992).

Through the last quarter of 1997, more than 900 gas-producing wells had been completed within the Uinta Basin Continuous Gas Assessment Unit (Appendix A) (Petroleum Information/Dwights LLC, 1999). Most of the gas production is concentrated in the southeastern part in the GNB field, which represents a coalesced field including Natural Buttes and some 13 additional smaller gas fields in the area (Osmond, 1992). A summary of GNB reservoir and gas characteristics, based on Osmond (1992), is as follows: the majority of the production is from fluvial channel sandstone reservoirs in the Wasatch Formation and, to a lesser degree, fluvial channel sandstone reservoirs in the Mesaverde Group. Gas was first discovered in the field in 1952, although the credited "discovery well" was drilled in 1955. Wasatch Formation reservoirs are as much as 40 ft thick, and production depths range from 2,800 to 8,100 ft; most Wasatch reservoirs are normally pressured. Mesaverde Group reservoirs are as much as 70 ft thick with production depths ranging from 4,500 to 8,600 ft; these reservoirs are typically overpressured, and are the tightest (lowest permeability) reservoirs in the field. Heating values for gas produced from Wasatch reservoirs range from 1,048 to 1,134 Btu, and from 1,066 to 1,179 Btu for Mesaverde reservoirs. The chemical wetness of gases from both Wasatch and Mesaverde reservoirs at GNB ranges from C_1/C_{1-5} 0.91 to 0.95 (Rice and others, 1992). The CO_2 content of GNB gas is generally less than 2 percent, with lowest concentrations (<0.5 percent) in gas from Wasatch reservoirs.

A graph showing the estimated ultimate recovery (EUR) for gas wells in all fields in the assessment unit, based on production from 803 wells, is shown in figure 27; EUR distributions by thirds is shown in figure 28. [Note: “Thirds” refers to the tripartite division of the number of wells drilled during the exploration and development period.] With respect to the 803 wells drilled in Assessment Unit 50200261, each third—early, middle, and late—would include about 268 wells regardless of the time period (years) involved. Only wells with minimum recoveries of more than 0.02 billion cubic feet of gas (BCFG) were used to calculate the EUR distributions. Figure 28 represents EUR distributions based on production from the first (early), second (middle), and third (late) third of the 803 producing gas wells used in our production analysis of the assessment unit. It should be emphasized that most of the production data is from the GNB field, which encompasses only a small percentage (<10 percent) of the entire assessment unit area.

Figure 28 shows two trends of interest to resource assessment: (1) it appears that the earlier wells had overall higher maximum EUR projections, suggesting that the “best wells” in GNB field may have been discovered in the early phases of development; and (2) although earlier wells had higher maximum EUR’s, more recent production has improved in terms of minimum recovery, as represented by late average EUR’s. The latter could be the result of improved subsurface analytical techniques allowing for more consistent identification of gas-saturated reservoirs rather than water-saturated sandstone, particularly in regard to reservoirs in the Wasatch Formation. Improved recovery technology may also be a factor.

The EUR distributions were the primary basis for estimating minimum, median, and maximum ultimate recoveries for untested cells in the assessment unit. These estimates are shown alongside the EUR distribution for all wells in all fields (fig. 27). The estimated minimum total recovery of 0.02 BCFG was based on considerations of the minimum recovery that might be required for an untested cell to be “commercially” viable within similar geologic and production constraints characteristic of producing gas wells in GNB field. Our estimated median total recovery (0.5 BCFG) is slightly lower than the average EUR of about 0.7 BCFG estimated for 50 percent of the most recent one-third of the producing wells in the assessment unit (fig. 28). The EUR estimates are heavily biased toward GNB, which may be somewhat of a unique “sweet spot” in terms of fault and fracture conduits for gas migration and accumulation (Osmond, 1992). For this reason, we estimated a slightly lower median recovery for untested cells to account for some uncertainty as to whether similar geologic conditions characteristic of the GNB field exist elsewhere in the assessment unit. In contrast, our estimated maximum total recovery for untested cells of 40 BCFG reflects the possibility that another field with GNB characteristics might indeed exist. With so much untested area (>90 percent of the total assessment unit), this seems to be a plausible conclusion.

Because Assessment Unit 50200261 represents a basin-centered accumulation, and is defined to include thermally mature source rocks throughout its entire extent, a potential for gas resources exists essentially everywhere within its boundaries. However, that part of the assessment unit outside of the GNB field has not been extensively tested; only about 10 percent of the total number of tested cells (see Appendix A) are in areas other than GNB. Some of these are wells listed as dry holes (Petroleum Information/Dwights LLC, 1999) but they actually encountered significant gas shows, based on reported drill-stem tests, and may have been completed as producers had they occurred within GNB, where a gas-production infrastructure, including roads and pipelines, is available. Possible reasons for the scarcity of tests outside GNB might include (1) lack of infrastructure, particularly in the western part of the assessment unit, (2) excessive drilling depths along the axis of the basin in the northern part of the assessment unit, and (3) poor gas recovery in “wildcat” wells in previously untested areas.

In established areas such as the GNB field, fault and fracture systems associated with reservoir strata in the Wasatch Formation and Mesaverde Group may have allowed for gas migration and enhanced reservoir permeability in otherwise tight sandstones (for example, see Osmond, 1992). It is likely that similar fault and fracture systems exist elsewhere in the assessment unit. An additional geologic factor enhancing gas-production potential may relate to lacustrine shale units in the basal part of the Green River Formation. Lacustrine shale units overlie producing gas reservoirs in the GNB field (fig. 29), and these shale units may have acted as seals, impeding significant gas migration into reservoirs stratigraphically above the Mesaverde TPS. These lacustrine shale units extend throughout much of the assessment unit in the central Uinta Basin (for example, see Johnson, 1985), and therefore may provide a potential widespread seal for gas accumulation in untested areas. However, the lack of wells penetrating the Mesaverde TPS in much of the assessment unit, particularly in areas overlying the deep Uinta Basin trough, precludes a complete understanding of the distribution of fracture systems, and the quality and abundance of source rocks and reservoir rocks. Although the potential for successful gas production exists throughout the assessment unit, we anticipate that the percentage of successful tests (wells producing more than a minimum of 0.02 BCFG) will probably decrease as untested areas outside of established fields are developed.

Our estimate for the minimum percentage of the untested assessment unit area that has the potential for additions to reserves in the next 30 years is 4 percent (Appendix B; table B-1). This value is based on the expectation that additional gas production will focus primarily on infill drilling within the restricted area in the GNB field. Our estimated median area with the potential for additional reserves in the next 30 years is 30 percent of the untested assessment unit area (Appendix B; table B-1). This value represents additions to reserves from infill drilling coupled with expansion of fields into nearby untested areas that may have geologic characteristics similar

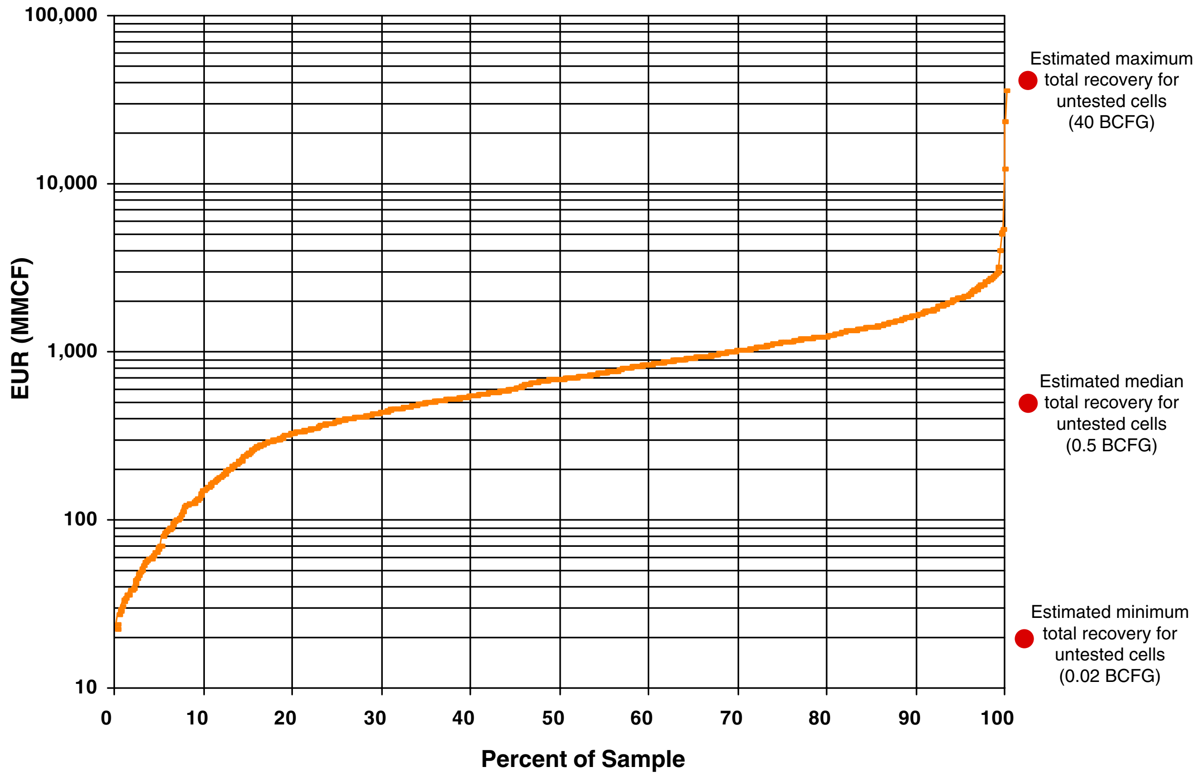


Figure 27. Distribution of estimated ultimate recoveries (EUR's) for 803 gas wells within Uinta Basin Continuous Gas Assessment Unit (AU 50200261), Mesaverde Total Petroleum System, Uinta Basin, Utah. Only wells with minimum EUR's exceeding 0.02 billion cubic feet of gas (BCFG) are shown.

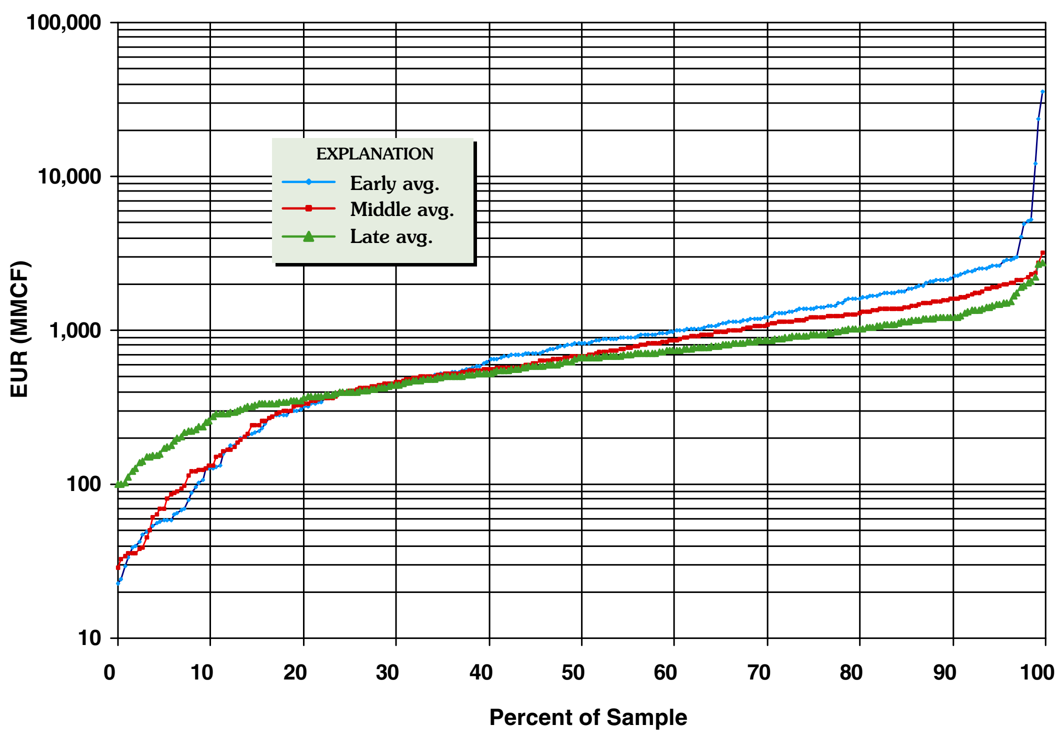


Figure 28. Distribution of estimated ultimate recoveries (EUR's) by thirds for 803 gas wells within Uinta Basin Continuous Gas Assessment Unit (AU 50200261), Mesaverde Total Petroleum System, Uinta Basin, Utah. Only wells with minimum EUR's exceeding 0.02 billion cubic feet of gas (BCFG) are shown.

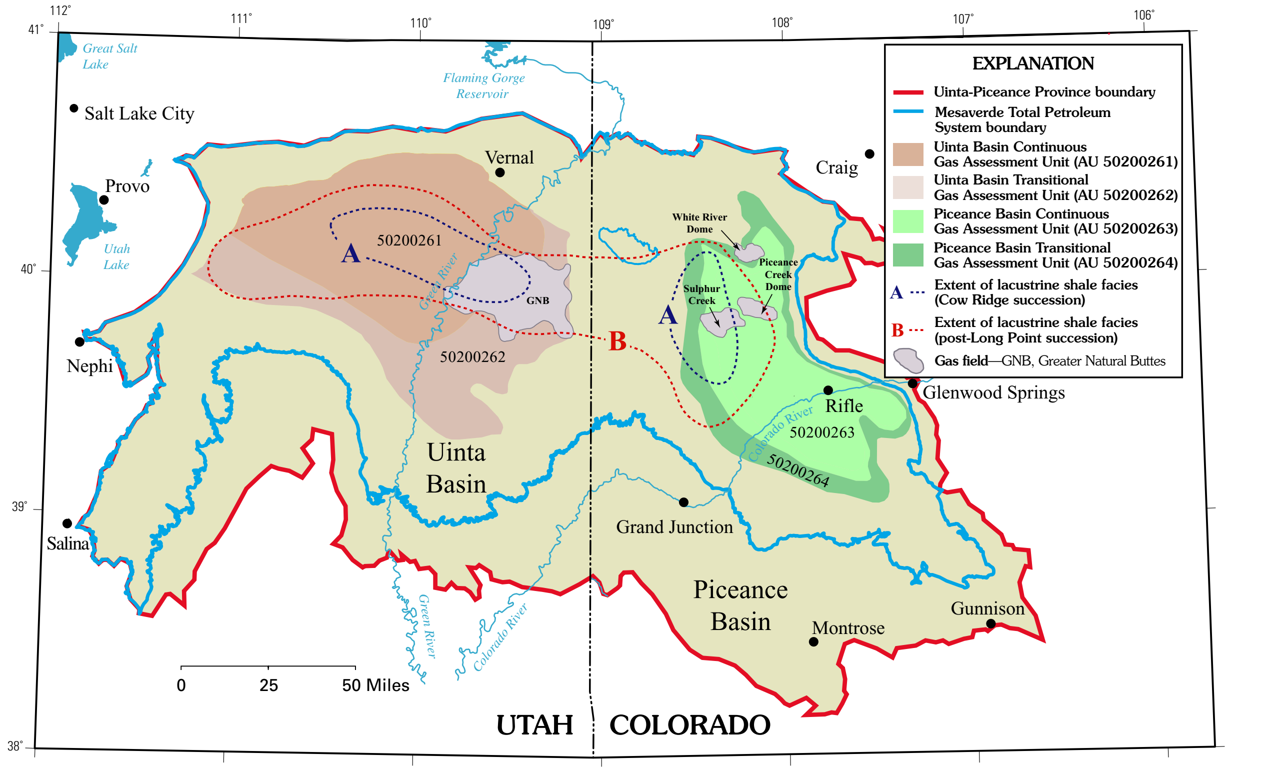


Figure 29. Extent of Green River Formation lacustrine shale facies within continuous and transitional gas assessment units, Mesaverde Total Petroleum System, Uinta and Piceance Basins, Utah and Colorado. Extent of lacustrine shale facies based on Johnson (1985).

to those of GNB (Osmond, 1992). Our maximum estimate of the untested area that has potential for additions to gas reserves in the next 30 years is 50 percent (Appendix B; table B-1). This estimate includes reserve additions from within and near existing gas fields producing from the Mesaverde TPS, coupled with potentially new production from the Mesaverde TPS. New Mesaverde TPS production could come from previously undiscovered areas, or from additional gas production in fields (for example, Altamont-Bluebell field) where existing wells currently producing from the Green River Formation could be deepened to penetrate potential reservoirs in the Wasatch Formation and Mesaverde Group along the deep basin trough of the Uinta Basin, where depths to the Mesaverde TPS exceed 20,000 ft.

Uinta Basin Transitional Gas Assessment Unit (AU 50200262)

Assessment Unit 50200262 is generally defined as that area in the Uinta Basin where strata in the Mesaverde TPS include and overlie source rocks in the basal part of the Mesaverde Group with Ro values between 0.75 percent and 1.10 percent (fig. 26; Nuccio and Roberts, Chapter 4, this CD-ROM). The median estimated area of this unit (Appendix B; table B-2) encompasses about 1,274,000 acres (2,000 mi^2), and its northern boundary is coincident with the southern limit of the Uinta Basin Continuous Gas Assessment Unit (50200261). In the GNB field and vicinity, the assessment unit boundary departs from the projected Ro=0.75 percent isoreflectance line to include wells in which existing production is better ascribed to transitional gas accumulations. Variability in the estimated area to be included (minimum-maximum extent; Appendix B; table B-2) relates primarily to uncertainty as to the outward extent of the transition zone surrounding the basin-centered accumulation (AU 50200261).

Stratigraphically, Assessment Unit 50200262 extends vertically from the base of the lowest coal zone in the Mesaverde Group to the base of the Green River Formation (pls. 1, 2). The base of the Neslen Formation marks the base of the lowest coal zone in the eastern part of the unit, whereas in the western part the lowest coal zone occurs in the Blackhawk Formation. Lenticular, fluvial channel sandstones in the Wasatch Formation and Mesaverde Group are the primary gas reservoirs. Gas accumulations are sealed by relatively impermeable mudrock that surrounds many of the sandstone units, and by the process of capillary seal. Gas-charged reservoirs are typically intermixed with water-charged reservoirs throughout the entire vertical extent of the unit. Gas saturation is thought to be less complete in this transitional gas assessment unit than in the adjacent continuous gas assessment unit (AU 50200261) because underlying source rocks are less mature.

