Chapter 6

Geologic Assessment of Undiscovered Oil and Gas Resources of the Mancos/Mowry Total Petroleum System, Uinta-Piceance Province, Utah and Colorado

Click here to return to
Volume Title Page

By Mark A. Kirschbaum

Chapter 6 *of*

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

By USGS Uinta-Piceance Assessment Team

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

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Version 1.0 2003

For sale by U.S. Geological Survey, Information Services
Box 25286, Denver Federal Center
Denver, CO 80225

Published in the Central Region, Denver, Colorado
Manuscript approved for publication July 24, 2002

ISBN=0-607-99359-6

Contents

Plates

[Plates 2–4 include linked figures showing graphic logs and photographs of core. Look for camera icons on plate]

Figures

Tables

Geologic Assessment of Undiscovered Oil and Gas Resources of the Mancos/Mowry Total Petroleum System, Uinta-Piceance Province, Utah and Colorado

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Abstract

The Mancos Shale and Mowry Shale are important source rocks in the Uinta-Piceance Province, Utah and Colorado, and together form the Mancos/Mowry Total Petroleum System. Both Types II and III organic matter are present. The highest total organic carbon is in the Mowry and lowermost Mancos. Gas was generated beginning about 76 million years ago (Ma), with peak generation between 57 and 20 Ma. Gas migrated into nearby fluvial, tidal, shoreface, and offshore sandstone reservoirs of the Morrison, Cedar Mountain, and Frontier Formations; the Dakota, Castlegate, and Sego Sandstones; the Morapos Sandstone Member of the Mancos Shale; the Corcoran, Cozzette, and Rollins Sandstone Members of the Iles or Mount Garfield Formations; and the Prairie Canyon Bed of the Bluegate Member of the Mancos Shale, referred to as the Mancos B in this report. Natural fractures formed concurrent with the development of Laramide structures, resulting in enhanced permeabilities in the generally tightly cemented sandstones of the Mancos/Mowry successions.

Three gas assessment units were defined within the Mancos/Mowry Total Petroleum System based on the concept that gas generated from the Mancos Shale and Mowry Shale charged all porous sandstones and competent fractured beds within, and in contact with, the entire stratigraphic column of the Mancos/Mowry Shales where maturities were great enough to generate gas (that is, vitrinite reflectance (R_o) greater than about 0.75 percent). The three assessment units (AU) are: Piceance Basin Continuous Gas AU 50200361, Uinta Basin Continuous Gas AU 50200362, and Uinta-Piceance Transitional and Migrated Gas AU 50200363. Production estimates from these reservoirs are based on a subset of the 2,268 producing wells (cells) in our historical database. Median total recoveries per cell are estimated to be between 0.2 and 0.5 billion cubic feet of gas (BCFG); the maximum estimated recovery is between 7 and 16 BCFG. These values are slightly higher than historical data because these assessment areas are not maturely explored and we assume the best producing wells (cells) have not yet been found for these reservoir units. Total resources for all three assessment units that have potential for production over the next 30 years are estimated at a mean of about 6.5 trillion cubic feet of gas (TCFG) with a range from 3.9 to 10.4 TCFG.

Introduction

The Mancos Shale and Mowry Shale are combined in this study into one total petroleum system (TPS). The TPS approach defines a mappable area that includes a pod of active source rock, all known and undiscovered reservoirs, and the processes and mechanisms required for oil and gas accumulations to exist (generation, trap, and seal) (Magoon and Dow, 1994). The Mancos/Mowry is one of five major source-rock intervals that produce hydrocarbons in the Uinta-Piceance Province (figs.1–3). The Mancos/Mowry is a complex unit of organic-rich shale and interbedded sandstones that is present throughout the assessment area of the Uinta-Piceance Province. Marine shales were deposited during the Late Cretaceous in a foreland basin setting along the entire width of the Western Interior Seaway. The Uinta and Piceance Basins formed during the latest Cretaceous and early Tertiary (Laramide orogeny) and partitioned the marine deposits of the Mancos/Mowry into two structural basins separated by a broad uplift, the Douglas Creek arch. Burial of the Mancos and Mowry Shales during Late Cretaceous and early Tertiary time moved them into the hydrocarbon generation window at about 76 Ma and the main period of generation continued until about 10 Ma (Nuccio and Roberts, Chapter 4, this CD-ROM). Hydrocarbon migration was most likely concurrent with generation. Most of the reservoir units are composed of distal to proximal shoreface sandstones, and fluvial and tidally influenced channel sandstones (fig. 4). Most reservoirs are in direct contact with some part of the Mancos/Mowry with the exception of fluvial sandstones in the Cedar Mountain and Morrison Formations (fig. 3). Natural fractures formed during the development of Laramide structures, and this fracture network resulted in enhanced permeabilities in the generally tightly cemented sandstones of the Mancos successions. Gas generation enhanced the fracturing, creating some overpressured continuous accumulations of gas. Field studies by Lorenz and Finley (1991) suggested that the sandstones tend to be fractured, but the enclosing plastic shales are not. Enclosing tongues of shale of the Mancos/Mowry seal most gas reservoirs. Maximum burial was generally near the end of Laramide deformation, and prior to uplift and dissection by the Colorado River drainage beginning about 10 Ma. During this period of erosion between 10 Ma and the present, the shale seals may have been especially important in preserving the gas in tight

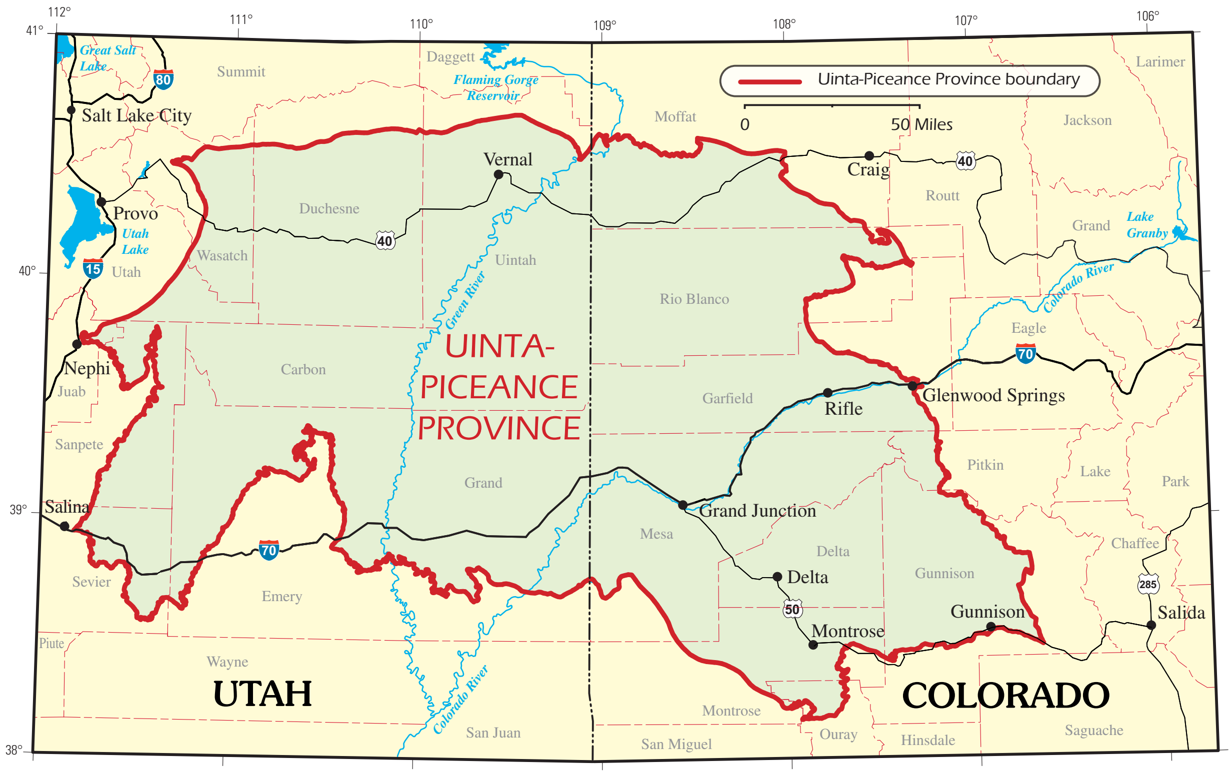


Figure 1. Index map of the Uinta-Piceance Province (red line), which also includes some hanging-wall structural elements where the province is fault bounded.