Through the last quarter of 1997, more than 190 gas-producing wells had been completed within this transitional assessment unit (Appendix A) (Petroleum Information/

Dwights LLC, 1999). Most of the reported production is from fluvial sandstone reservoirs in the Wasatch Formation, with fewer wells having production from fluvial reservoirs in the Mesaverde Group (Petroleum Information/Dwights LLC, 1999). The earliest production was in 1953 from the Wasatch Formation in the Peters Point field (fig. 3). The majority of current production is concentrated in the eastern part of the assessment unit in the Rock House and Oil Springs fields, which are included in the GNB field (Osmond, 1992.) An additional area of Wasatch Formation gas production is in the Stone Cabin field, adjacent to Peters Point (fig. 3). Based on characteristics described for the overall GNB field (Osmond, 1992), Wasatch Formation and Mesaverde Group reservoirs exceed 40 ft in thickness, and individual well production typically targets multiple pay zones. Total well depths (based on 45 data points) in the Oil Springs and Rock House fields range from about 3,200 to 7,380 ft, and average about 5,400 ft (Petroleum Information/Dwights LLC, 1999). In the Peters Point and Stone Cabin fields, total well depths in this area (based on 10 wells) range from 3,300 to 8,300 ft, averaging about 5,400 ft; detailed information on the reservoir characteristics in these two fields was not obtained.

A graph showing the EUR's for gas wells in all fields in Assessment Unit 50200262, based on production from 117 wells, is shown in figure 30; EUR by thirds is shown in figure 31. Only wells with minimum recoveries of more than 0.02 BCFG were used to calculate the EUR distributions. It is also important to emphasize that most of the production data reflects results from GNB (including Rock House and Oil Springs fields).

The EUR's calculated for all wells in all fields in the Uinta Basin Transitional Gas Assessment Unit (fig. 30) are generally lower than EUR's estimated for the adjacent Uinta Basin Continuous Gas Assessment Unit (AU 50200261) (fig. 27). This could reflect the lower thermal maturity levels of source rocks underlying Assessment Unit 50200262, and the resulting incomplete gas saturation in Mesaverde TPS units. The decline in middle third average EUR's (fig. 31) may suggest that more productive areas were discovered early on. The modest rise in EUR's for the late third of the wells relative to the middle third, however, does suggest a better recognition of gas-charged reservoirs and possible improvement of completion practices.

The EUR distributions were the primary basis for our estimates of minimum, median, and maximum ultimate recoveries for untested cells in the transitional gas assessment unit. These estimates are shown alongside the EUR distribution for all wells in all fields in the assessment unit (fig. 30). The estimated minimum total recovery of 0.02 BCFG was based on considerations of the minimum recovery that might be required for an untested cell to be "commercially" viable within similar geologic and production constraints characteristic of producing gas wells in GNB and Peters Point/Stone Cabin fields. Our estimated median total recovery (0.25 BCFG) is slightly lower than the late third average EUR of 0.30 BCFG estimated for 50 percent of the most recent one-third of the producing wells in the assessment unit (fig. 31). This slightly lower estimate takes into account that most of the production on which the EUR's are based is from GNB, and we anticipate that median recovery in untested cells away from GNB may not achieve similar levels. This follows similar criteria applied to median EUR estimates for the adjacent Uinta Basin Continuous Gas Assessment Unit (AU 50200261). Our estimated maximum total recovery for untested cells of 15 BCFG reflects the possibility that untested cells may exist that have maximum EUR's similar to those exhibited by the earliest third of the wells (fig. 31), again considering that more than 90 percent of the area is untested.

Because Assessment Unit 50200262 includes and overlies thermally mature (Ro between 0.75 percent and 1.10 percent) source rocks, it has the potential for gas resources throughout the entire extent of its boundaries. In contrast to the adjacent Uinta Basin Continuous Gas Assessment Unit (AU 50200261), however, the number of successful tests may be lower because of incomplete gas saturation and the increased chance of penetrating water-wet reservoirs. Areas of the assessment unit outside of the GNB and Peters Point/Stone Cabin fields have not been extensively tested; only about 20 percent of the total number of tested cells are outside of these fields. Possible reasons for the scarcity of tests outside the established fields might include the lack of infrastructure (roads, pipelines, and so forth), and poor gas recovery in tests of more remote areas in the assessment unit.

As described for the adjacent Uinta Basin Continuous Gas Assessment Unit (AU 50200261), our considerations for additions to gas reserves from Assessment Unit 50200262 over the next 30 years relate primarily to geologic uncertainty in untested areas. Established gas fields such as the Rock House and Oil Springs fields (in GNB) and the Peters Point and Stone Cabin fields include, or are in close proximity to, known faults and fracture systems that could enhance gas migration and accumulation. These systems may extend along mapped trends into the currently untested areas. In addition, potential lacustrine shale seals in the Green River Formation are present in western and eastern areas of the assessment unit (fig. 29), and these could enhance the possibility of trapping gas in Mesaverde TPS units. However, the percentage of successful tests (wells producing more than a minimum 0.02 BCFG) will likely decrease in untested areas where geologic conditions similar to those observed in established fields do not exist, and because of the greater occurrence of water-saturated sandstones in this assessment unit.

Our estimate for the minimum percentage of the untested area of AU 50200262 that has the potential for additions to reserves in the next 30 years is 12 percent (Appendix B; table B-2). This value assumes that additional gas production will focus primarily on infill drilling and result in an increase in production within existing fields. Our estimated median percentage of untested area with the potential for adding reserves in the next 30 years is 20 percent. This value includes additions to reserves from infill drilling, coupled with expansion of fields into currently untested areas that may have similar

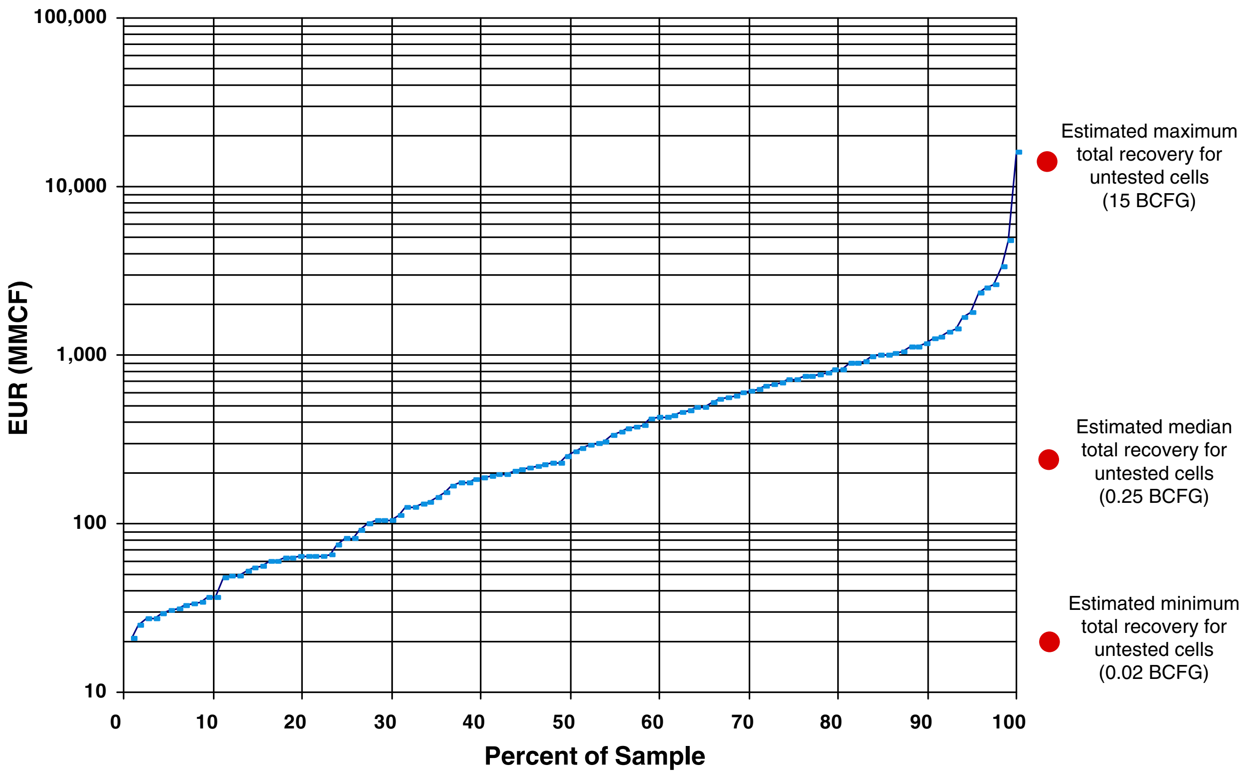


Figure 30. Distribution of estimated ultimate recoveries (EUR's) for 117 gas wells within Uinta Basin Transitional Gas Assessment Unit (AU 50200262), Mesaverde Total Petroleum System, Uinta Basin, Utah. Only wells with minimum EUR's exceeding 0.02 billion cubic feet of gas (BCFG) are shown.

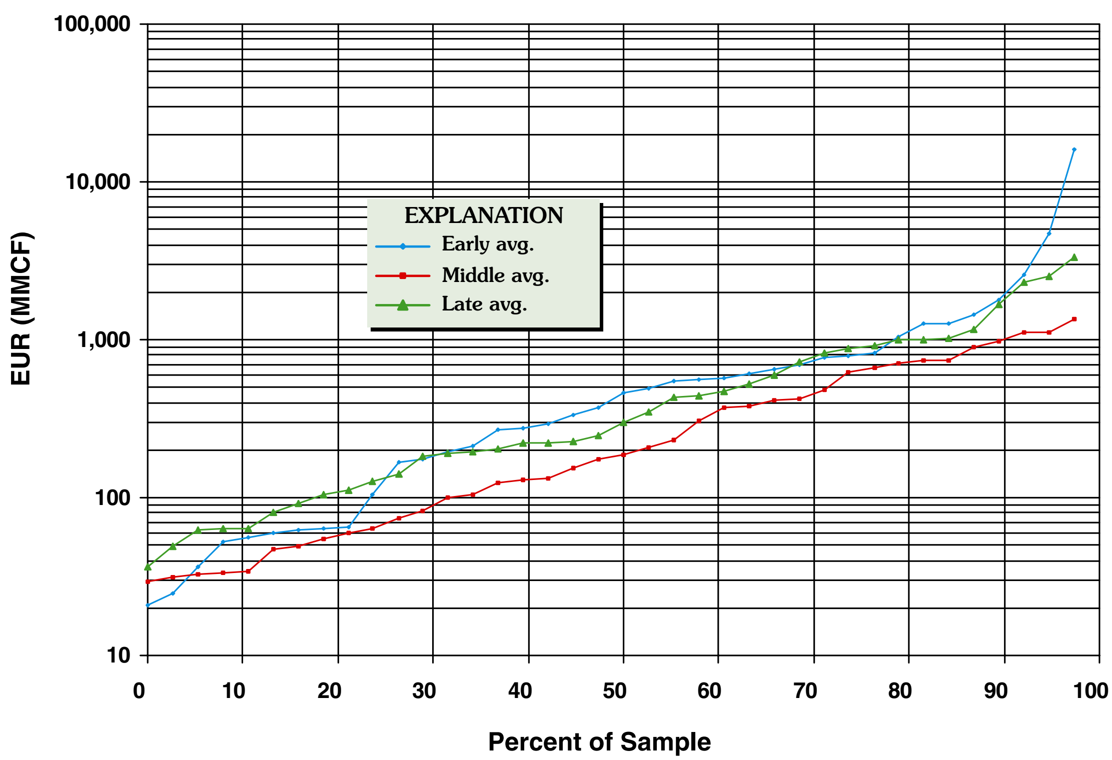


Figure 31. Distribution of estimated ultimate recoveries (EUR's) by thirds for 117 gas wells within Uinta Basin Transitional Gas Assessment Unit (AU 50200262), Mesaverde Total Petroleum System, Uinta Basin, Utah. Only wells with minimum EUR's exceeding 0.02 billion cubic feet of gas (BCFG) are shown.

geologic characteristics to those of established fields. Our estimated maximum untested area that has potential for additions to gas reserves in the next 30 years is 38 percent (Appendix B; table B-2). This estimate includes reserve additions from within and near existing gas fields, coupled with potentially new production from previously untested areas in the assessment unit. Added production could occur in new discoveries of "sweet spots" or gas fairways associated with fault and fracture systems in the Mesaverde TPS beneath Green River Formation lacustrine shale units.

Piceance Basin Continuous Gas Assessment Unit (AU 50200263)

Assessment Unit 50200263 is defined as that area of the Piceance Basin where a basin-centered continuous gas accumulation developed from the generation and predominantly vertical migration of gas from thermally mature coal and carbonaceous shale source rocks in the lower part of the Mesaverde Group. The assessment unit encompasses 1,273,000 acres (2,000 mi^2) in the central part of the Piceance Basin (fig. 26), and represents an area in which strata in the Mesaverde TPS include and overlie source rocks in the basal part of the Mesaverde Group with Ro values greater than or equal to 1.10 percent (Johnson and others, 1987; Nuccio and Roberts, Chapter 4, this CD-ROM). The boundary of the assessment unit is defined solely on the basis of the projected Ro=1.10 percent isoreflectance line.

Stratigraphically, the assessment unit extends vertically from the base of the lowest coal zone (Cameo-Fairfield coal group) in the Mesaverde Group (Williams Fork Formation) to the base of the Green River Formation (pl. 1). Lenticular, fluvial channel sandstones in the Mesaverde Group and Wasatch Formation are the primary gas reservoirs. Gas accumulations are sealed by relatively impermeable mudrock that surrounds many of the sandstone units, and by the process of capillary seal within the basin-centered accumulation (for example, see Law and Dickinson, 1985). Reservoir pressures vary from significantly overpressured in the lower strata to normally pressured or underpressured in the upper strata. Although the unit is considered to represent a continuous gas accumulation, it includes water-saturated sandstones in upper stratigraphic levels. In previous studies, strata in the upper part of this assessment unit were included in a transitional gas assessment unit (Johnson and others, 1987) because they exhibited water-saturation characteristics similar to those of gas reservoirs in the adjacent Piceance Basin Transitional Gas Assessment Unit (AU 50200264) (fig. 26). Additionally, individual sandstone reservoirs in the upper part of the Mesaverde TPS (Wasatch Formation) may have conventional permeabilities (>0.1 mD).

Through the last quarter of 1997, some 680 gas-producing wells had been completed within the assessment unit (Appendix A) (Petroleum Information/Dwights LLC, 1999). Significant gas production began in the 1950's, with most of the gas production (>70 percent) in the Rulison, Parachute, Grand Valley, Mamm Creek, and Sulphur Creek fields (fig. 3). Production is primarily from fluvial channel sandstone reservoirs in the Williams Fork Formation of the Mesaverde Group and, to a lesser degree, fluvial channel sandstone reservoirs in the Wasatch Formation; seven wells reported production from the Fort Union Formation (Petroleum Information/Dwights LLC, 1999). Mesaverde Group reservoirs are typically from 20 to 60 ft thick (Tremain, 1993), although amalgamated fluvial channel sandstones can reach hundreds of feet in thickness (Johnson, 1989). Total depths for wells producing from the Mesaverde Group range from about 1,600 ft to more than 14,000 ft, and average about 7,400 ft (Petroleum Information/ Dwights LLC, 1999). Porosities range from 7 to 12 percent, and permeability is generally 0.1 mD or less (Johnson, 1989; Tremain, 1993).

Based on characteristics of Wasatch Formation reservoirs in the Rulison field, net pay zones in this formation reach a maximum thickness of 135 ft, and average 70 ft. The total depths of wells with production in the Wasatch Formation range from about 1,340 to 9,800 ft (Petroleum Information/ Dwights LLC, 1999). Sandstone porosity averages about 6.5 percent, and permeability ranges from 0.06 to 0.25 mD (Hemborg, 1993).

A graph showing the EUR's for gas wells in all fields in Assessment Unit 50200263, based on production from 490 wells, is shown in figure 32; EUR by thirds is shown in figure 33. Only wells with minimum recoveries of more than 0.02 billion cubic feet of gas (BCFG) were used to calculate the EUR distributions. Most of the production data is from the Rulison, Parachute, Grand Valley, Mamm Creek, and Sulphur Creek fields. Additionally, in the Grand Valley, Parachute, and Rulison fields, operators have plans to recomplete each well several times in order to produce as much of the "behind pipe gas" as possible. Therefore, the EUR's presented in this report represent current completions only, and do not include the anticipated production potential for behind pipe gas that is not yet being produced. When this potential is added, the EUR's should be considerably higher, and may range from 0.09 BCFG (minimum) to 2.7 BCFG (maximum) (Hoak and Klawitter, 1997).

Figure 32 clearly indicates that production has improved in the most recent one-third of wells. This could be the result of increased infill drilling or recompletions in known producing areas coupled with an overall improvement in exploration and completion techniques. A comparison of the EUR distribution for all wells in all fields in the Piceance Basin Continuous Gas Assessment Unit (fig. 32) with EUR's for all wells in all fields in the Uinta Basin Continuous Gas Assessment Unit (AU 50200261) (fig. 27) indicates that EUR'S in Piceance Basin wells are generally lower than in the Uinta Basin.