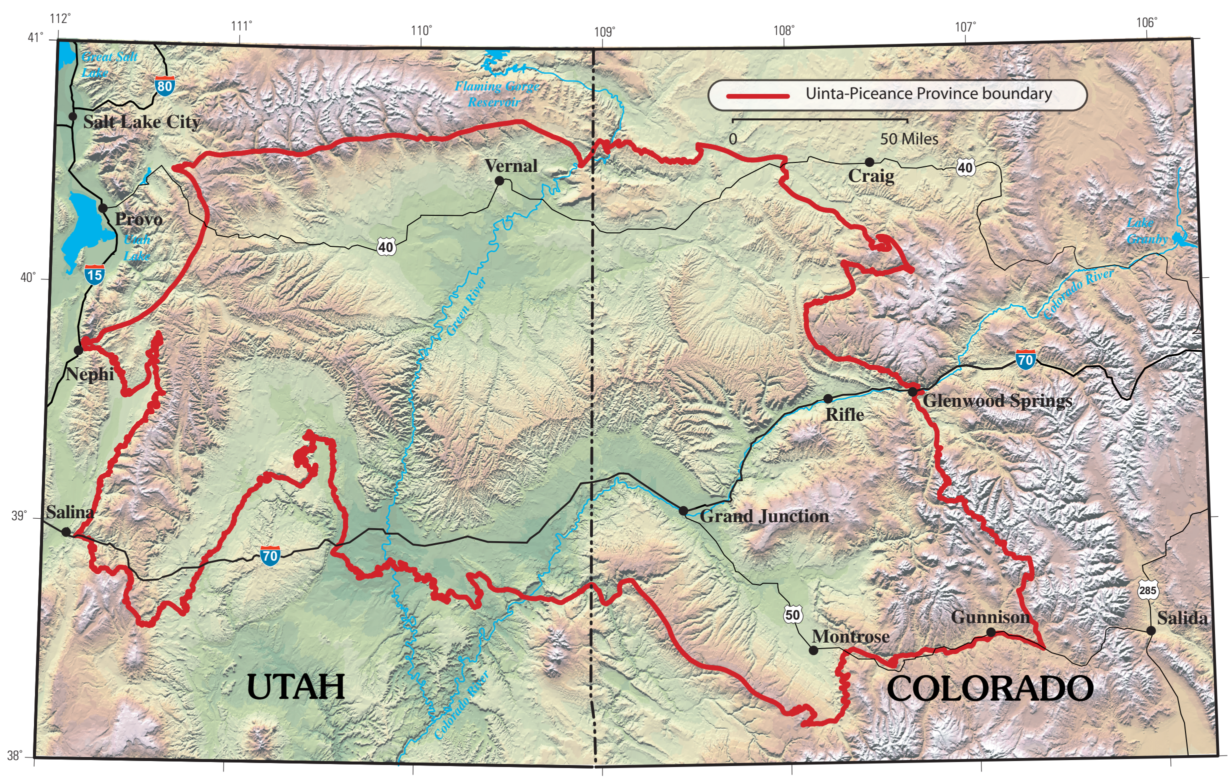
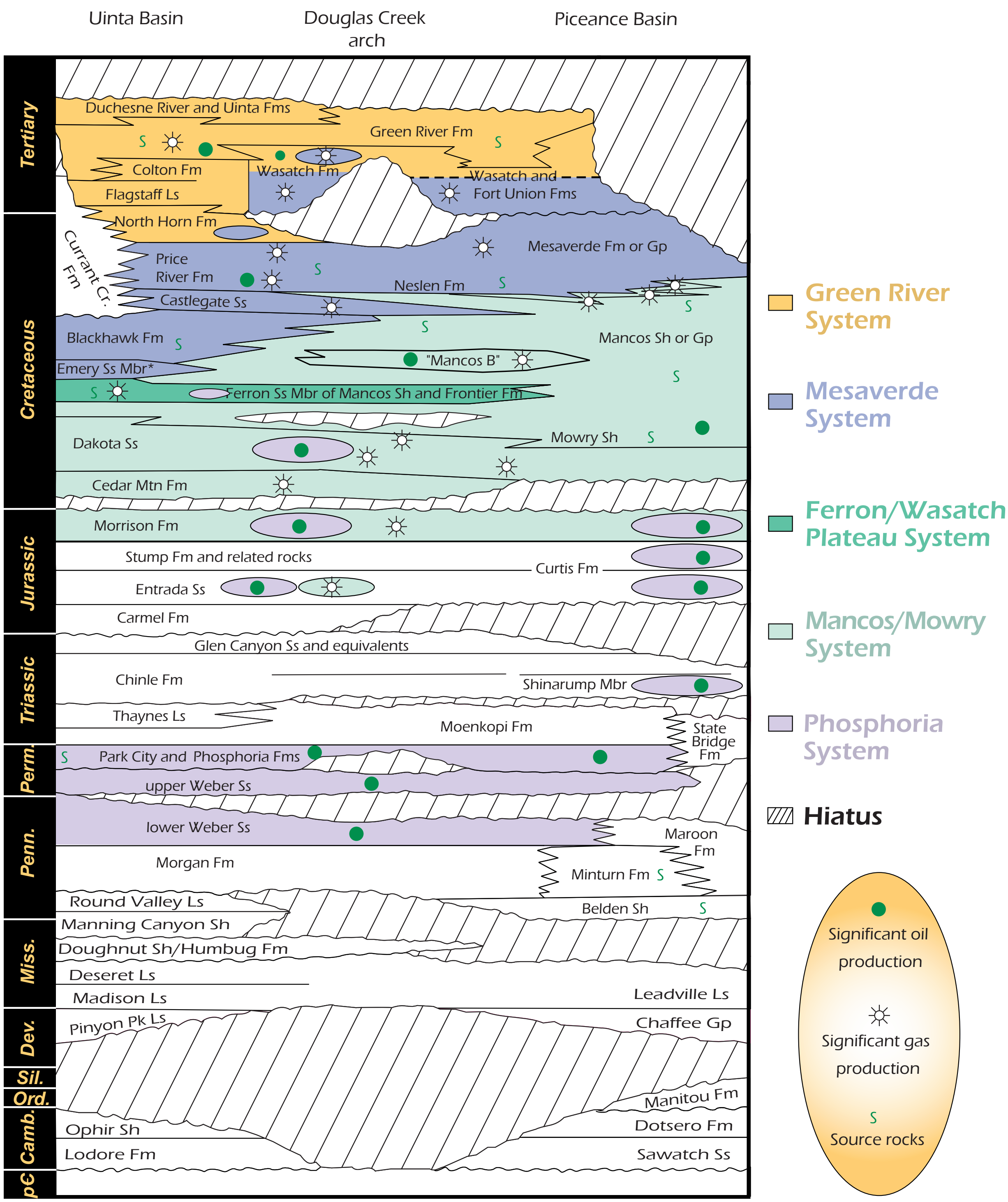


Figure 2. Digital elevation model showing the topography of the Uinta-Piceance Province.



* Emery Sandstone Member of the Mancos Shale

Figure 3. Diagrammatic columnar section of the five major total petroleum systems in the Uinta and Piceance Basins, significant oil and gas producing units, and potential source rocks. Diagram modified from Sanborn (1977) and Spencer and Wilson (1988).

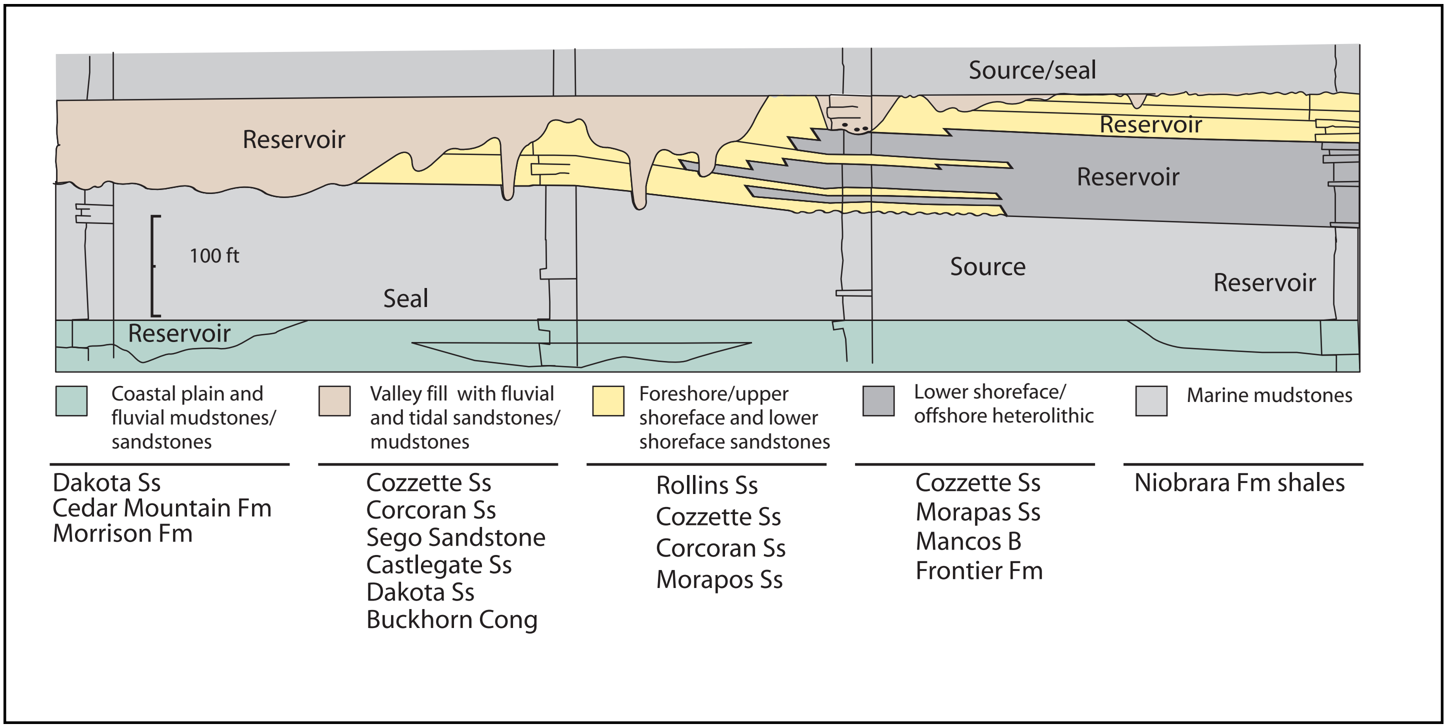


Figure 4. Generalized depositional environments, seals, source rocks, and reservoirs of the Mancos/Mowry Total Petroleum System.

reservoirs by not allowing invasion of surface waters or slowing the rate of diffusion of the trapped gas (Johnson, 1989, p. 35).

Acknowledgments

The author thanks Laura Roberts for providing the structure, depth to drilling, and vitrinite reflectance maps used in the assessment, Vito Nuccio for discussions on the thermal maturity of the Mancos/Mowry TPS, and Troy Cook for interpretations and graphs of production data. Significant discussions and input were also provided by the U.S Geological Survey's, (USGS), National Oil and Gas assessment team, consisting of Ron Charpentier, Troy Cook, Bob Crovelli, Tim Klett, Chris Schenk, and Jim Schmoker, with additional input from Russ Dubiel, Tom Finn, Ron Johnson, Paul Lillis, Steve Roberts, and Chuck Spencer. I appreciate the comprehensive reviews by Chris Schenk and Jennie Ridgley and editing by Alex Donatich. Thanks to Chris Anderson for compiling and managing the data in a Geographic Information System and Wayne Husband for graphic design and drafting.

Mancos/Mowry Total Petroleum System

The Mancos and Mowry Shales are present throughout nearly the entire study area (fig. 5). The two shale units are in excess of 5,000 ft thick throughout most of the basin. A pod of active source rock is present within the centers of both the Uinta and Piceance Basins (fig. 6) and extends across the Douglas Creek arch for those parts of the TPS that are low in the stratigraphic section (figs. 7, 8). Oil is produced from the Mancos B on the Douglas Creek arch and from offshore deposits of shale that have been fractured in the Rangely Field. This oil was sourced from Mancos/Mowry Shales (Lillis and others, Chapter 3, this CD-ROM). Some reservoirs also contain oil from an unknown Paleozoic source around the Uncompahgre uplift and from Permian Phosphoria oil in structures near the south-central basin margin and in fault propagation folds on the northern margin of the basins (see Johnson, Chapter 9, this CD-ROM). Gas reservoirs within the Mancos/Mowry TPS include: (1) fluvial deposits of the Morrison Formation, Cedar Mountain Formation, and Dakota Sandstone; (2) tidally influenced valley fill and associated shoreface deposits of the Dakota, Castlegate, and Sego Sandstones, the Morapos Sandstone Member of the Mancos Shale, and the Corcoran, Cozzette, and Rollins Sandstone Members of the Iles Formation or Mount Garfield Formation; and (3) distal shoreface to tidally influenced deposits of the Mancos B (fig. 4). Some of these reservoirs are in conventional stratigraphic/structural traps, but the majority of the hydrocarbons currently being produced are from continuous gas accumulations.