The EUR distributions were the primary basis for our estimates of minimum, median, and maximum ultimate recoveries for untested cells in Assessment Unit 50200263. These estimates are shown alongside the EUR distribution for all wells in all fields in figure 32. The estimated minimum total recovery of 0.02 BCFG was based on the minimum recovery

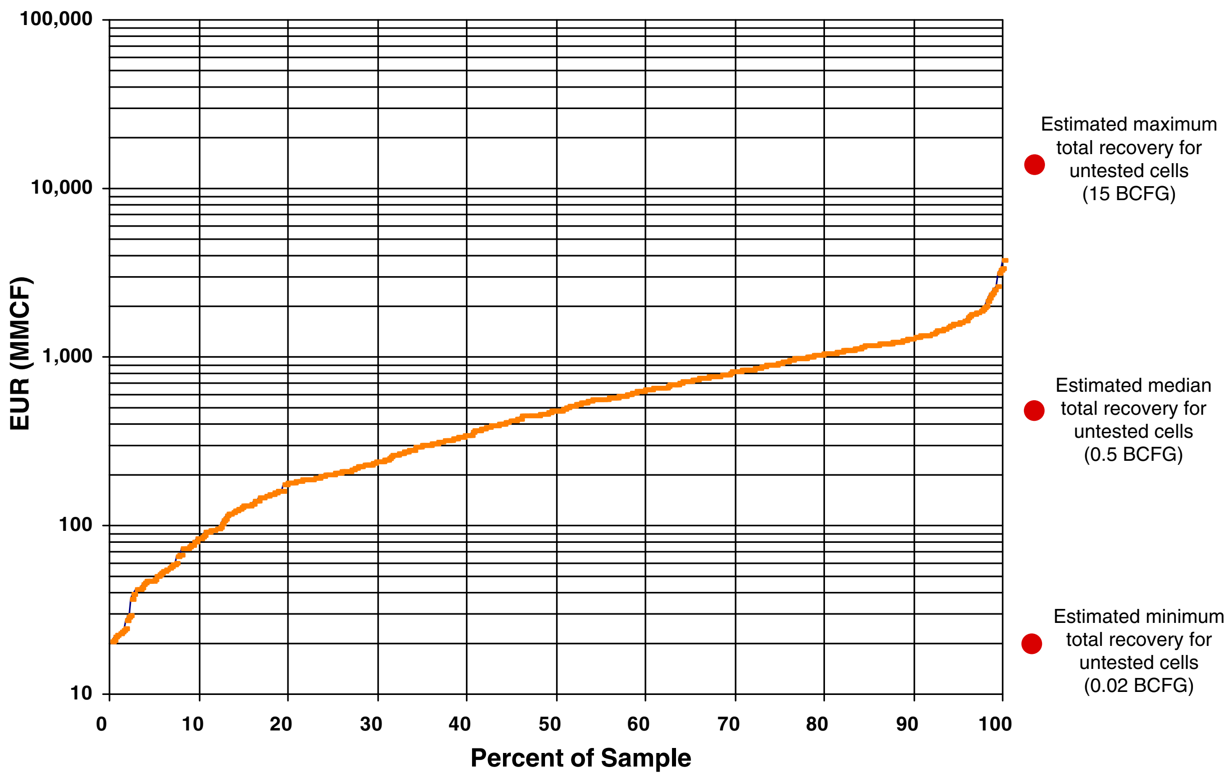


Figure 32. Distribution of estimated ultimate recoveries (EUR's) for 490 gas wells within Piceance Basin Continuous Gas Assessment Unit (AU 50200263), Mesaverde Total Petroleum System, Piceance Basin, Colorado. Only wells with minimum EUR's exceeding 0.02 billion cubic feet of gas (BCFG) are shown.

that might be required for an untested cell to be "commercially" viable within similar geologic and production constraints characteristic of producing gas wells in the Rulison, Parachute, Grand Valley, and Mamm Creek fields. The estimated median total recovery (0.5 BCFG) is slightly lower than the late average EUR of 0.65 BCFG estimated for 50 percent of the most recent one-third of the producing wells (fig. 33). Because the EUR estimates are heavily biased toward four highly productive fields that might represent unique "sweet spots," we estimated a slightly lower median recovery for untested cells to account for uncertainty as to whether similar fields exist elsewhere in the assessment unit. In contrast, the estimated maximum total recovery for untested cells of 15 BCFG is based on the possibility that additional wells could result in higher maximum recoveries than those seen to date, particularly considering that more than 90 percent of the assessment unit is untested.

Given the presence of thermally mature source rocks (Ro>1.10 percent) throughout the entire extent of this assessment unit, the potential for gas resources is present everywhere within its boundaries. However, the abundant, low-permeability fluvial channel sandstone reservoirs in the Mesaverde Group typically require enhanced permeability from natural fractures within the reservoirs to obtain viable gas production (for example, see Johnson, 1989; Tremain, 1993). Known fracture systems in fields such as Rulison, Grand Valley, and Parachute are considered primary components for successful gas production in these highly productive areas. Estimates of additions to gas reserves within this assessment unit over the next 30 years, therefore, are subject to much uncertainty over whether similar fractured reservoir systems are present in untested areas of the assessment unit. Much of the established production is from fields within valleys cut by the Colorado River and its tributaries. Unloading because of this downcutting and erosion may have increased permeability by opening up pore throats and fractures (Law and Dickinson, 1985; Johnson, 1989). Additionally, drilling depths in the valleys are several thousands of feet less than on the surrounding mesas and uplands. The additional depths required to test Mesaverde TPS reservoirs will increase exploration costs, and possibly decrease the percentage of successful wells in some untested areas. Lacustrine shale seals in the Green River Formation extend into the northwestern part of this assessment unit (fig. 29), and their presence could enhance the possibility for gas accumulation in the underlying Mesaverde TPS in that area.

The estimated minimum percentage of the untested parts of the Piceance Basin Continuous Gas Assessment Unit (AU 50200263) that have the potential for adding reserves in the next 30 years is 8 percent (Appendix B; table B-3). This value is based on the expectation that additional gas production will focus primarily on infill drilling and result in an increase in production within existing fields. The estimated median potential area with the possibility for additional reserves in the next 30 years is 20 percent (Appendix B; table B-3).

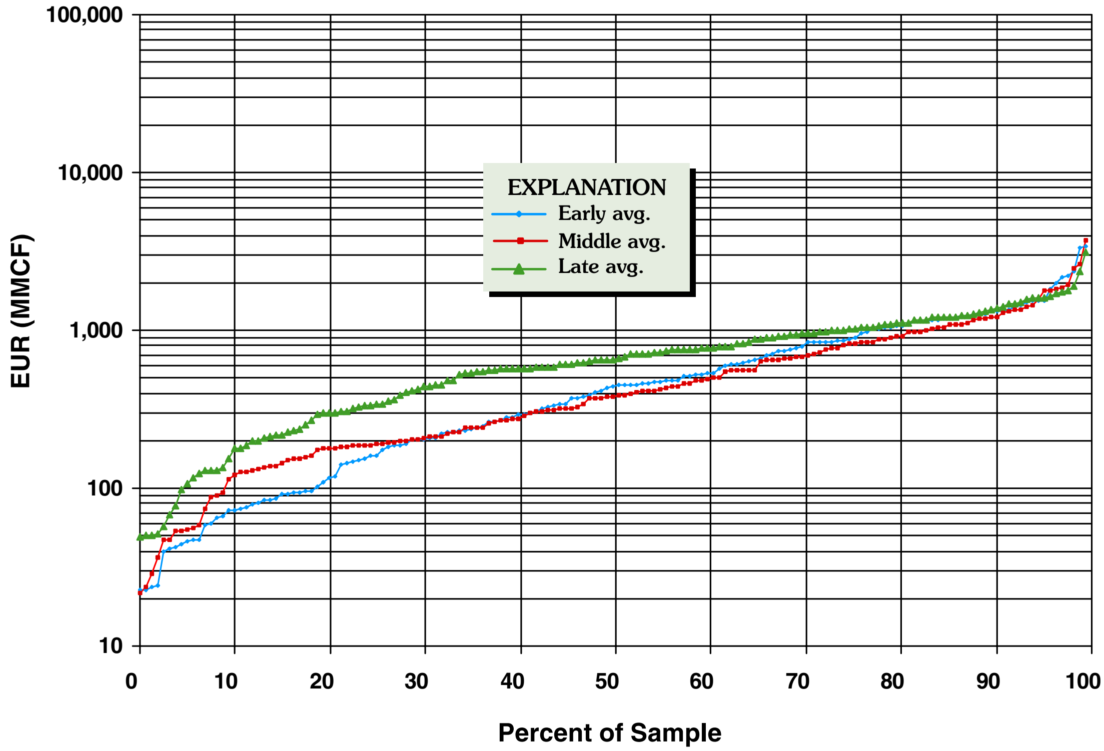


Figure 33. Distribution of estimated ultimate recoveries (EUR's) by thirds for 490 gas wells within Piceance Basin Continuous Gas Assessment Unit (AU 50200263), Mesaverde Total Petroleum System, Piceance Basin, Colorado. Only wells with minimum EUR's exceeding 0.02 billion cubic feet of gas (BCFG) are shown.

This estimate includes additions to reserves from infill drilling, coupled with expansion of fields into currently untested areas that may have geologic characteristics similar to those of fields such as Rulison, Grand Valley, and Parachute, where rates of gas production might balance the expense of deeper wells. The estimated maximum untested area that has potential for additions to gas reserves in the next 30 years is 35 percent (Appendix B; table B-3). This estimate assumes that much of the untested area will be drilled, and includes reserve additions from within and near existing gas fields, coupled with potentially new production from previously untested areas. Added production could be due to new discoveries of "sweet spots" or gas fairways enhanced by fracture systems, and areas where Green River Formation lacustrine shale units overlie Mesaverde TPS strata. The success ratio for wells in untested areas, however, will likely be much less than success ratios in established fields.

Piceance Basin Transitional Gas Assessment Unit (AU 50200264)

Assessment Unit 50200264 surrounds the Piceance Basin Continuous Gas Assessment Unit (AU 50200263) (fig. 26), and is defined as that area in the Piceance Basin where strata in the Mesaverde TPS include and overlie source rocks in the lower part of the Mesaverde Group (Cameo-Fairfield coal group in the Williams Fork Formation) with Ro values between 0.75 percent and 1.10 percent (Nuccio and Roberts, Chapter 4, this CD-ROM). The median estimated area of the assessment unit (Appendix B; table B-4) encompasses about 622,000 acres (970 mi^2). Variability in the estimated assessment unit area (minimum-maximum extent) relates primarily to uncertainty as to where to draw the outside unit boundary.

The assessment unit extends stratigraphically from the base of the Cameo-Fairfield coal group to the base of the first significant lacustrine shale in the Green River Formation. Gas accumulations are thought to be the result of primarily vertical migration of gas from underlying thermally mature coal and carbonaceous shale. Gas saturation is probably less complete than in the Piceance Basin Continuous Gas Assessment Unit because the source rocks are less mature; thus, a higher percentage of water-saturated sandstone reservoirs is anticipated in this assessment unit. Reservoir pressures vary from being moderately overpressured in the lower part of the assessment unit to being normally pressured and (or) underpressured in the upper part. Some of the gas-charged reservoirs may have conventional permeability (>0.1 mD) as well as gas-water contacts, particularly in upper stratigraphic intervals of the Mesaverde TPS.

Through the last quarter of 1997, 89 gas-producing wells had been completed within Assessment Unit 50200264 (Appendix A) (Petroleum Information/Dwights LLC, 1999).

Much of the gas production is from the White River Dome, Divide Creek, and Parachute (part) fields. Most reported production is from fluvial channel sandstone reservoirs in the Mesaverde Group, with lesser production from fluvial channel reservoirs in the Wasatch Formation (Petroleum Information/Dwights LLC, 1999). One well has reported production from the Fort Union Formation. Total depths (based on 56 data points) for wells producing from Mesaverde Group reservoirs range from about 550 to 11,000 ft, and average about 5,300 ft. Wells with reported production from the Wasatch Formation range in total depth from about 560 to 7,150 ft, and average about 2,150 ft (Petroleum Information/Dwights LLC, 1999). Mesaverde Group reservoir porosity and permeability are assumed to be similar to those of reservoirs in the adjacent Piceance Basin Continuous Gas Assessment Unit (AU 50200263), where porosity ranges from 7 to 12 percent and permeability is typically less than 0.1 mD (Johnson, 1989; Tremain, 1993). Wasatch Formation porosity in the White River Dome field is 14 percent (NRG Associates, 1999), and permeability in the overall transitional gas assessment unit ranges from <0.1 mD to as much as 0.25 mD, based on reservoir characteristics for the Wasatch Formation reported by Hemborg (1993).

A graph showing EUR's for gas wells in all fields in Assessment Unit 50200264, based on production from 40 wells, is shown in figure 34; EUR by thirds is shown in figure 35. Only wells with minimum recoveries of more than 0.02 billion cubic feet of gas (BCFG) were used to calculate the EUR distributions.

The EUR's calculated for all wells in the fields of Assessment Unit 50200264 (fig. 34) are generally lower than the EUR's estimated for the adjacent Piceance Basin Continuous Gas Assessment Unit (fig. 32). This could reflect the low thermal maturity levels of source rocks underlying Assessment Unit 50200264, and the resulting incomplete gas saturation in Mesaverde TPS units. The modest overall rise in EUR's for the last third of the wells (fig. 35), however, suggests that completion practices may be improving. However, only slight improvement in EUR's with time (early-late averages) is evident.

The EUR distributions were the primary basis for our estimates of minimum, median, and maximum ultimate recoveries for untested cells in Assessment Unit 50200264. These estimates are shown alongside the EUR distribution for all wells in all of the fields (fig. 34). The estimated minimum total recovery of 0.02 BCFG was based on considerations of the minimum recovery that might be required for an untested cell to be "commercially" viable within similar geologic and production constraints characteristic of currently producing gas wells. The estimated median total recovery (0.25 BCFG) is roughly equivalent to the average EUR estimated for 50 percent of the most recent one-third of the producing wells in the assessment unit (fig. 35). We anticipate that median recovery in untested cells will likely achieve similar levels, particularly because there has been no significant improvement in EUR's with time. Because more than 90 percent of the assessment unit is untested, the estimated maximum total recovery of 4 BCFG reflects the possibility that untested cells may achieve production levels slightly exceeding maximum EUR levels exhibited by the majority of wells drilled to date.

Because Assessment Unit 50200264 includes and overlies thermally mature (Ro between 0.75 percent and 1.10 percent) source rocks, gas resources could be discovered throughout its entire extent. In contrast to the adjacent Piceance Basin Continuous Gas Assessment Unit (AU 50200263), however, the number of successful tests may be low because of incomplete gas saturation and the increased chance of penetrating water-wet reservoirs. Established gas fields such as the White River Dome and Divide Creek fields exist within known structures where associated faults and fracture systems could enhance gas migration and accumulation. In addition, potential lacustrine shale seals in the Green River Formation overlie the Mesaverde TPS in western areas of the assessment unit (fig. 29), and these seals could enhance the possibility of trapping gas in Mesaverde TPS units. However, the percentage of successful tests (wells producing more than a minimum 0.02 BCFG) will likely decrease unless favorable geologic conditions similar to those observed in established fields exist elsewhere, and if there is no appreciable increase in the number of water-saturated sandstones due to less complete gas saturation. Reliable evaluations of these factors are greatly hampered by a general lack of geologic data in these untested areas.

The estimate for the minimum percentage of untested area for Assessment Unit 50200264 that has the potential for additions to reserves in the next 30 years is 1 percent (Appendix B; table B-4). This value is based on the assumption that additional gas production will focus primarily on infill drilling, resulting in an increase in production in existing fields only. The estimated median of the untested area with the potential for additional reserves in the next 30 years is 12 percent (Appendix B; table B-4), a value that includes additions to reserves from infill drilling, coupled with minor expansion of fields into currently untested areas that may have similar geologic characteristics. This estimate is based on the conclusion that only a small part of the untested area will meet these criteria. The estimated maximum amount of the untested area that has potential for additions to gas reserves in the next 30 years is 20 percent (Appendix B; table B-4). This estimate includes reserve additions from within and near existing gas fields producing from the Mesaverde TPS, coupled with limited possibilities for new production from previously untested areas in the assessment unit. Added production could relate to new discoveries of "sweet spots" or gas fairways associated with fault and fracture systems beneath Green River Formation lacustrine shale units. Overall, however, these estimates are low, in large part because of the apparent lack of improvement in EUR's with time. Although small "sweet spots" will undoubtedly be found over the next 30 years, significant improvement in gas production from untested cells

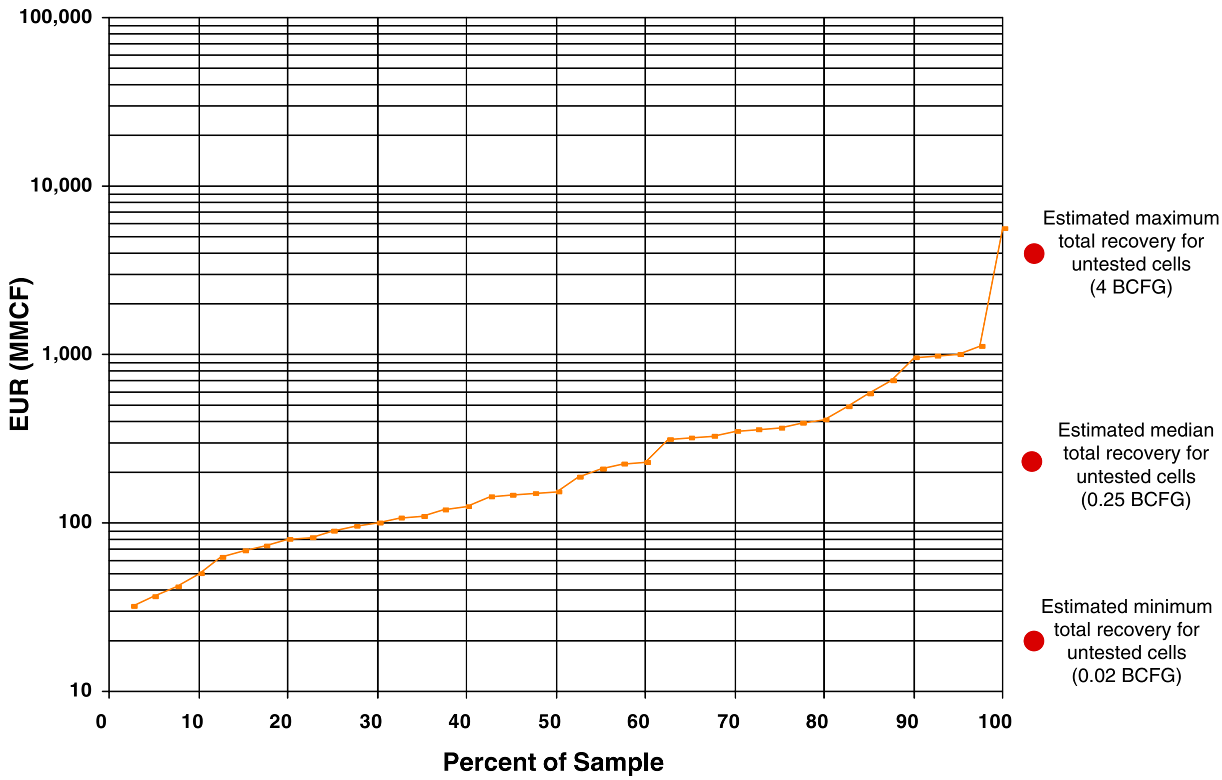


Figure 34. Distribution of estimated ultimate recoveries (EUR's) for 40 gas wells within Piceance Basin Transitional Gas Assessment Unit (AU 50200264), Mesaverde Total Petroleum System, Piceance Basin, Colorado. Only wells with minimum EUR's exceeding 0.02 billion cubic feet of gas (BCFG) are shown.

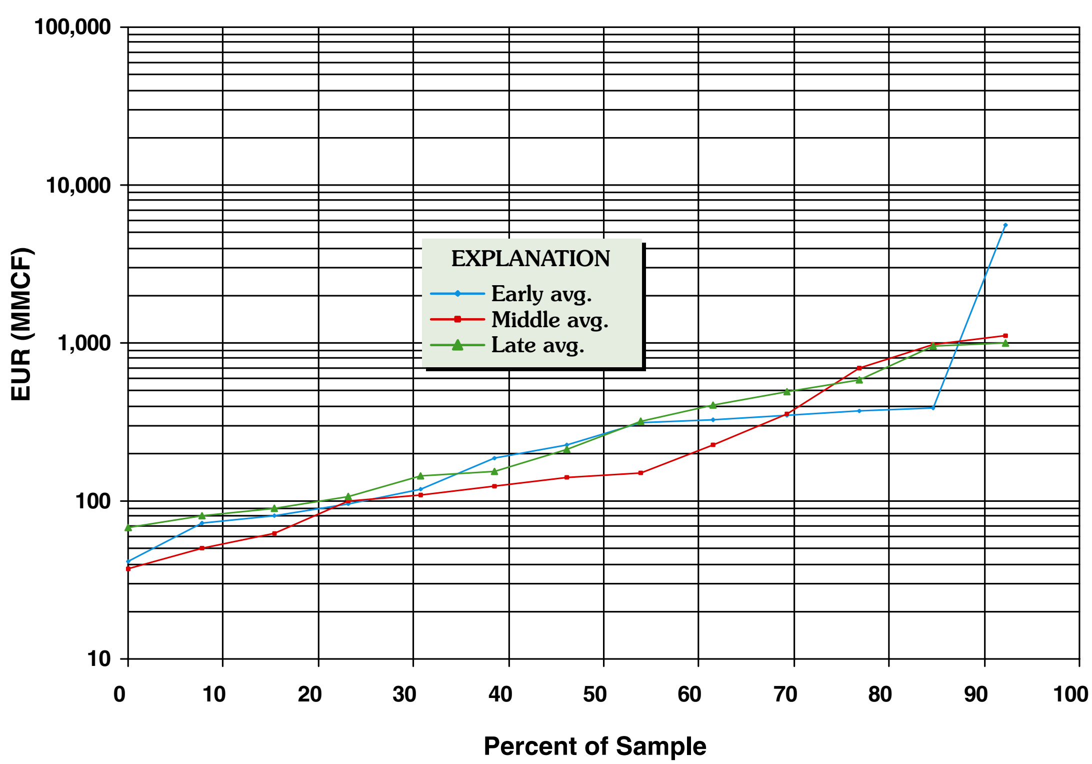


Figure 35. Distribution of estimated ultimate recoveries (EUR's) by thirds for 40 gas wells within Piceance Basin Transitional Gas Assessment Unit (AU 50200264), Mesaverde Total Petroleum System, Piceance Basin, Colorado. Only wells with minimum EUR's exceeding 0.02 billion cubic feet of gas (BCFG) are shown.

is questionable. Because EUR's have remained relatively constant through time, it is anticipated that improvements in technology will keep productivity more or less constant as less desirable sites are drilled.

Uinta-Piceance Basin Conventional Gas Assessment Unit (AU 50200201)

Assessment Unit 50200201 (fig. 36) represents that area in the Uinta-Piceance Province in which migrated gas is produced from or has the potential to be produced from Mesaverde TPS reservoirs in conventional-type structural and stratigraphic traps with discrete gas-water contacts. The unit includes existing and potential production from relatively shallow gas accumulations that were charged with gas that migrated vertically and laterally from thermally mature (Ro>0.75 percent) source rocks in the deeper areas of the Uinta and Piceance Basins (fig. 13). Source rocks for the migrated gas are coal beds and carbonaceous units in the lower part of the Mesaverde Group. This conventional assessment unit overlies continuous and transitional gas assessment units in both basins where source-rock thermal maturities in Mesaverde Group coal zones exceed Ro=0.75 percent, and extends into the basin margin areas where source-rock thermal maturities are less than Ro=0.75 percent (fig. 36).

Gas reservoirs are primarily fluvial channel sandstones in the Wasatch Formation, although a small potential for conventional-type accumulations in Mesaverde Group fluvial channel sandstones exists in basin margin areas. Because so much of the Wasatch Formation gas production in the Uinta-Piceance Province is associated with the continuous (basin-centered) and transitional assessment units, it is difficult to distinguish areas of Wasatch production that are more characteristic of conventional-type accumulations. Two fields were identified in the Piceance Basin, the Piceance Creek Dome and Sulphur Creek fields (fig. 36), in which Wasatch production appears to be conventional. In these fields, productive Wasatch Formation reservoirs are separated from continuous-type (basin-centered) production in the underlying Mesaverde Group by many thousands of feet of nonproductive strata in the Fort Union Formation. Because of this thick nonproductive interval, there is a distinct, recognizable break between the continuous- and conventional-type production. Additionally, EUR's for Wasatch wells (fig. 37) in these two fields are generally higher than EUR's for wells producing from the Mesaverde Group. Because the combining of Wasatch Formation and Mesaverde Group production was considered to result in an overestimation of EUR's for wells in these fields, only Wasatch

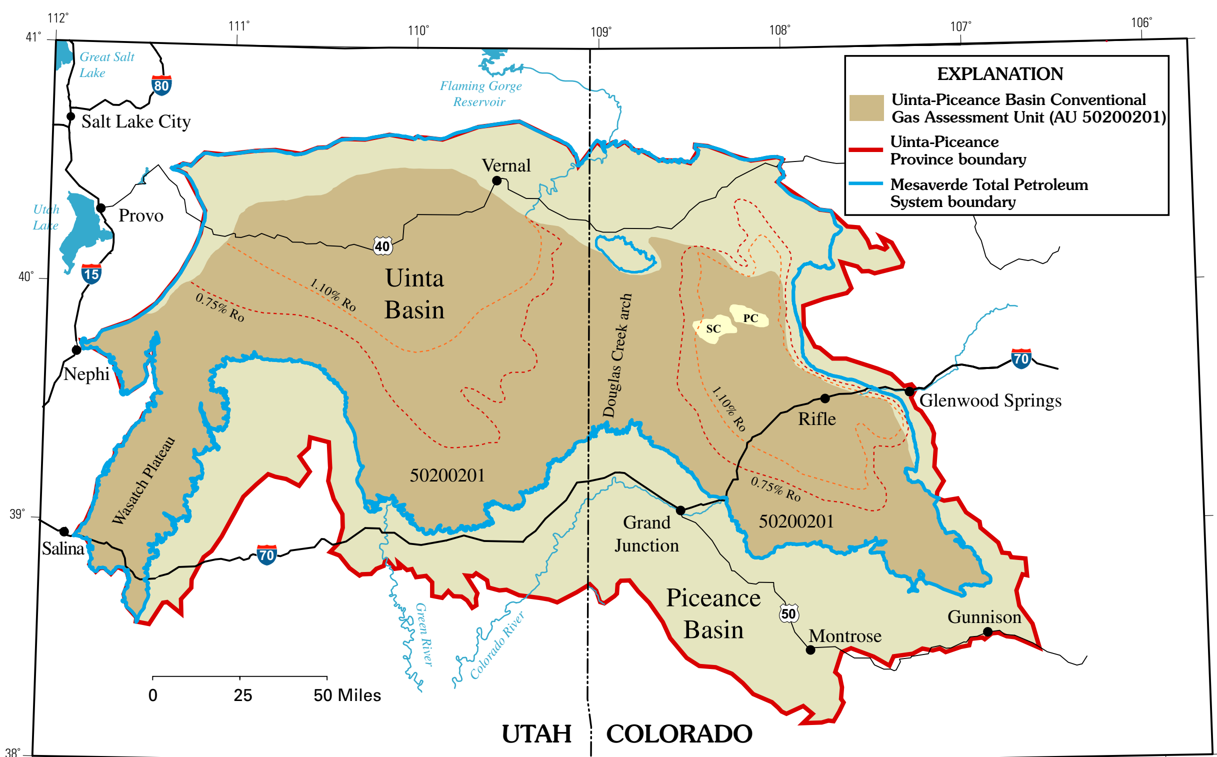


Figure 36. Uinta-Piceance Basin Conventional Gas Assessment Unit (AU 50200201), Uinta and Piceance Basins, Utah and Colorado. Piceance Creek Dome (PC) and Sulphur Creek (SC) fields include conventional gas production from the Wasatch Formation. Vitrinite isoreflectance (Ro) lines for the base of the Mesaverde Group are from Nuccio and Roberts (Chapter 4, this CD-ROM).

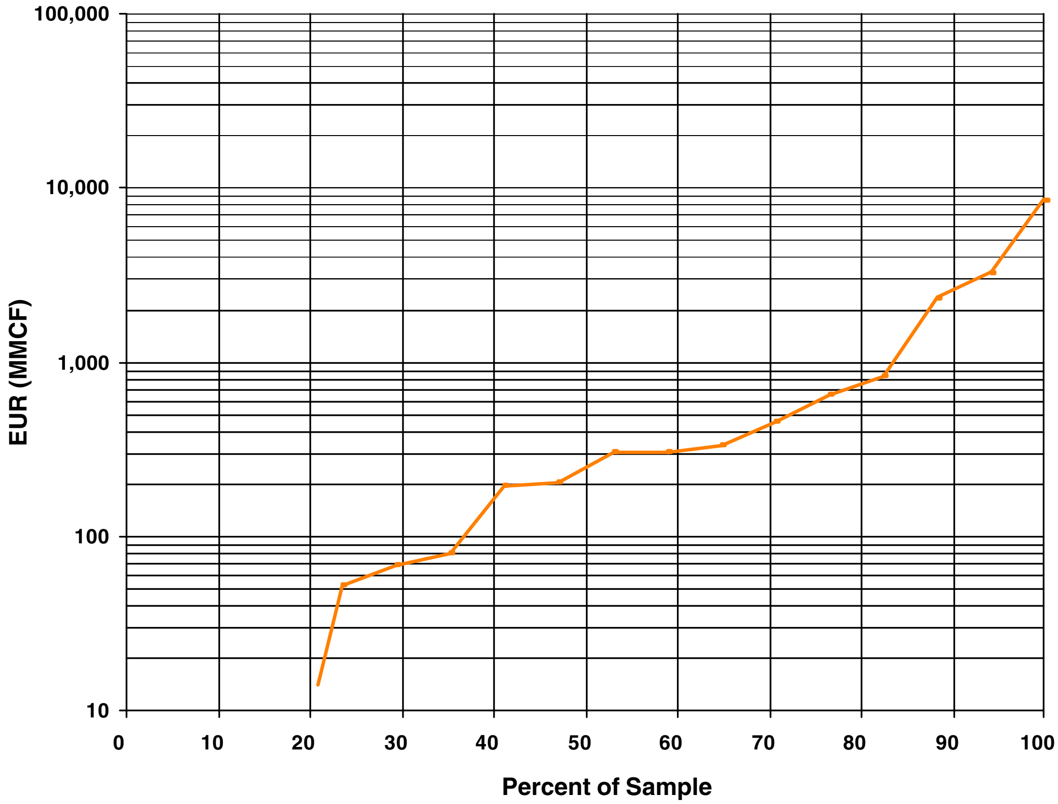


Figure 37. Distribution of estimated ultimate recoveries (EUR's) for 17 gas wells within Uinta-Piceance Basin Conventional Gas Assessment Unit (AU 50200201), Mesaverde Total Petroleum System, Uinta and Piceance Basins, Utah and Colorado. Only wells with reported gas production from the Wasatch Formation in the Sulphur Creek and Piceance Creek Dome fields are shown.

Formation production was allocated to Assessment Unit 50200201. In that only two fields with conventional-type Wasatch production have been identified, the assessment unit is designated as "frontier."

Both the Piceance Creek Dome and Sulphur Creek fields exceed a minimum field size of 0.5 million barrels of oil equivalent (MMBOE). Through the last quarter of 1997, 64 wells reported Wasatch gas production from these fields; about 70 percent of the wells are in the Piceance Creek Dome field (Petroleum Information/Dwights LLC, 1999). Total depths of the wells generally range between 3,000 and 8,000 ft, and average about 4,800 ft. Sandstone reservoirs have porosities ranging from 11 to 15 percent, and the pay zones are generally 10–50 ft thick (see, for comparison, Spencer, 1998).

The minimum estimated number of additional gas fields greater than the minimum size (>0.5 MMBOE) that might be discovered in the next 30 years is 1 (Appendix B; table B-5). This is a conservative number, and assumes that the majority of shallow, conventional-type gas accumulations in the Mesaverde TPS (particularly the Wasatch Formation) have been already discovered. Median and maximum estimates for new field discoveries are 8 and 18, respectively (Appendix B; table B-5). The minimum size of potential new fields is estimated to be 3 MMBOE, the median is 5 MMBOE, and the maximum is 140 MMBOE (Appendix B; table B-5).

Uinta Basin Blackhawk Formation Coalbed Gas Assessment Unit (AU 50200281)

Assessment Unit 50200281 has a median area of about 1,737,000 acres (2,700 mi^2), and includes the Wasatch Plateau and the Book Cliffs and Tabby Mountain coal fields in the Uinta Basin (fig. 38). The unit primarily encompasses areas where the Blackhawk Formation or equivalent coal-bearing units in the Mesaverde Formation contain significant coal beds at depths of 6,000 ft or less. In the Book Cliffs coal field (fig. 38) a line representing 6,000 ft of overburden above the top of the lower Castlegate Sandstone was used to delimit the northern (basinward) extent, and in the northern Wasatch Plateau a line representing 6,000 ft of overburden above the top of the Blackhawk Formation was used. The eastern limit of the assessment unit is the estimated pinch out of Blackhawk Formation coal-bearing intervals into shoreface and offshore-marine deposits (see Hettinger and Kirschbaum, Chapter 12, this CD-ROM). The Tabby Mountain coal field produces coal from the Mesaverde Formation on the hanging wall of the Uinta Basin boundary fault, a thrust fault that marks the northern boundary of the Uinta Basin and southern boundary of the Uinta uplift (fig. 4). The entire estimated extent of Mesaverde Formation coal on the hanging wall was assumed to be at depths less than 6,000 ft, and hence all of that area was included in the assessment unit, although there are no subsurface data to confirm this.

The western part of the Wasatch Plateau includes an additional subarea of hypothetical coalbed methane resources that is defined in part by thermal maturity. These hypothetical resources occur in coals of the Emery Sandstone Member of the Mancos Shale, which underlies the Blackhawk Formation in this area (fig. 1). The extent of the Emery Sandstone Member subarea is defined by the presence of coal beds as indicated on geophysical well logs and by a thermal maturity of Ro=0.75 percent for coals in the underlying Ferron Sandstone Member of the Mancos Shale. No thermal maturity information is available for coals in the Emery Sandstone Member.

Potential variability in the assessment unit area (minimum-maximum area; Appendix B; table B-6) is primarily related to (1) the lack of a consistent stratigraphic datum for defining the 6,000-ft depth cutoff throughout the assessment unit, (2) the lack of subsurface control for defining the extent of Blackhawk and Emery coal-bearing facies in the western Wasatch Plateau, and (3) uncertainty as to the areal extent of Mesaverde coal deposits in the Tabby Mountain coal field, also due to a lack of subsurface control.