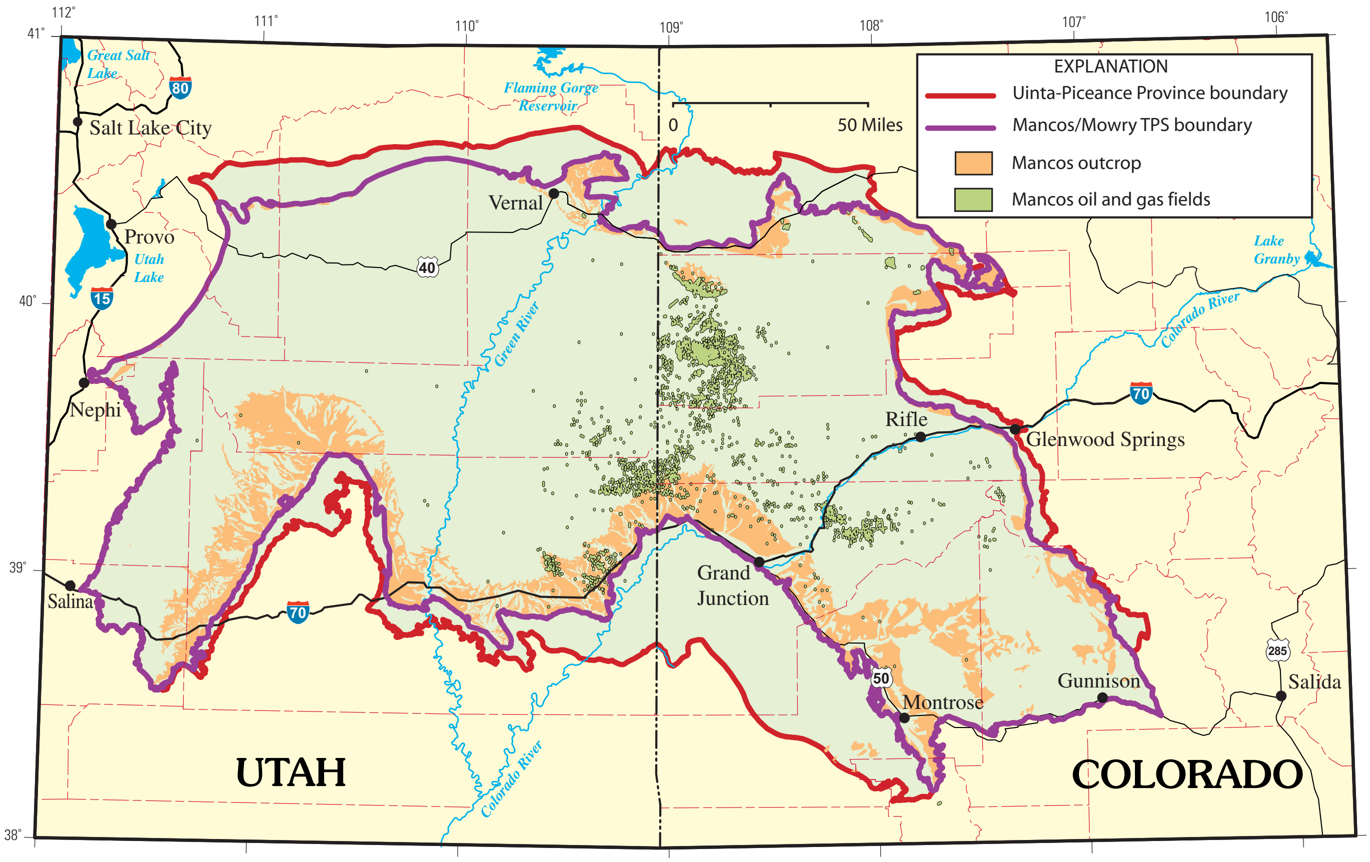


Figure 5. Extent of the Mancos/Mowry Total Petroleum System boundary as defined by the edge of Mancos Shale outcrop and limits of migration of hydrocarbons, and distribution of associated oil and gas fields.

Source Rock

The Mancos/Mowry Shales originally extended across the entire study area and vary in thickness from about 1,700 ft in the westernmost part of the Uinta Basin to about 5,000 ft in the middle part of the Uinta Basin. They are about 5,500 ft thick in the Piceance Basin (pl. 1; Johnson and Rice, 1990). The Mancos/Mowry Shales are a complex unit representing continuous marine deposition in the two basins for about 29 million years (m.y.) (*Neogastroplites cornutus*, 98.5 Ma, to *Baculites clinolobatus*, 69.4 Ma, Obradovich, 1993). The shales intertongue with marginal-marine sandstones and with coastal plain mudstones and coals in both the Piceance and Uinta Basins. An increasing number of sandstone tongues split the marine shales into discrete subunits towards the western part of the Uinta Basin (fig. 9, pl. 1).

The Mancos/Mowry ranges in lithology from black organic-rich shale to siltstones and sandy siltstones. The Mowry is restricted to the northern part of the Uinta Basin and the northern and eastern parts of the Piceance Basin, where it accumulated as marine muds lateral to fluvial and nearshore sandstones of the Dakota Sandstone depositional system (fig. 10). The Mancos is composed of gray to black shale, siltstone, and sandy siltstone, and contains a number of sandstone beds as well, such as the Coon Springs Bed and Mancos B (Prairie Canyon Bed).

The most organic-rich parts of the Mancos/Mowry TPS are the black shales of the Mowry Shale and the lowest parts of the Mancos. The Mowry contains a mix of Type II and Type III organic matter (Burtner and Warner, 1984). The Mowry has total organic carbon (TOC) values of 1.6–2.4 percent based on eight analyses within the boundaries of the Uinta-Piceance Province (Burtner and Warner, 1984). The Mancos contains both terrestrial and marine organic matter as reflected in the percentages of terrestrial versus marine palynomorphs found within the Mancos interval (fig. 11) (Cushman, 1994). Increases in terrestrial input generally match an increase in grain size within the Mancos. Plant fragments are also common constituents in the Mancos. Outcrop samples taken from the complete Mancos section in the southwestern part of the Piceance Basin have TOC values ranging from 0.18 to 3.36 percent, with some of the highest values coming

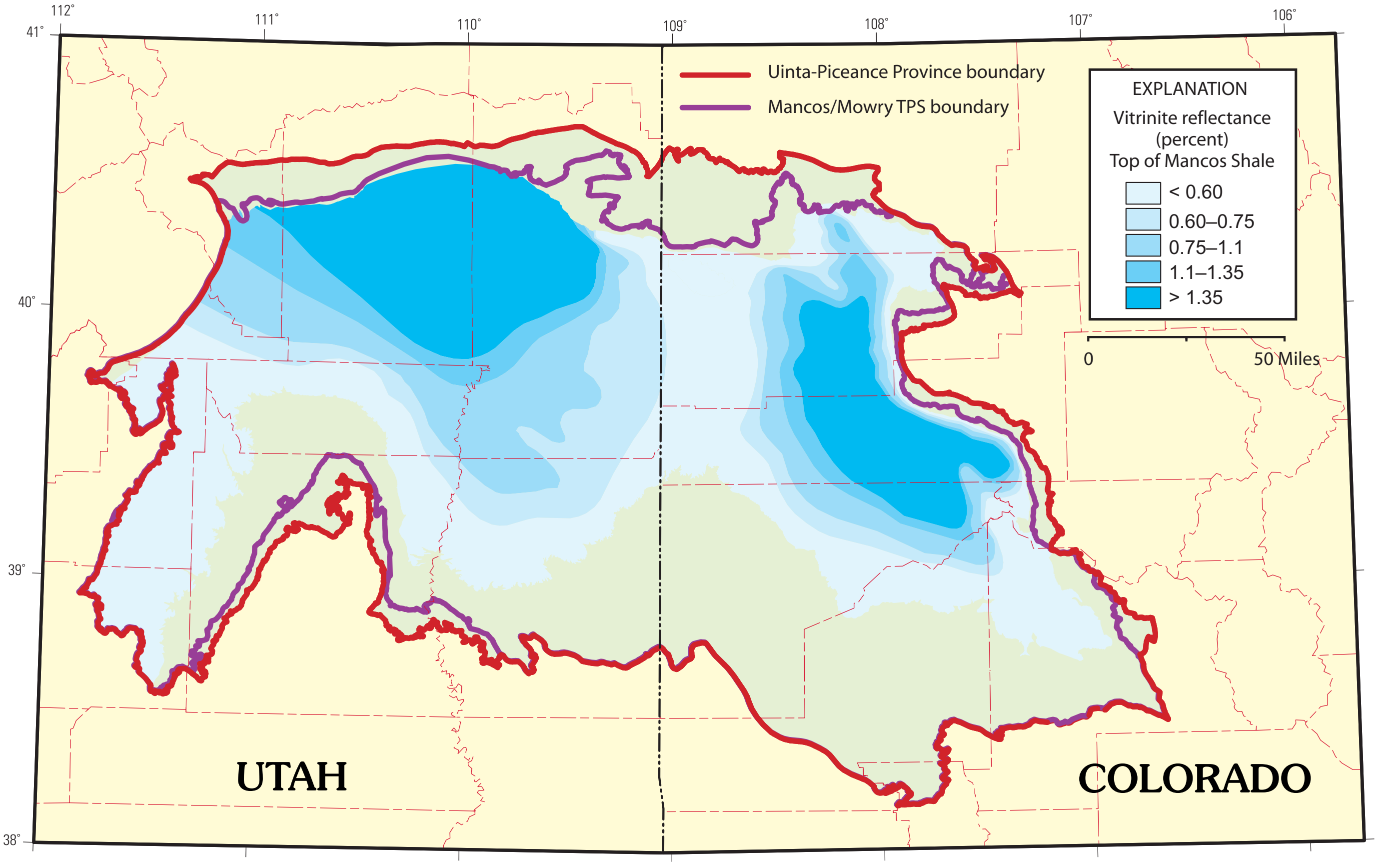


Figure 6. Contour map of thermal maturity values for the top of the Mancos Shale (based on coal zones in overlying Mesaverde Formation and equivalents). (From Nuccio and Roberts, Chapter 4, this CD-ROM).

from the lower 70 ft of the Mancos sampled near Delta, Colo. (Johnson and Rice, 1990).

Chemical and isotopic composition of gases collected from the Morrison, Cedar Mountain, Dakota, Mancos B, Corcoran, and Cozzette are interpreted by Johnson and Rice (1990) to be sourced from the Mancos Shale. Oils analyzed from the Rangely anticline during this project (Lillis and others, Chapter 3, this volume) indicate that oil in the Mancos B and Mancos from the Rangely anticline are sourced from the Mancos whereas oils in the Entrada, Morrison, and some Dakota reservoirs have other sources (Lillis and others, Chapter 3, this CD-ROM). The sources of gas in these units may still be entirely or partly Mancos/ Mowry, but in this study, the gas is included within the Mancos/ Mowry TPS.

Structure

The study area consists of two large basins, the Uinta and Piceance, separated by the Douglas Creek arch (figs. 12, 13). The Uinta Basin is an asymmetric basin, located mostly in Utah, with its deepest part to the north along the buried south-vergent Uinta Basin boundary fault (figs. 12, 13). The Uinta Basin is bounded to the east by the Douglas Creek arch and is bounded on the southeast by the edge of the Paradox Basin and the San Rafael Swell. The boundary between the Paradox and Uinta Basins is variously placed because the northeast plunge of the Uncompahgre uplift is not clearly defined. The southwestern margin of the Uinta Basin is also somewhat variable in its boundary with the Wasatch Plateau, which is included in the study area. The westernmost limit of the basin is the Charleston-Nebo thrust.