The Blackhawk Formation ranges from about 400 to 1,500 ft in thickness, and although it is coal bearing throughout, thicker coal beds are primarily restricted to the lower 500 ft or less of the formation (for example, see Spieker, 1931; Fisher and others, 1960; Adams and Kirr, 1984). In the Wasatch Plateau, as many as 22 coal beds greater than 4 ft in thickness have been identified in the lower 300 ft of the Blackhawk Formation; apparent coal rank varies from high-volatile C to high-volatile B bituminous (Doelling and Graham, 1972; Adams and Kirr, 1984). In the southern part of the Wasatch Plateau, total net coal thickness in the Blackhawk is as much as 40 ft (Dubiel and others, 2000). In the Book Cliffs coal field area, the number of coal beds in the lower part of the formation in the subsurface typically ranges from 9 to 11 beds, and the total net coal thickness is as much as 80 ft locally (D. Tabet, Utah Geological Survey, written commun., 2000). Individual coal beds are as thick as 25 ft, and are high-volatile B bituminous in apparent rank (Adams and Kirr, 1984). In the Tabby Mountain coal field, the coal-bearing Mesaverde Formation is from 550 to 4,000 ft thick, and coal beds as thick as 29 ft have been measured in outcrops. The apparent rank of the coal, based on limited data, is high-volatile C bituminous (Doelling and Graham, 1972; Adams and Kirr, 1984). Thermal maturity values for coal beds in the Blackhawk Formation in the Book Cliffs coal field and Wasatch Plateau vary from less than 0.60 percent Ro in outcrops, to greater than 0.75 percent Ro in limited areas near the estimated 6,000-ft depth cutoff. Based on limited drill-hole data (four wells) in the western part of the Wasatch Plateau, the Emery Sandstone Member of the Mancos Shale includes as many as nine coal beds in an interval ranging from 600 to 800 ft thick. Individual coal beds are as thick as 10 ft,

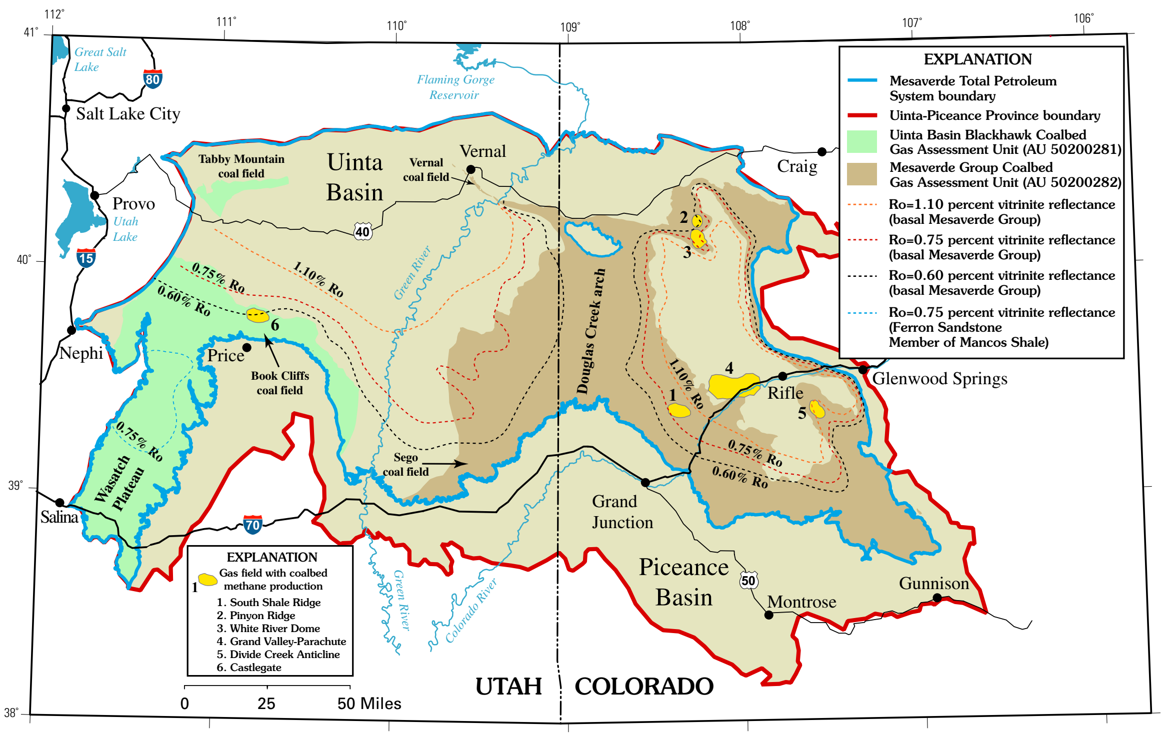


Figure 38. Uinta Basin Blackhawk Coalbed Gas Assessment Unit (AU 50200281), Mesaverde Group Coalbed Gas Assessment Unit (AU 50200282), and associated gas fields with coalbed methane production, Uinta and Piceance Basins, Utah and Colorado. Vitrinite isoreflectance (Ro) lines are from Nuccio and Roberts (Chapter 4, this CD-ROM).

and total net coal thickness for the coal-bearing interval is as much as 32 ft.

Subsurface tests for coalbed methane resources in the Blackhawk Formation began in the 1970's, and the first "commercially viable" well was drilled in 1990 in the Castlegate field in the Book Cliffs coal field area north of Price (fig. 38) (Gloyn and Sommer, 1993). Efforts to produce coalbed methane in this area have varied considerably since the early 1990's. From 1994 to 1997, cumulative coalbed methane production from the field totaled 2,663,439 thousand cubic feet (MCF) (D. Tabet, Utah Geological Survey, written commun., 2000). In 2000, the J.M. Huber Corporation rejuvenated efforts to produce coalbed methane from this field; cumulative production from five new wells in the field, as of August 2000, totaled 49,621 MCF of gas and 189,456 barrels of water (D. Tabet, Utah Geological Survey, written commun., 2000). Gloyn and Sommer (1993) reported that gas contents for coal beds in the Blackhawk Formation in the Book Cliffs coal field range from 0 to 352 cubic feet per ton. Past operators in the Castlegate field reported gas contents ranging from 380 to 435 cubic feet per ton (Hampton and others, 1999).

A graph showing the estimated ultimate EUR's, based on past production from 16 wells in the Castlegate field (Blackhawk Formation) is shown in figure 39. Because coalbed methane production has not been continuous in recent years, the EUR graph represents cumulative production. Also, because of the relatively limited field history and limited production data, EUR's by thirds were not estimated for the field. Only wells with minimum production exceeding 0.05 BCFG are represented in the EUR graph.

The estimates for the minimum, median, and maximum EUR's in untested cells in the assessment unit are shown in figure 39. The minimum of 0.05 BCFG was determined using comparative studies of coalbed methane production from the Ferron Sandstone Member of the Mancos Shale in the Wasatch Plateau. The median estimate of 0.25 BCFG reflects a moderate level of anticipated advancements in completion/production technology, as well as additional exploration efforts in this largely untested assessment unit (>98 percent of the total area). The maximum estimate of 10 BCFG is based, in part, on comparative coalbed methane production from the Ferron Sandstone Member in the Wasatch Plateau (Drunkards Wash and Buzzards Bench fields), and also considers the potential for coalbed gas in the untested area of thermally mature (Ro>0.75 percent) coal beds in the Emery Sandstone Member in the western Wasatch Plateau (fig. 38).

The estimate for the minimum percentage of the untested assessment unit area that has the potential for additions to reserves in the next 30 years is 0.5 percent (Appendix B; table B-6). This value assumes that additional coalbed methane production will focus primarily on infill drilling within the Castlegate field alone, with similar or slightly improved production results. The estimated median area with the potential for additional reserves in the next 30 years is 7 percent (Appendix B; table B-6), a value that includes additions to reserves from infill drilling, coupled with minor expansion of the Castlegate

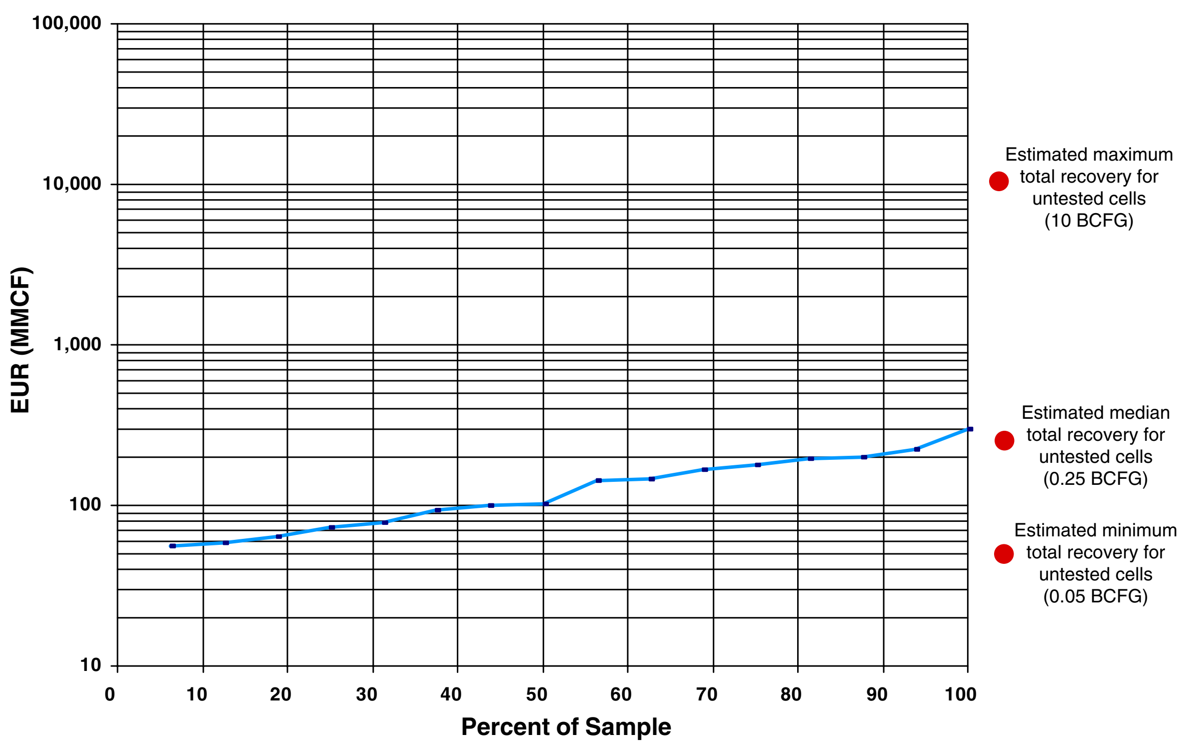


Figure 39. Distribution of estimated ultimate recoveries (EUR's) for 16 coalbed methane gas wells within Uinta Basin Blackhawk Coalbed Gas Assessment Unit (AU 50200281), Mesaverde Total Petroleum System, Uinta Basin, Utah. Only wells with minimum EUR's exceeding 0.05 billion cubic feet of gas (BCFG) are shown.

field area if technological advances and (or) well economics improve. The estimated maximum untested area that has potential for additions to gas reserves in the next 30 years is 20 percent (Appendix B; table B-6). This estimate includes reserve additions from within and near the Castlegate field, coupled with new production from previously untested areas. Added production could also result from future coalbed methane discoveries in the Emery Sandstone Member and Blackhawk Formation in largely unexplored areas of the Wasatch Plateau.

Mesaverde Group Coalbed Methane Assessment Unit (AU 50200282)

Assessment Unit 50200282 encompasses a median area of 4,815,000 acres (7,500 mi^2) in the southeastern and northeastern Uinta Basin (Sego and Vernal coal fields, respectively), along the Douglas Creek arch, and in the Piceance Basin (fig. 38). The unit represents areas where the Williams Fork Formation in the Piceance Basin contains significant coal beds at depths estimated to be 7,000 ft or less, and areas where coal-bearing units in the Neslen Formation (Sego coal field, Uinta Basin) and the Mesaverde Formation (Vernal coal field, Uinta Basin) contain significant coal beds at depths estimated to be 6,000 ft or less. The depth cutoff was extended to 7,000 ft in the Piceance Basin in order to include all coalbed methane production in the Grand Valley and Parachute fields. The top of the Rollins Sandstone Member of the Iles Formation (pl. 1), which marks the base of the Cameo-Fairfield coal group in the lower part of the Mesaverde Group, was used to define the location of the 7,000-ft depth cutoff. In the Sego coal field, the location of the 6,000-ft depth cutoff was estimated using the top of the lower Castlegate Sandstone, which is stratigraphically below the Neslen Formation (fig. 8); the western boundary in that coal field is the approximate limit of coal-bearing strata in the Neslen Formation having a total net coal thickness of 10 ft or greater. In the Vernal coal field (fig. 38), the position of the 6,000-ft depth cutoff is poorly defined due to lack of subsurface control. Variability in the extent of the area to be included in the assessment unit (minimum-maximum area; Appendix B; table B-7) is primarily related to (1) the lack of a consistent stratigraphic datum for defining the depth cutoff throughout the assessment unit, and (2) uncertainty as to the areal extent of Mesaverde coal deposits in the Vernal coal field, due to a lack of subsurface control in that area.

The thermal maturity of coal within Assessment Unit 50200282 varies from Ro<0.65 percent in outcrop to Ro>1.35 percent in deeper areas within the basin. More than 5,000 ft of erosion and downcutting in the Colorado River drainage in the Piceance Basin has decreased the drilling depths to higher rank (more thermally mature) coal beds. Coal in the Williams Fork Formation with Ro=1.1 percent or greater is present in a belt as much as 10 mi wide along the southwest margin of the Piceance Basin, and in an area as much as 7 mi wide on the northeast flank of Divide Creek anticline (fig. 40).

In the Sego coal field, the coal-bearing Neslen Formation typically ranges from about 200 to 500 ft in thickness (Hettinger and Kirschbaum, Chapter 12, this CD-ROM). Coal beds occur primarily in the lower part of the formation, although coal beds are locally present through the entire formation. As many as nine coal beds are typically present, with more coal beds present near the Colorado-Utah border. Individual beds are generally less than 10 ft thick, and commonly less than 5 ft thick; total net coal thickness for the Neslen Formation is as much as 28 ft, but is generally between 10 and 20 ft (D. Tabet, Utah Geological Survey, written commun., 2000). In the Vernal coal field of the Uinta Basin (fig. 38), coal beds are present in the upper member of the Mesaverde Formation (Doelling and Graham, 1972). Locally, there are as many as eight coal beds; individual beds are generally less than 10 ft thick. Coalbed dips range from about 16° to 60°, and typically exceed 30° (Doelling and Graham, 1972). In the Piceance Basin, major coal beds are present in the Cameo-Fairfield coal group in the Williams Fork Formation (fig. 40). This coal group is present in the subsurface throughout most of the basin and includes, in ascending order, the Cameo-Wheeler, South Canyon, and Coal Ridge coal zones (Hettinger and Kirschbaum, Chapter 12, this CD-ROM). The maximum reported coalbed thickness is 35 ft (Johnson, 1989). Total net coal thickness in the Cameo-Fairfield coal group varies from near zero in the extreme southeastern part of the Piceance Basin to greater than 180 ft in the northeastern corner (fig. 9). Throughout most of the basin, however, the zone contains from 20 to 80 ft of total net coal; in the southwestern part of the basin, total net coal thickness near the Utah-Colorado border decreases to less than 20 ft (Hettinger and Kirschbaum, Chapter 12, this CD-ROM). Coalbed gas content is about 600 standard cubic ft/ton (scf/t) at depths of 7,000 ft, and may be as high as 765 scf/t at a depth of about 7,100 ft (Johnson and others, 1996).

Attempts to produce coalbed methane in commercial quantities from Assessment Unit 50200282 have, thus far, not been very successful. There is no recorded coalbed methane production, for example, from the Sego or Vernal coal fields in the Uinta Basin. The potential for coalbed methane resources in the Sego coal field may be diminished by the relatively thin coal beds, and the lack of appreciable thickness of total net coal accumulation in the Neslen Formation. Additionally, coal beds in this area may be undersaturated with respect to gas (Rice and others, 1996). Steep dips and gas leakage in outcrops could hamper commercial development of coalbed methane in the Vernal coal field, although no reported tests have been completed to date. In the Piceance Basin, the first recorded coalbed methane production well was completed in 1978; the well produced about 75 million cubic ft (MMCF) of gas at depths ranging from 7,800 to 8,050 ft before being abandoned. Commercial viability of these wells may have been related to tax credits at that time, and to commingled gas production from associated sandstone reservoirs (Johnson and others, 1996). From 1978 to 1987, there were additional

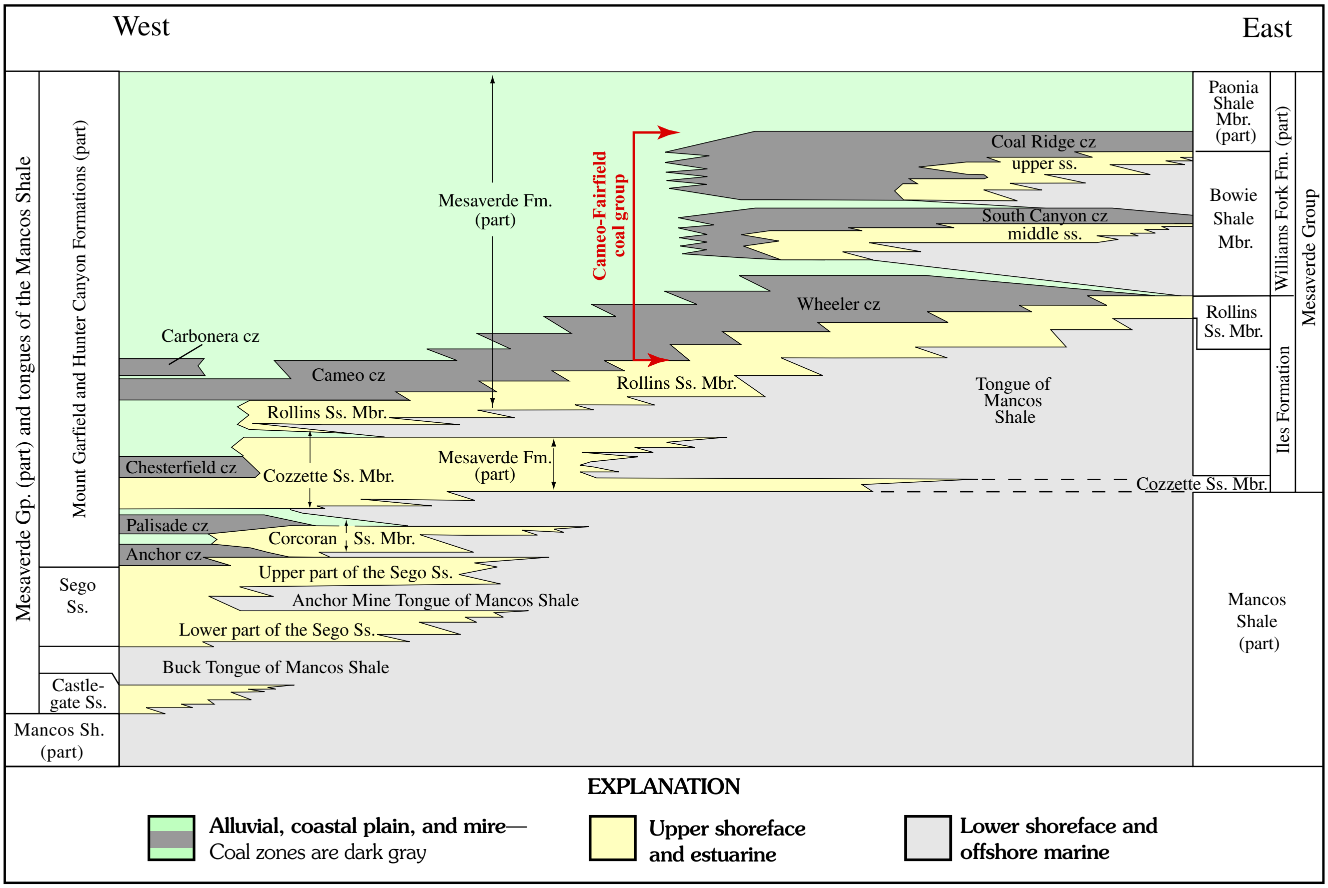


Figure 40. West-east generalized stratigraphic cross section showing distribution of depositional facies and major coal zones in Mesaverde Group and Mesaverde Formation, southern Piceance Basin, Colorado. Abbreviations: Ss., Sandstone; ss., sandstone; Mbr., member; cz, coal zone; Sh., shale; Gp., Group; Fm., Formation; pt., part. Modified from Hettinger and others (2000).

attempts to produce coalbed gas from the relatively high rank coals in the southern part of the Piceance Basin. All of these projects were abandoned because of high water and low gas productivity. Coal beds along the southwestern margin of the Piceance Basin contain little water within the cleat systems, and, for this reason, require little dewatering prior to methane production (Reinecke and others, 1991; Johnson and Flores, 1998). However, coalbed methane wells in that part of the basin were not highly productive. From 1989 to 1992, Barrett Resources, Inc. completed 51 wells in coal beds at the Grand Valley and Parachute fields (fig. 3). Forty-two of these wells, however, were dual coal bed and sandstone completions. It soon became apparent that the coal beds were contributing only modest amounts of gas to the overall production, and attempts to complete in coal beds in these fields were eventually abandoned. By 1995, coalbed methane production from these fields had largely ceased (Petroleum Information/Dwights LLC, 1999). There have been few, if any, serious attempts to complete coalbed methane wells in Assessment Unit 50200282 since 1995.