The Piceance Basin is located entirely within Colorado and is also asymmetric, with its deepest parts to the northeast (fig. 12). The basin is bounded on the north by relatively small south-vergent thrust faults, which are splays off the larger Uinta Basin boundary fault. The east side of the basin is bounded by the Grand Hogback monocline, the surface expression of a buried west-vergent thrust that reaches the surface in the southeastern part of the basin. The southwestern part of the Piceance Basin is bounded by the Uncompahgre uplift, an anticlinal structure that forms the hanging wall of the south-vergent Uncompahgre thrust;

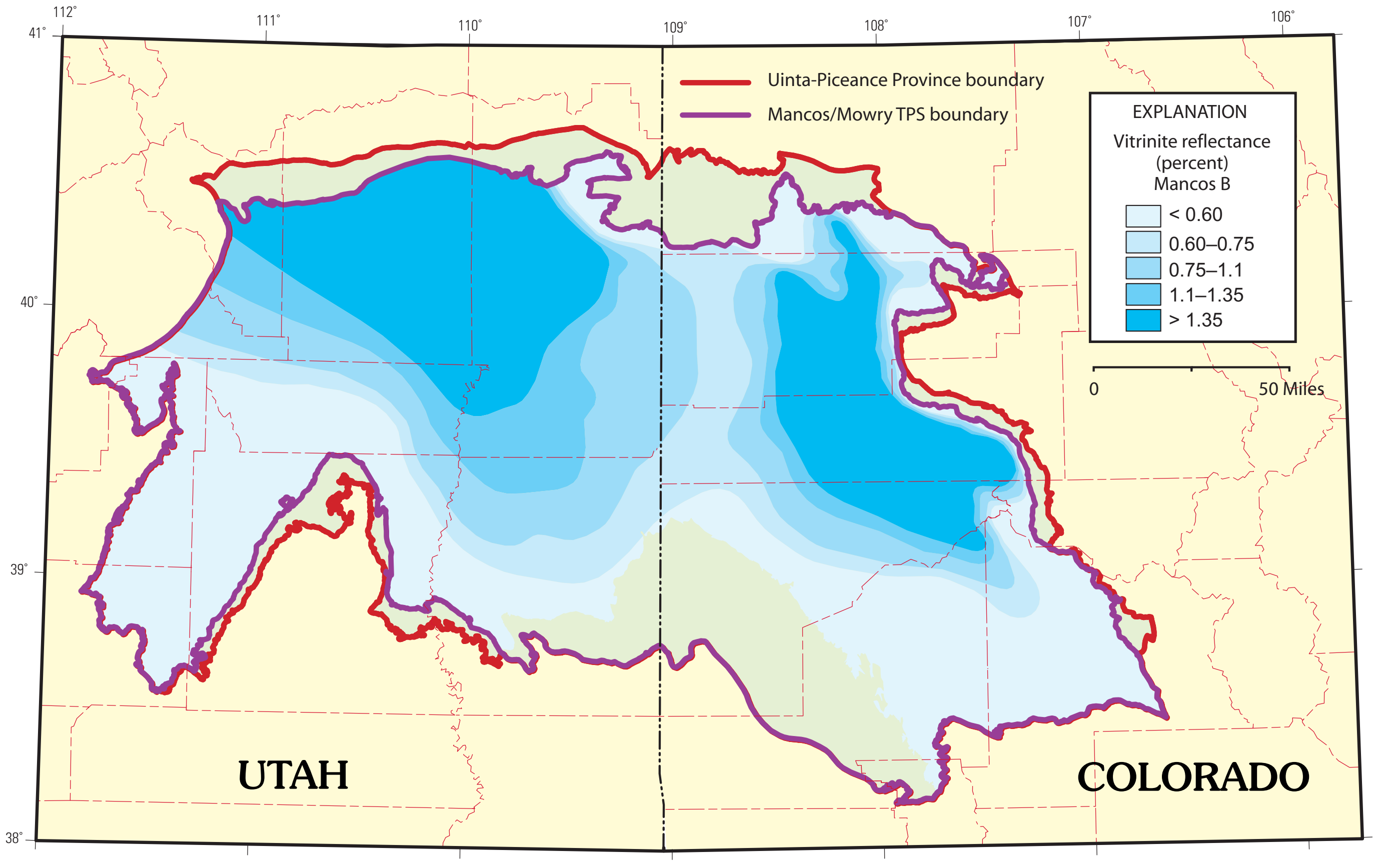


Figure 7. Contour map of thermal maturity values for the middle part of the Mancos Shale (average of base of Mesaverde Formation and base of Mancos Shale maps). (From Nuccio and Roberts, Chapter 4, this CD-ROM.)

the basin boundary was picked at the crest of the anticline. The western boundary of the Piceance Basin is the Douglas Creek arch.

The Douglas Creek arch is a north-south-trending anticline that is cut by numerous southwest-northeast-trending normal faults. The rocks in the fold are highly fractured and the fractures provide the permeability needed for the tight reservoirs of the Mancos B and Dakota to produce gas on the arch. There are a number of smaller northwest-trending anticlines superimposed on the arch, as well as south of the arch (fig. 13). Some of these anticlines are apparently superimposed over two left-lateral wrench faults, whereas others are subsidiary folds to the Uncompahgre uplift (Stone, 1969, 1977, his fig. 1). The existence of left-lateral wrench faults is supported by the work of Potter and others (1992). Wrench faults explain a number of en-echelon anticlines and associated faults or fault complexes present along parts of the Douglas Creek arch (see Stone, 1969, 1977; Moretti and others, 1992).