Excluding the Grand Valley and Parachute fields, areas producing coalbed methane in the Piceance Basin include the South Shale Ridge, White River Dome, Pinyon Ridge, and Divide Creek Anticline fields (fig. 9). Of the more than 90 wells that may have tested coalbed methane, only 44 were identified as solely coalbed methane producers. The total depths of the wells in these fields range from about 3,390 to 8,560 ft, and average about 5,240 ft (Petroleum Information/Dwights LLC, 1999). Coalbed gas production in the White River Dome and Pinyon Ridge fields may be enhanced by higher permeability associated with folding and fracturing; elsewhere, however, low permeability of the coal inhibits large-scale coalbed gas production (Johnson and others, 1996). Many of the isolated wells attempting to produce coalbed gas were never hooked up to a pipeline and, thus, had no obtainable production data.

Figure 41 shows the EUR distribution for 11 coalbed methane wells in Assessment Unit 50200282, all in the Piceance Basin. Only wells with minimum production exceeding 0.02 BCFG are represented in figure 41. Production data are mainly from the White River Dome and South Shale Ridge fields. As previously discussed, no wells in the Grand Valley and Parachute fields were used for EUR distributions because of commingled sandstone and coalbed reservoir production. Also, because of the limited production data and the relatively short lived coalbed methane production in the Piceance Basin,

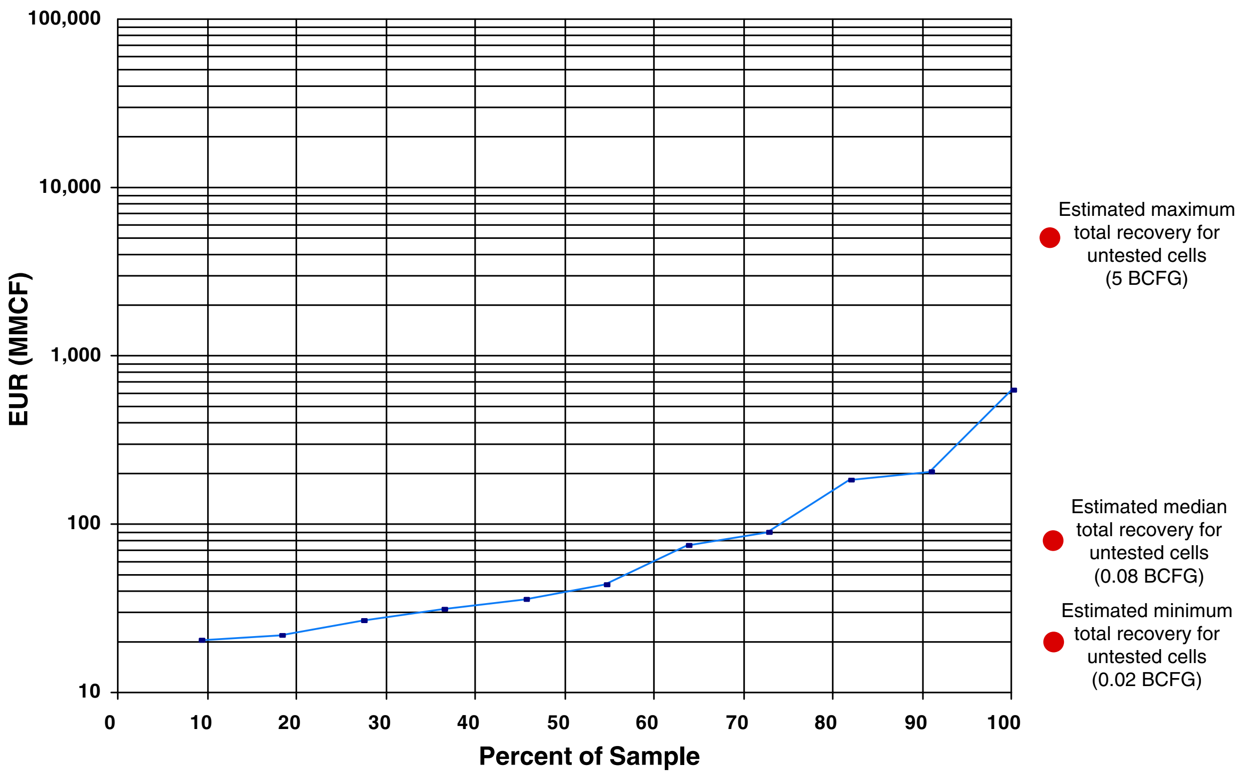


Figure 41. Distribution of estimated ultimate recoveries (EUR's) for 33 coalbed methane gas wells within Mesaverde Group Coalbed Gas Assessment Unit (AU 50200282), Mesaverde Total Petroleum System, Uinta and Piceance Basins, Utah and Colorado. Only wells with minimum EUR's exceeding 0.02 billion cubic feet of gas (BCFG) are shown.

reasonable EUR's by thirds could not be calculated. The failure to complete commercially viable coalbed methane wells in this assessment unit may be reflected by the EUR distribution (fig. 41), which is comparatively lower (overall) than the EUR distribution from coalbed methane wells in the Castlegate field in the Uinta Basin (fig. 39).

The estimates for the minimum, median, and maximum EUR's for untested cells in the Mesaverde Coalbed Gas Assessment Unit are shown in figure 41. The minimum of 0.02 BCFG was based primarily on comparison of minimum recoveries in wells producing coalbed gas to date. The median estimate of 0.08 BCFG reflects some advancements in technology that may be expected to take place; additional exploration in this largely untested assessment unit (>98 percent of the total area) will improve coalbed gas recovery relative to the majority of current and historic production. The maximum estimate of 5 BCFG is based on assumptions that advancements in production technology will improve coalbed gas recovery, and takes into account the potential for higher coalbed methane recovery in untested areas with thick, total net coal thicknesses, and possible fracture-enhanced permeability.

Because of the lack of progress in solving the problems in producing commercial quantities of coalbed gas in the Mesaverde Coalbed Gas Assessment Unit during the past 5 years, it is difficult to estimate how much of the included area has potential for additions to reserves over the next 30 years. Clearly, this assessment unit is largely untested, but has the potential for new discoveries of coalbed gas. The estimate of the minimum percentage of the untested area that has a potential for additions to reserves in the next 30 years is 1 percent (Appendix B; table B-7). This value assumes that problems in producing coalbed gas in this assessment unit will not be overcome to any great degree, and that future coalbed gas production will result largely from recompleting existing gas wells after depletion of the gas resource in associated sandstone reservoirs. Recompletion in existing wells is far cheaper than drilling new wells, and may make coalbed gas economically viable. Our median estimate of 5 percent assumes that some number of additional "sweet spots" (for example, fracture-enhanced permeability) will be found in untested areas that will augment coalbed gas production from recompleted wells in established fields (Appendix B; table B-7). Our maximum estimate of 14 percent (Appendix B; table B-7) is based on the probability that advanced recovery techniques will increase the productivity in fields currently producing coalbed gas, and that additional reserves will be discovered, especially in areas of thick coal accumulation (fig. 9).

Assessment of Undiscovered Resources—Summary of Results

Tabulated estimates of undiscovered gas and natural gas liquid (NGL) resources for assessment units in the Mesaverde TPS are listed in Appendix C. No estimates of undiscovered oil resources are reported, because oil production from the Mesaverde TPS is negligible. The resource estimates are summarized for each accumulation type (Appendix C; table C-1), and for each assessment unit (Appendix C; table C-2). These tabulated results reflect estimates of undiscovered gas and NGL resources in the Mesaverde TPS that have the potential to contribute to petroleum reserves in the next 30 years.

The mean estimate for undiscovered gas resources in the Mesaverde TPS is about 13.2 trillion cubic feet (TCF). The vast majority (>99 percent) of the estimated resources are associated with continuous-type accumulations.

A summary of the mean, undiscovered gas resources in individual assessment units is as follows:

Uinta Basin Continuous Gas Assessment Unit (AU 50200261)

This assessment unit contains a mean estimate of 7.4 TCF of gas.

Uinta Basin Transitional Gas Assessment Unit (AU 50200262)

This assessment unit contains a mean estimate of 1.5 TCF of gas.

Piceance Basin Continuous Gas Assessment Unit (AU 50200263)

This assessment unit contains a mean estimate of 3.1 TCF of gas.

Piceance Basin Transitional Gas Assessment Unit (AU 50200264)

This assessment unit contains a mean estimate of 0.3 TCF of gas.

Uinta-Piceance Basin Conventional Gas Assessment Unit (AU 50200201)

This assessment unit contains a mean estimate of 0.066 TCF of gas.

Uinta Basin Blackhawk Formation Coalbed Gas Assessment Unit (AU 50200281)

This assessment unit contains a mean estimate of 0.5 TCF of gas.

Mesaverde Group Coalbed Gas Assessment Unit (AU 50200282)

This assessment unit contains a mean estimate of 0.4 TCF of gas.

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Appendix A: Process and Methodology for Determining Tested Cells within Continuous and Transitional Gas Assessment Units, Mesaverde Total Petroleum System, Uinta and Piceance Basins, Utah and Colorado

An important factor in estimating the potential addition to reserves from continuous- or transitional-type accumulations relates to the number of tested cells within each assessment unit within the total petroleum system (TPS). In general, tested cells for a given assessment unit include drill holes with reported hydrocarbon production from reservoirs within the TPS, as well as drill holes that may have tested TPS reservoirs and encountered little or no hydrocarbon, resulting in abandoned wells or wells producing from more favorable reservoirs overlying or underlying the TPS. Drill-hole data used in the determination of tested cells for each assessment unit were obtained from Petroleum Information's (PI) Well History Control System (WHCS) files (Petroleum Information/Dwights LLC, 1999); drill-hole data included completed wells through the last quarter of 1998.

In our assessment of the Mesaverde TPS, we defined a tested cell as (1) a drill hole with hydrocarbon production from a reservoir unit (or units) within the TPS, (2) a drill hole with no reported production (dry hole) that penetrates and terminates within the TPS (with some exceptions), (3) a drill hole that terminates in strata underlying the TPS and produces from reservoirs in strata overlying the TPS, and (4) a dry hole that terminates in strata immediately underlying the TPS (fig. A-1). Exceptions to criterion 2 above were drill holes that terminated within 100 ft or less of the top of the Mesaverde TPS in fields with known or potential production in the Green River Formation. These wells were interpreted as tests of the overlying Green River Total Petroleum System.

The general process for determining tested cells for continuous and transitional assessment units (Assessment Units 50200261, 50200262, 50200263, and 50200264) in the Mesaverde TPS is described below. Tested cell results for each continuous and transitional assessment unit follow the description for determining tested cells.

Process steps for determining the number of tested cells for continuous and transitional assessment units in the Mesaverde TPS.

Step 1: Data on all wells present within the assessment unit were retrieved from the WHCS files.

Step 2: From the assessment unit well dataset, a subset of wells completely penetrating the TPS was retrieved. The retrieval was based on a search of all wells that terminate (TD) in formations older than (stratigraphically below) the oldest (lowest) unit in the TPS. For the Mesaverde TPS, wells that TD in the Mancos Shale or underlying formations were retrieved.

From the complete TPS penetration well subset:

A. A subset of dry and junked and abandoned holes was selected. From this dry hole subset, all wells with TD's below the Mancos Shale (for example, Dakota Sandstone and Cedar Mountain and Morrison Formations) were excluded from the tested cell category.

From the dry hole subset, all wells with TD's in the Mancos Shale were considered as tested cells.

From the complete TPS penetration well subset:

B. A subset of wells with reported production from TPS units was removed. These data points will be counted as tested cells in Step 3 (below), and were removed here to avoid "double counting." All dry holes were also removed as they had been accounted for in Step A.

From the remaining data in the complete TPS penetration well subset:

Wells with reported production below the Mancos Shale (for example, Dakota Sandstone and Cedar Mountain and Morrison Formations) were excluded from the tested cell data set.

Wells with reported production from shoreface successions in the basal part of the TPS (for example, Castlegate, Sego, and Corcoran Sandstones; fig. A-1) were included in the tested cell data set.

Wells with reported production in the Green River Formation or equivalent units were included in the tested cell data set.

Step 3: From the assessment unit total well data set (see Step 1), all gas wells and dry holes were retrieved. From the gas wells and dry hole subset:

A subset of all producing gas wells with reported production from TPS units was included in the tested cell data set.

A subset of all dry holes that terminate (TD) in TPS units was retrieved. These wells were considered as tested cells for the TPS except in certain areas (for example, central Uinta Basin) where drill holes that terminated in uppermost Mesaverde TPS strata were interpreted as tests of the overlying Green River TPS.

Step 4: The final tested cell count for each assessment unit was determined by summing the number of tested cells as determined in Steps 2 and 3.

Uinta Basin Continuous Gas Assessment Unit (AU 50200261): Tested cell summary

Number of wells within the assessment unit: 3,828

Number of wells completely penetrating the TPS: 53

a. Dry holes (complete penetrations) considered as tested cells: 10
b. Producing wells (complete penetrations) considered as tested cells: 18

Number of producing gas wells in assessment unit: 924 (tested cells)

Number of dry holes terminating in TPS units: 264

a. Number of dry holes excluded: 142 (tests of Green River TPS)
b. Number of dry holes considered as tested cells: 122

Total tested cells for assessment unit: 1,074

Uinta Basin Transitional Gas Assessment Unit (AU 50200262): Tested cell summary

Number of wells within the assessment unit: 656

Number of wells completely penetrating the TPS: 79

a. Dry holes (complete penetrations) considered as tested cells: 25
b. Producing wells (complete penetrations) considered as tested cells: 4

Number of producing gas wells in assessment unit: 194 (tested cells)

Number of dry holes terminating in TPS units: 118

a. Number of dry holes excluded: 36 (tests of Green River TPS)
b. Number of dry holes considered as tested cells: 82

Total tested cells for assessment unit: 305

Piceance Basin Continuous Gas Assessment Unit (AU 50200263): Tested cell summary

Number of wells within the assessment unit: 988

Number of wells completely penetrating the TPS: 65

a. Dry holes (complete penetrations) considered as tested cells: 5
b. Producing wells (complete penetrations) considered as tested cells: 17

Number of producing gas wells in assessment unit: 680 (tested cells)

Number of dry holes terminating in TPS units: 122

a. Number of dry holes excluded: 2 (tests of Green River TPS)
b. Number of dry holes considered as tested cells: 120

Total tested cells for assessment unit: 822

Piceance Basin Transitional Gas Assessment Unit (AU 50200264): Tested cell summary

Number of wells within the assessment unit: 422

Number of wells completely penetrating the TPS: 106

a. Dry holes (complete penetrations) considered as tested cells: 13
b. Producing wells (complete penetrations) considered as tested cells: 41

Number of producing gas wells in assessment unit: 67 (tested cells)

Number of dry holes terminating in TPS units: 69

a. Number of dry holes excluded: 2 (tests of Green River TPS)
b. Number of dry holes considered as tested cells: 67

Total tested cells for assessment unit: 188

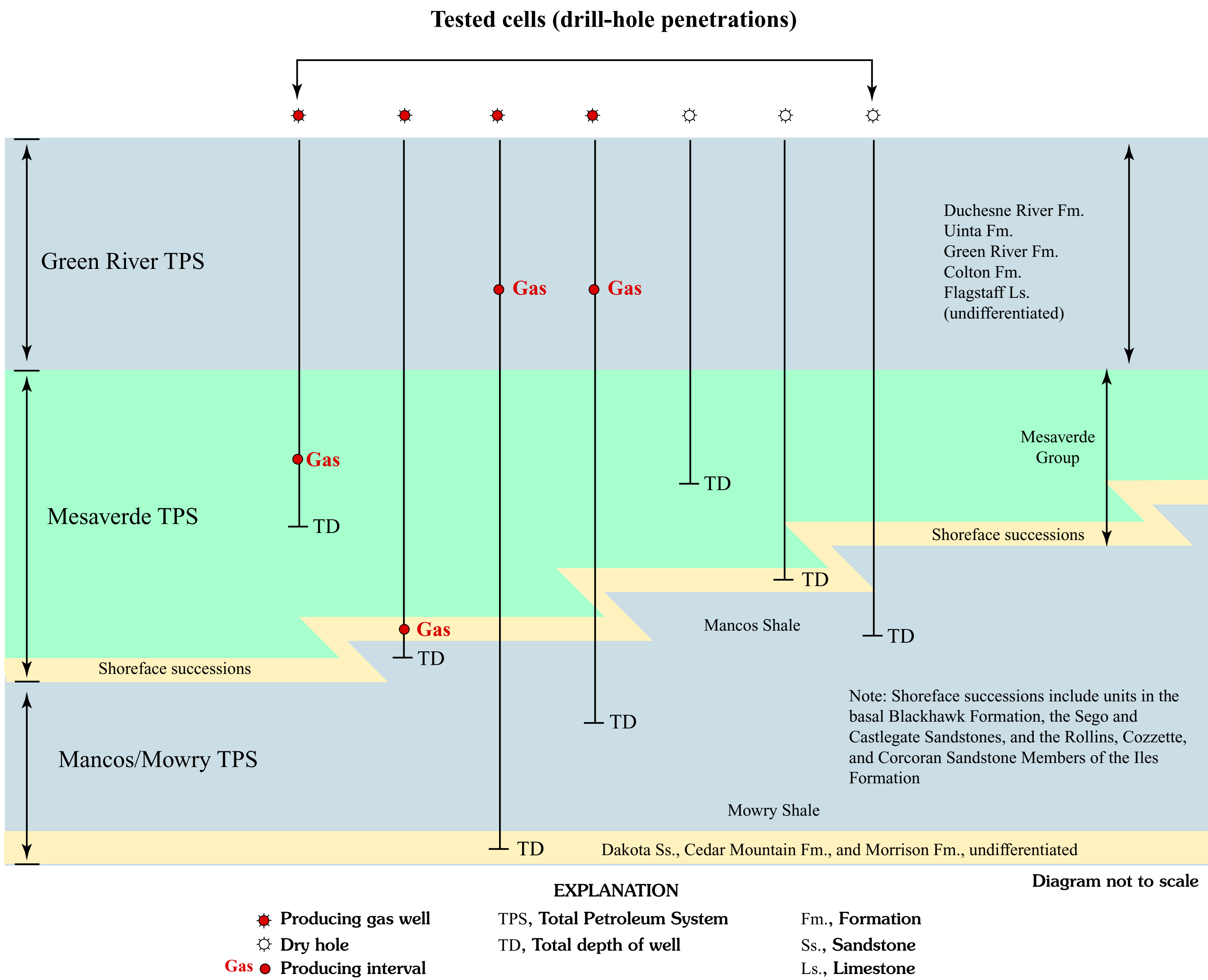


Figure A1. Drill-hole criteria used in determining the number of tested cells within continuous and transitional gas assessment units in the Mesaverde Total Petroleum System.

Appendix B. Basic input data forms (tables) for the FORSPAN assessment model (continuous accumulations) and the SEVENTH APPROXIMATION data form (table) for conventional assessment units.
[Basic input data used in our estimates of the potential additions to gas reserves in the Mesaverde Total Petroleum System over the next 30 years are listed in tables within this appendix. Tables include input data forms for six continuous-type assessment units (AU's 50200261, 50200262, 50200263, 50200264, 50200281, and 50200282), and one conventional-type assessment unit (AU 50200201)]

Table B-1. Basic input data form for the Uinta Basin Continuous Gas Assessment Unit (AU 50200261), Mesaverde Total Petroleum System, Utah.

FORSPAN ASSESSMENT MODEL FOR CONTINUOUS ACCUMULATIONS--BASIC INPUT DATA FORM (Version 4, 10-5-00)

IDENTIFICATION INFORMATION

Assessment Geologist:…	S.B. Roberts and R.C. Johnson	Date:	10/12/00
Region:……………………	North America	Number:	5
Province:…………………	Uinta-Piceance	Number:	5020
Total Petroleum System:.	Mesaverde	Number:	502002
Assessment Unit:……….	Uinta Basin Continuous Gas	Number:	50200261
Based on Data as of:……	PI production data current through third quarter 1999		
Notes from Assessor…..	Continuous gas, where base of Mesaverde ≥ 1.1 Ro		

CHARACTERISTICS OF ASSESSMENT UNIT (A.U.)

Assessment-Unit type: Oil (<20,000 cfg/bo) **or Gas** (≥20,000 cfg/bo) Gas
What is the minimum total recovery per cell?… 0.02 (mmbo for oil A.U.; bcfg for gas A.U.)
Number of evaluated cells:………… 1074
Number of evaluated cells with total recovery per cell ≥ minimum: …….. 869
Established (>24 cells ≥ min.) X Frontier (1-24 cells) ____ Hypothetical (no cells) ____
Median total recovery per cell (for cells ≥ min.): (mmbo for oil A.U.; bcfg for gas A.U.)
1st 3rd discovered 0.8 2nd 3rd 0.7 3rd 3rd 0.66

Assessment-Unit Probabilities:

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

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

4. **ACCESS:** Adequate location for necessary petroleum-related activities for an untested cell with total recovery ≥ minimum ……………………………………………………………… 1.0

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES IN NEXT 30 YEARS

1. Total assessment-unit area (acres): (uncertainty of a fixed value)
   minimum 1,845,000 median 2,050,000 maximum 2,255,000

2. Area per cell of untested cells having potential for additions to reserves in next 30 years (acres):
   (values are inherently variable) minimum 20 median 92 maximum 240

3. Percentage of total assessment-unit area that is untested (%): (uncertainty of a fixed value)
   minimum 95 median 96 maximum 97

4. Percentage of untested assessment-unit area that has potential for additions to reserves in next 30 years (%): (a necessary criterion is that total recovery per cell ≥ minimum)
   (uncertainty of a fixed value) minimum 4 median 30 maximum 50

Table B-1—Continued. Basic input data forms (tables) for the FORSPAN assessment model (continuous accumulations) and the SEVENTH APPROXIMATION data form (table) for conventional assessment units.

Assessment Unit (name, no.) Uinta Basin Continuous Gas, 50200261

TOTAL RECOVERY PER CELL

Total recovery per cell for untested cells having potential for additions to reserves in next 30 years:
(values are inherently variable)

	minimum	median	maximum
(mmbo for oil A.U.; bcfg for gas A.U.)	0.02	0.5	40

AVERAGE COPRODUCT RATIOS FOR UNTESTED CELLS
(uncertainty of a fixed value)

	minimum	median	maximum
Oil assessment unit:			
Gas/oil ratio (cfg/bo)……………………………...…….			
NGL/gas ratio (bngl/mmcfg)………………………..….			
Gas assessment unit:			
Liquids/gas ratio (bliq/mmcfg)….……………..…….	0.75	1.5	2.25

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

	minimum	median	maximum
Oil assessment unit:			
API gravity of oil (degrees)…………….………….			
Sulfur content of oil (%)……………………….…..….			
Drilling depth (m) ……………...………………..….			
Depth (m) of water (if applicable)……………….			
Gas assessment unit:			
Inert-gas content (%)………………………......…..	1.00	2.00	10.00
CO_2 content (%)…………………………………..…..	0.10	0.50	1.00
Hydrogen-sulfide content (%)……………...…….	0.00	0.00	0.00
Drilling depth (m)…………………………………	1350	2800	6700
Depth (m) of water (if applicable)……………….			

Table B-2. Basic input data form for the Uinta Basin Transitional Gas Assessment Unit (AU 50200262), Mesaverde Total Petroleum System, Utah.

FORSPAN ASSESSMENT MODEL FOR CONTINUOUS ACCUMULATIONS--BASIC INPUT DATA FORM (Version 4, 10-5-00)

IDENTIFICATION INFORMATION

Assessment Geologist:…	S.B. Roberts and R.C. Johnson	Date:	10/12/00
Region:……………………	North America	Number:	5
Province:…………………	Uinta-Piceance	Number:	5020
Total Petroleum System:.	Mesaverde	Number:	502002
Assessment Unit:……….	Uinta Basin Transitional Gas	Number:	50200262
Based on Data as of:……	PI production data current through third quarter 1999		
Notes from Assessor…..	Gas in area where base of Mesaverde is between 0.75 and 1.1 Ro		

CHARACTERISTICS OF ASSESSMENT UNIT (A.U.)

Assessment-Unit type: Oil (<20,000 cfg/bo) **or Gas** (≥20,000 cfg/bo) Gas

What is the minimum total recovery per cell?… 0.02 (mmbo for oil A.U.; bcfg for gas A.U.)

Number of evaluated cells:………… 305

Number of evaluated cells with total recovery per cell ≥ minimum: …….. 145

Established (>24 cells ≥ min.) X Frontier (1-24 cells) ______ Hypothetical (no cells) ______

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

1st 3rd discovered 0.45 2nd 3rd 0.2 3rd 3rd 0.3

Assessment-Unit Probabilities:

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

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

4. **ACCESS:** Adequate location for necessary petroleum-related activities for an untested cell with total recovery ≥ minimum ……………………………………………………………… 1.0

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES IN NEXT 30 YEARS

1. Total assessment-unit area (acres): (uncertainty of a fixed value)
   minimum 1,069,000 median 1,274,000 maximum 1,479,000

2. Area per cell of untested cells having potential for additions to reserves in next 30 years (acres):
   (values are inherently variable) minimum 20 median 92 maximum 240

3. Percentage of total assessment-unit area that is untested (%): (uncertainty of a fixed value)
   minimum 97 median 98 maximum 99

4. Percentage of untested assessment-unit area that has potential for additions to reserves in next 30 years (%): (a necessary criterion is that total recovery per cell ≥ minimum)
   (uncertainty of a fixed value) minimum 12 median 20 maximum 38

Table B-2—Continued. Basic input data form for the Uinta Basin Transitional Gas Assessment Unit (AU 50200262), Mesaverde Total Petroleum System, Utah.

Assessment Unit (name, no.) Uinta Basin Transitional Gas, 50200262

TOTAL RECOVERY PER CELL

Total recovery per cell for untested cells having potential for additions to reserves in next 30 years:
(values are inherently variable)
(mmbo for oil A.U.; bcfg for gas A.U.) minimum 0.02 median 0.25 maximum 15

AVERAGE COPRODUCT RATIOS FOR UNTESTED CELLS
(uncertainty of a fixed value)

	minimum	median	maximum
Oil assessment unit:			
Gas/oil ratio (cfg/bo)………………………...…….			
NGL/gas ratio (bngl/mmcfg)……………………..….			
Gas assessment unit:			
Liquids/gas ratio (bliq/mmcfg)…………………..……	0.75	1.5	2.25

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

	minimum	median	maximum
Oil assessment unit:			
API gravity of oil (degrees)…………….…………			
Sulfur content of oil (%)………………………...…			
Drilling depth (m) ……………...…………….……			
Depth (m) of water (if applicable)………………			
Gas assessment unit:			
Inert-gas content (%)……………………….....…..	1.00	2.00	10.00
CO_2 content (%)……………………………..…..	0.10	0.50	1.00
Hydrogen-sulfide content (%)……………...……..	0.00	0.00	0.00
Drilling depth (m)………………………………….	1500	2500	3500
Depth (m) of water (if applicable)………………			

Table B-3. Basic input data form for the Piceance Basin Continuous Gas Assessment Unit (AU 50200263), Mesaverde Total Petroleum System, Colorado.

FORSPAN ASSESSMENT MODEL FOR CONTINUOUS ACCUMULATIONS--BASIC INPUT DATA FORM (Version 4, 10-5-00)

IDENTIFICATION INFORMATION

Assessment Geologist:…	R.C. Johnson and S.B. Roberts	Date:	10/13/00
Region:……………………	North America	Number:	5
Province:………………….	Uinta-Piceance	Number:	5020
Total Petroleum System:.	Mesaverde	Number:	502002
Assessment Unit:……….	Piceance Basin Continuous Gas	Number:	50200263
Based on Data as of:……	PI production data current through third quarter 1999		
Notes from Assessor…..	Continuous gas, where base of Mesaverde > 1.1 Ro		

CHARACTERISTICS OF ASSESSMENT UNIT (A.U.)

Assessment-Unit type: **Oil** (<20,000 cfg/bo) **or** **Gas** (≥20,000 cfg/bo) Gas
What is the minimum total recovery per cell?… 0.02 (mmbo for oil A.U.; bcfg for gas A.U.)
Number of evaluated cells:………… 822
Number of evaluated cells with total recovery per cell ≥ minimum: …….. 646
Established (>24 cells ≥ min.) X Frontier (1-24 cells) ____ Hypothetical (no cells) ____
Median total recovery per cell (for cells ≥ min.): (mmbo for oil A.U.; bcfg for gas A.U.)
1st 3rd discovered 0.44 2nd 3rd 0.39 3rd 3rd 0.63

Assessment-Unit Probabilities:

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

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

4. **ACCESS:** Adequate location for necessary petroleum-related activities for an untested cell with total recovery ≥ minimum ……………………………………………………………… 1.0

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES IN NEXT 30 YEARS

1. Total assessment-unit area (acres): (uncertainty of a fixed value)
   minimum 1,273,000 median 1,273,000 maximum 1,273,000

2. Area per cell of untested cells having potential for additions to reserves in next 30 years (acres):
   (values are inherently variable) minimum 20 median 67 maximum 180

3. Percentage of total assessment-unit area that is untested (%): (uncertainty of a fixed value)
   minimum 96 median 97 maximum 98

4. Percentage of untested assessment-unit area that has potential for additions to reserves in next 30 years (%): (a necessary criterion is that total recovery per cell ≥ minimum)
   (uncertainty of a fixed value) minimum 8 median 20 maximum 35

Table B-3—Continued. Basic input data form for the Piceance Basin Continuous Gas Assessment Unit (AU 50200263), Mesaverde Total Petroleum System, Colorado.

Assessment Unit (name, no.) Piceance Basin Continuous Gas, 50200263

TOTAL RECOVERY PER CELL

Total recovery per cell for untested cells having potential for additions to reserves in next 30 years:
(values are inherently variable)
(mmbo for oil A.U.; bcfg for gas A.U.) minimum 0.02 median 0.5 maximum 15

AVERAGE COPRODUCT RATIOS FOR UNTESTED CELLS
(uncertainty of a fixed value)

	minimum	median	maximum
Oil assessment unit:			
Gas/oil ratio (cfg/bo)………………………...…….			
NGL/gas ratio (bngl/mmcfg)…………………….….			
Gas assessment unit:			
Liquids/gas ratio (bliq/mmcfg)….……………..……	1.5	3	4.5

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

	minimum	median	maximum
Oil assessment unit:			
API gravity of oil (degrees)…………….…………			
Sulfur content of oil (%)………………………....			
Drilling depth (m) ……………...……………….……			
Depth (m) of water (if applicable)……………….			
Gas assessment unit:			
Inert-gas content (%)……………………….....…..	0.10	0.30	0.50
CO_2 content (%)……………………………….……..	0.10	3.00	5.00
Hydrogen-sulfide content (%)……………...…….	0.00	0.00	0.00
Drilling depth (m)………………………………….	1200	2700	4300
Depth (m) of water (if applicable)……………….			

Table B-4. Basic input data form for the Piceance Basin Transitional Gas Assessment Unit (AU 50200264), Mesaverde Total Petroleum System, Colorado.

FORSPAN ASSESSMENT MODEL FOR CONTINUOUS ACCUMULATIONS--BASIC INPUT DATA FORM (Version 4, 10-5-00)

IDENTIFICATION INFORMATION

Assessment Geologist:…	R.C. Johnson and S.B. Roberts	Date:	10/13/00
Region:……………………	North America	Number:	5
Province:………………….	Uinta-Piceance	Number:	5020
Total Petroleum System:.	Mesaverde	Number:	502002
Assessment Unit:……….	Piceance Basin Transitional Gas	Number:	50200264
Based on Data as of:……	PI production data current through third quarter 1999		
Notes from Assessor…..	Gas in area where base of Mesaverde is between 0.75 and 1.1 Ro		

CHARACTERISTICS OF ASSESSMENT UNIT (A.U.)

Assessment-Unit type: Oil (<20,000 cfg/bo) **or Gas** (≥20,000 cfg/bo) Gas

What is the minimum total recovery per cell?… 0.02 (mmbo for oil A.U.; bcfg for gas A.U.)

Number of evaluated cells:………… 188

Number of evaluated cells with total recovery per cell ≥ minimum: ……... 56

Established (>24 cells ≥ min.) X Frontier (1-24 cells) ___ Hypothetical (no cells) ___

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

1st 3rd discovered 0.25 2nd 3rd 0.14 3rd 3rd 0.25

Assessment-Unit Probabilities:

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

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

4. **ACCESS:** Adequate location for necessary petroleum-related activities for an untested cell with total recovery ≥ minimum ……………………………………………………………… 1.0

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES IN NEXT 30 YEARS

1. Total assessment-unit area (acres): (uncertainty of a fixed value)
   minimum 498,000 median 622,000 maximum 746,000

2. Area per cell of untested cells having potential for additions to reserves in next 30 years (acres):
   (values are inherently variable) minimum 20 median 80 maximum 180

3. Percentage of total assessment-unit area that is untested (%): (uncertainty of a fixed value)
   minimum 95 median 97 maximum 99

4. Percentage of untested assessment-unit area that has potential for additions to reserves in next 30 years (%): (a necessary criterion is that total recovery per cell ≥ minimum)
   (uncertainty of a fixed value) minimum 1 median 12 maximum 20

Table B-4—Continued. Basic input data form for the Piceance Basin Transitional Gas Assessment Unit (AU 50200264), Mesaverde Total Petroleum System, Colorado.

Assessment Unit (name, no.) Piceance Basin Transitional Gas, 50200264

TOTAL RECOVERY PER CELL

Total recovery per cell for untested cells having potential for additions to reserves in next 30 years:
(values are inherently variable)
(mmbo for oil A.U.; bcfg for gas A.U.) minimum 0.02 median 0.25 maximum 4

AVERAGE COPRODUCT RATIOS FOR UNTESTED CELLS
(uncertainty of a fixed value)

Oil assessment unit:	minimum	median	maximum
Gas/oil ratio (cfg/bo)………………………...…….			
NGL/gas ratio (bngl/mmcfg)……………………..….			
Gas assessment unit:			
Liquids/gas ratio (bliq/mmcfg)….…………..…….	1	2	3

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

Oil assessment unit:	minimum	median	maximum
API gravity of oil (degrees)…………….………….			
Sulfur content of oil (%)…………………………..….			
Drilling depth (m) ……………...……………..…..			
Depth (m) of water (if applicable)……………….			
Gas assessment unit:			
Inert-gas content (%)…………………………....…..	0.10	0.30	0.50
CO_2 content (%)…………………………………..…..	0.10	3.00	5.00
Hydrogen-sulfide content (%)……………...…….	0.00	0.00	0.00
Drilling depth (m)………………………………….	750	1800	2700
Depth (m) of water (if applicable)……………….			

Table B-5. Basic input data form for the Uinta-Piceance Basin Conventional Gas Assessment Unit (AU 50200201), Mesaverde Total Petroleum System, Utah and Colorado.

SEVENTH APPROXIMATION
DATA FORM FOR CONVENTIONAL ASSESSMENT UNITS (Version 2, 10-5-00)

IDENTIFICATION INFORMATION

Date:…………………………..	10/16/00		
Assessment Geologist:……..	S.B. Roberts and R.C. Johnson		
Region:………………………..	North America	Number:	5
Province:………………………	Uinta-Piceance	Number:	5020
Priority or Boutique.…………			
Total Petroleum System:……	Mesaverde	Number:	502002
Assessment Unit:……………	Uinta-Piceance Basin Conventional Gas	Number:	50200201
Based on Data as of:……….	NRG Associates through 1998		
* Notes from Assessor			

CHARACTERISTICS OF ASSESSMENT UNIT

Oil (<20,000 cfg/bo overall) **or** Gas (≥20,000 cfg/bo overall):… Gas

What is the minimum field size?………. 0.5 mmboe grown
(the smallest field that has potential to be added to reserves in the next 30 years)

Number of discovered fields exceeding minimum size:………… Oil: 0 Gas: 2
Established (>13 fields) ______ Frontier (1-13 fields) X Hypothetical (no fields) ______

Median size (grown) of discovered oil fields (mmboe):
1st 3rd ______ 2nd 3rd ______ 3rd 3rd ______
Median size (grown) of discovered gas fields (bcfg):
1st 3rd ______ 2nd 3rd ______ 3rd 3rd ______

Assessment-Unit Probabilities:

Attribute	Probability of occurrence (0-1.0)
1. **CHARGE:** Adequate petroleum charge for an undiscovered field ≥ minimum size………………	1.0
2. **ROCKS:** Adequate reservoirs, traps, and seals for an undiscovered field ≥ minimum size……	1.0
3. **TIMING OF GEOLOGIC EVENTS:** Favorable timing for an undiscovered field ≥ minimum size	1.0

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

4. **ACCESSIBILITY:** Adequate location to allow exploration for an undiscovered field ≥ minimum size………………………………………………..………………..……..………… 1.0

UNDISCOVERED FIELDS

Number of Undiscovered Fields: How many undiscovered fields exist that are ≥ minimum size?:
(uncertainty of fixed but unknown values)

Oil fields:…………………………………min. no. (>0)	0	median no.	0	max no.	0
Gas fields:……………………………….min. no. (>0)	1	median no.	8	max no.	18

Size of Undiscovered Fields: What are the anticipated sizes (**grown**) of the above fields?:
(variations in the sizes of undiscovered fields)

Oil in oil fields (mmbo)………………..……min. size		median size		max. size	
Gas in gas fields (bcfg):……………………min. size	3	median size	5	max. size	140

Table B-5—Continued. Basic input data form for the Uinta-Piceance Basin Conventional Gas Assessment Unit (AU 50200201), Mesaverde Total Petroleum System, Utah and Colorado.

Assessment Unit (name, no.)
Uinta-Piceance Basin Conventional Gas, 50200201

AVERAGE RATIOS FOR UNDISCOVERED FIELDS, TO ASSESS COPRODUCTS
(uncertainty of fixed but unknown values)

Oil Fields:	minimum	median	maximum
Gas/oil ratio (cfg/bo)………………………...………			
NGL/gas ratio (bngl/mmcfg)……………………...….			
Gas fields:	minimum	median	maximum
Liquids/gas ratio (bngl/mmcfg)….…………..……..	4	8	12
Oil/gas ratio (bo/mmcfg)………………………….….			

SELECTED ANCILLARY DATA FOR UNDISCOVERED FIELDS
(variations in the properties of undiscovered fields)

Oil Fields:	minimum	median	maximum
API gravity (degrees)…………………….………….			
Sulfur content of oil (%)…………………………...…..			
Drilling Depth (m) ……………...……………….……..			
Depth (m) of water (if applicable)……………...…..			
Gas Fields:	minimum	median	maximum
Inert gas content (%)…………………………....……	0.1	0.5	1
CO_2 content (%)……………………………….....….	0.1	0.5	1.5
Hydrogen-sulfide content (%)………………...……..	0	0	0
Drilling Depth (m)……………………………………	500	1700	5500
Depth (m) of water (if applicable)………………….			

Table B-6. Basic input data form for the Uinta Basin Blackhawk Coalbed Gas Assessment Unit (AU 50200281), Mesaverde Total Petroleum System, Utah.

FORSPAN ASSESSMENT MODEL FOR CONTINUOUS ACCUMULATIONS--BASIC INPUT DATA FORM (Version 4, 10-5-00)

IDENTIFICATION INFORMATION

Assessment Geologist:…	S.B. Roberts and R.C. Johnson	Date:	10/13/00
Region:……………………	North America	Number:	5
Province:…………………	Uinta-Piceance	Number:	5020
Total Petroleum System:.	Mesaverde	Number:	502002
Assessment Unit:……….	Uinta Basin Blackhawk Coalbed Gas	Number:	50200281
Based on Data as of:……	PI production data current through third quarter 1999		
Notes from Assessor…..	Includes coalbed gas from the Emery Member of the Mancos Shale. Coalbed gas potential assessed to depth of 6,000 ft. Northern Coal Fairway/ Drunkards Wash and Central Coal Fairway/Buzzards Bench as partial analog.		

CHARACTERISTICS OF ASSESSMENT UNIT (A.U.)

Assessment-Unit type: Oil (<20,000 cfg/bo) **or Gas** (>20,000 cfg/bo) Gas

What is the minimum total recovery per cell … 0.05 (mmbo for oil A.U.; bcfg for gas A.U.)

Number of evaluated cells:………… 26

Number of evaluated cells with total recovery per cell > minimum: ……... 16

Established (>24 cells > min.) ______ Frontier (1-24 cells) X Hypothetical (no cells) ______

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

1st 3rd discovered 0.13 2nd 3rd 0.08 3rd 3rd 0.17

Assessment-Unit Probabilities:

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

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

4. **ACCESS:** Adequate location for necessary petroleum-related activities for an untested cell with total recovery > minimum ……………………………………………………… 1.0

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES IN NEXT 30 YEARS

1. Total assessment-unit area (acres): (uncertainty of a fixed value)
   minimum 1,650,000 median 1,737,000 maximum 1,823,000

2. Area per cell of untested cells having potential for additions to reserves in next 30 years (acres):
   (values are inherently variable) minimum 40 median 120 maximum 280

3. Percentage of total assessment-unit area that is untested (%): (uncertainty of a fixed value)
   minimum 99.7 median 99.8 maximum 99.9

4. Percentage of untested assessment-unit area that has potential for additions to reserves in next 30 years (%): (a necessary criterion is that total recovery per cell > minimum)
   (uncertainty of a fixed value) minimum 0.5 median 7 maximum 20

Table B-6—Continued. Basic input data form for the Uinta Basin Blackhawk Coalbed Gas Assessment Unit (AU 50200281), Mesaverde Total Petroleum System, Utah.

Assessment Unit (name, no.) Uinta Basin Blackhawk Coalbed Gas, 50200281

TOTAL RECOVERY PER CELL

Total recovery per cell for untested cells having potential for additions to reserves in next 30 years:
(values are inherently variable)
(mmbo for oil A.U.; bcfg for gas A.U.) minimum 0.05 median 0.25 maximum 10

AVERAGE COPRODUCT RATIOS FOR UNTESTED CELLS
(uncertainty of a fixed value)

	minimum	median	maximum
Oil assessment unit:			
Gas/oil ratio (cfg/bo)………………………...…….			
NGL/gas ratio (bngl/mmcfg)…………………..….			
Gas assessment unit:			
Liquids/gas ratio (bliq/mmcfg)….…………..……	0	0	0

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

	minimum	median	maximum
Oil assessment unit:			
API gravity of oil (degrees)…………….………….			
Sulfur content of oil (%)………………………...…			
Drilling depth (m) ……………...…………..……			
Depth (m) of water (if applicable)……………….			
Gas assessment unit:			
Inert-gas content (%)……………………....…..	0.10	2.20	3.00
CO_2 content (%)……………………………..…..	1.00	3.00	12.00
Hydrogen-sulfide content (%)…………...…….	0.00	0.00	0.00
Drilling depth (m)………………………………….	100	1000	1830
Depth (m) of water (if applicable)……………….			

Table B-7. Basic input data form for the Mesaverde Group Coalbed Gas Assessment Unit (AU 50200282), Mesaverde Total Petroleum System, Utah and Colorado.

FORSPAN ASSESSMENT MODEL FOR CONTINUOUS ACCUMULATIONS--BASIC INPUT DATA FORM (Version 4, 10-5-00)

IDENTIFICATION INFORMATION

Assessment Geologist:…	S.B. Roberts and R.C. Johnson	Date:	10/16/00
Region:……………………	North America	Number:	5
Province:…………………	Uinta-Piceance	Number:	5020
Total Petroleum System:.	Mesaverde	Number:	502002
Assessment Unit:……….	Mesaverde Group Coalbed Gas	Number:	50200282
Based on Data as of:……	PI production data current through third quarter 1999		
Notes from Assessor…..	Excludes the Blackhawk Formation.		
	Coalbed gas potential assessed to depth of 6,000 ft.		

CHARACTERISTICS OF ASSESSMENT UNIT (A.U.)

Assessment-Unit type: **Oil** (<20,000 cfg/bo) **or** **Gas** (≥20,000 cfg/bo) Gas

What is the minimum total recovery per cell?… 0.02 (mmbo for oil A.U.; bcfg for gas A.U.)

Number of evaluated cells:………… 90

Number of evaluated cells with total recovery per cell ≥ minimum: ……... 18

Established (>24 cells ≥ min.) ____ Frontier (1-24 cells) X Hypothetical (no cells) ____

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

1st 3rd discovered 0.25 2nd 3rd 0.09 3rd 3rd 0.04

Assessment-Unit Probabilities:

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

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

4. **ACCESS:** Adequate location for necessary petroleum-related activities for an untested cell with total recovery ≥ minimum ……………………………………………………………… 1.0

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES IN NEXT 30 YEARS

1. Total assessment-unit area (acres): (uncertainty of a fixed value)
   minimum 4,280,000 median 4,815,000 maximum 5,350,000

2. Area per cell of untested cells having potential for additions to reserves in next 30 years (acres):
   (values are inherently variable) minimum 40 median 120 maximum 280

3. Percentage of total assessment-unit area that is untested (%): (uncertainty of a fixed value)
   minimum 99.7 median 99.8 maximum 99.9

4. Percentage of untested assessment-unit area that has potential for additions to reserves in next 30 years (%): (a necessary criterion is that total recovery per cell ≥ minimum)
   (uncertainty of a fixed value) minimum 1 median 5 maximum 14

Table B-7—Continued. Basic input data form for the Mesaverde Group Coalbed Gas Assessment Unit (AU 50200282), Mesaverde Total Petroleum System, Utah and Colorado.

Assessment Unit (name, no.) Mesaverde Group Coalbed Gas, 50200282

TOTAL RECOVERY PER CELL

Total recovery per cell for untested cells having potential for additions to reserves in next 30 years:
(values are inherently variable)
(mmbo for oil A.U.; bcfg for gas A.U.) minimum 0.02 median 0.08 maximum 5

AVERAGE COPRODUCT RATIOS FOR UNTESTED CELLS

(uncertainty of a fixed value)

	minimum	median	maximum
Oil assessment unit:			
Gas/oil ratio (cfg/bo)……………………………..……..			
NGL/gas ratio (bngl/mmcfg)……………………..….			
Gas assessment unit:			
Liquids/gas ratio (bliq/mmcfg)….……………..……	0	0	0

SELECTED ANCILLARY DATA FOR UNTESTED CELLS

(values are inherently variable)

	minimum	median	maximum
Oil assessment unit:			
API gravity of oil (degrees)………….………….			
Sulfur content of oil (%)…………………………..….			
Drilling depth (m) …………..………………..……			
Depth (m) of water (if applicable)……………….			
Gas assessment unit:			
Inert-gas content (%)……………………….....…..	0.10	0.30	1.00
CO_2 content (%)…………………………………..…..	0.20	4.00	15.00
Hydrogen-sulfide content (%)………………...…….	0.00	0.00	0.00
Drilling depth (m)………………………………….	100	1000	1830
Depth (m) of water (if applicable)……………….			

Appendix C. Tabulated estimates for undiscovered gas and natural gas liquid (NGL) resources in the Mesaverde Total Petroleum System, Uinta-Piceance Province, Utah and Colorado. [Tabulated estimates of undiscovered gas and NGL resources for assessment units in the Mesaverde Total Petroleum System (TPS) are listed in tables C-1 and C-2. Because oil production from TPS units is negligible, no estimates of undiscovered oil resources are reported. The resource estimates are summarized for each accumulation type (table C-1), and for each assessment unit (table C-2). These tabulated results reflect our estimates of undiscovered gas and NGL resources in the Mesaverde TPS that have the potential to contribute to petroleum reserves in the next 30 years]

Table C-1. Summary of assessment results for the Mesaverde Total Petroleum System.

[MMBO, million barrels of oil. BCFG, billion cubic feet of gas. MMBNGL, million barrels of natural gas liquids. Prob., probability (including both geologic and accessibility probabilities) of at least one field (or. for continuous-type resources, cell) equal to or greater than the minimum. Results shown are fully risked estimates. For gas fields, all liquids are included under the NGL (natural gas liquids) category. F95 represents a 95 percent chance of at least the amount tabulated. Other fractiles are defined similarly. Fractiles are additive under the assumption of perfect positive correlation. Shading indicates not applicable]

Code and Field Type		Prob. (0-1)	Undiscovered Resources											
			Oil (MMBO)				Gas (BCFG)				NGL (MMBNGL)			
			F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean
Conventional resources														
Oil Fields														
Gas Fields		1.00					17.91	58.95	140.12	66.41	0.13	0.46	1.18	0.53
Total		1.00					17.91	58.95	140.12	66.41	0.13	0.46	1.18	0.53
Continuous-type resources														
Oil														
Gas		1.00					7,408.26	12,447.11	21,097.90	13,116.88	11.99	21.66	39.19	23.12
Total		1.00					7,408.26	12,447.11	21,097.90	13,116.88	11.99	21.66	39.19	23.12
Total resources														
Total							7,426.17	12,506.06	21,238.02	13,183.29	12.12	22.12	40.37	23.65

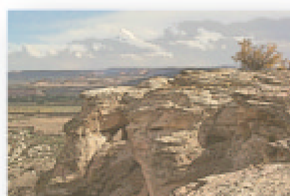
Table C-2. Summary of results for each assessment unit in the Mesaverde Total Petroleum System.

[MMBO, million barrels of oil. BCFG, billion cubic feet of gas. MMBNGL, million barrels of natural gas liquids. Minimum, for conventional resources this is the minimum field size assessed (MMBO or BCFG); for continuous-type resources this is the minimum cell estimated ultimate recovery assessed. Prob., probability (including both geologic and accessibility probabilities) of at least one field (or. for continuous-type resources, cell) equal to or greater than the minimum. Results shown are fully risked estimates. For gas fields, all liquids are included under the NGL (natural gas liquids) category. F95 represents a 95 percent chance of at least the amount tabulated. Other fractiles are defined similarly. Fractiles are additive under the assumption of perfect positive correlation. Shading indicates not applicable]

Code and Field Type	Minimum	Prob. (0-1)	Undiscovered Resources											
			Oil (MMBO)				Gas (BCFG)				NGL (MMBNGL)			
			F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean
502002	**Mesaverde Total Petroleum System- Conventional Resource Assessment Unit Summary**													
50200201	Uinta-Piceance Basin Conventional Gas Assessment Unit													
Oil Fields	0.5	1.00					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gas Fields	3						17.91	58.95	140.12	66.41	0.13	0.46	1.18	0.53
Total		1.00					17.91	58.95	140.12	66.41	0.13	0.46	1.18	0.53
502002	**Mesaverde Total Petroleum System- Continuous Resource Assessment Unit Summary**													
50200261	Uinta Basin Continuous Gas Assessment Unit													
Gas	0.02	1.00					4,134.19	7,018.47	11,915.02	7,391.36	5.52	10.31	19.27	11.09
50200262	Uinta Basin Transitional Gas Assessment Unit													
Gas	0.02	1.00					889.42	1,431.73	2,304.72	1,492.97	1.18	2.10	3.76	2.24
50200263	Piceance Basin Continuous Gas Assessment Unit													
Gas	0.02	1.00					1,902.23	2,956.15	4,594.01	3,064.27	5.00	8.69	15.09	9.19

Table C-2—Continued. Assessment unit results summary.

Code and Field Type	Minimum	Prob. (0-1)	Undiscovered Resources											
			Oil (MMBO)				Gas (BCFG)				NGL (MMBNGL)			
			F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean
50200264	Piceance Basin Transitional Gas Assessment Unit													
Gas	0.02	1.00					161.74	284.47	500.33	301.73	0.29	0.56	1.07	0.60
50200281	Uinta Basin Blackhawk Coalbed Gas Assessment Unit													
Gas	0.05	1.00					181.97	433.84	1,034.28	498.78	0.00	0.00	0.00	0.00
50200282	Mesaverde Group Coalbed Gas Assessment Unit													
Gas	0.02	1.00					138.72	322.45	749.54	367.77	0.00	0.00	0.00	0.00



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