Maturation

In northwestern Colorado and northeastern Utah, the Mowry Shale has a hydrogen index (HI) of between 32 and 276, maximum temperature (T_{max}) values of 795°–842°F, and 1.6–2.4 weight percent TOC (Burtner and Warner, 1984). Burtner and Warner (their table 2) showed that gas is generated at HI's of 0–150, gas and oil are generated at HI's of 150–300, and oil only is generated from HI's of >300. They showed the main phase of oil generation to occur at a T_{max} of between 815°F and 860°F, where TOC's of 0–0.5 have poor generation potential, 0.5–1.0 have fair potential, 1.0–2.0 have good potential, and >2.0 have very good potential. Based on these parameters, the Mowry Shale in the northern Uinta-Piceance Province has good potential to generate hydrocarbons.

The vitrinite reflectance (R_o) of the Mancos Shale ranges from slightly more than 0.5 percent R_o at the top of the section to about 1.0 percent R_o at the base on the Douglas Creek arch,

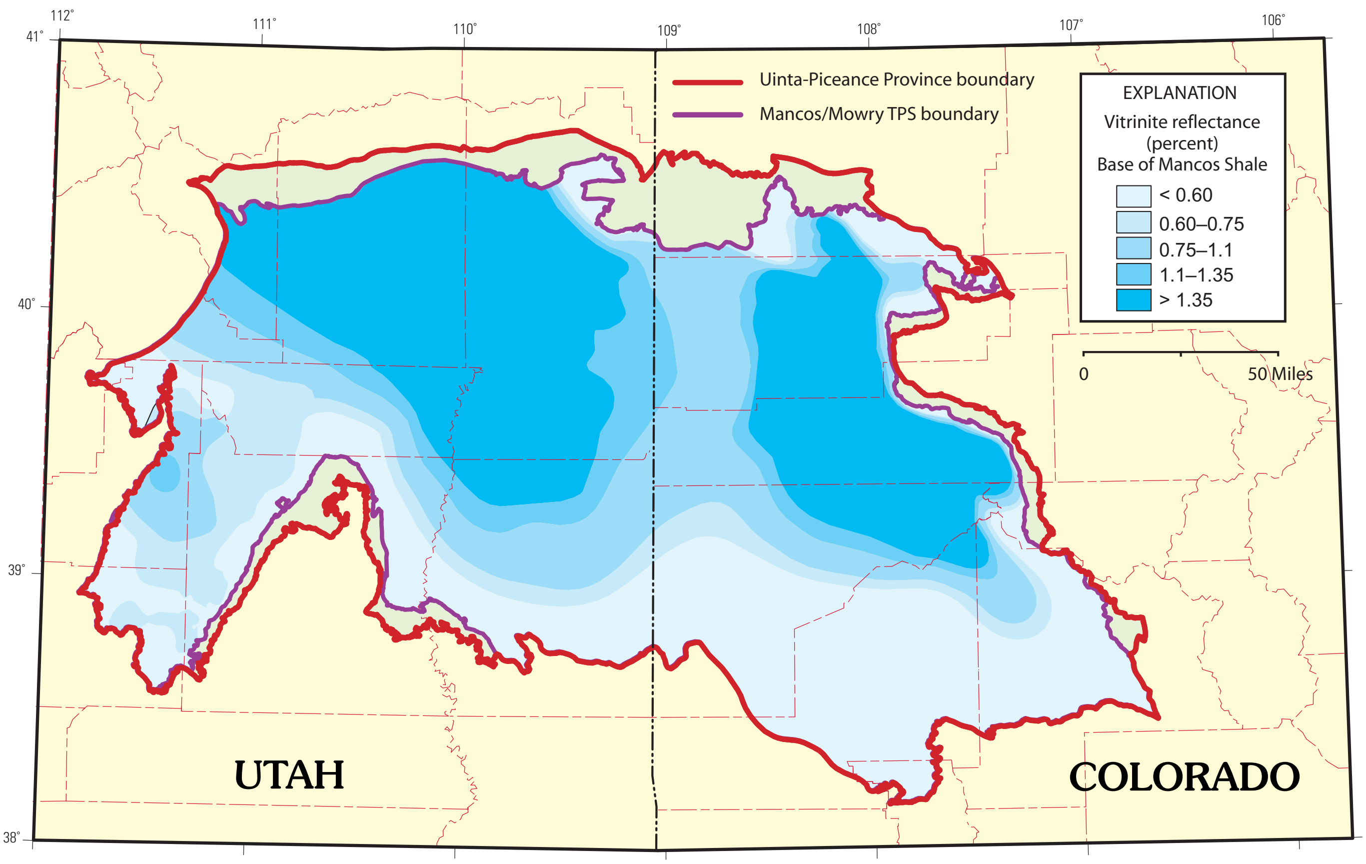


Figure 8. Contour map of thermal maturity for the base of the Mancos and Mowry Shales. (From Nuccio and Roberts, Chapter 4, this CD-ROM).

exceeds 1.8 percent R_o in the middle of the Piceance Basin, and is about 0.5 percent R_o at the Grand Hogback monocline (Johnson and Rice, 1990, their fig. 4; M.J. Pawlewicz, USGS, written commun., 2000; also see fig. 6). Contours of vitrinite reflectance on the base of the Cameo-Fairfield coal zone in the basal part of the Mesaverde Group, which approximates the top of the Mancos, indicates that maturation of the Mancos exceeds values of 0.6 percent R_o over much of the Piceance Basin (fig. 6). Peak gas generation from the lower Mancos and Mowry was between about 57 and 53 Ma (Nuccio and Roberts, Chapter 4, this CD-ROM). Data collected at the Multiwell Experiment (MWX) site in the Piceance Basin suggest that the maximum burial phase for Mesaverde coals was between 35 and 9 Ma (Barker, 1989). This timing of maximum burial should apply to the upper Mancos as well.

In most of the Uinta Basin, thermal maturity values at the base of the Mesaverde (top of Mancos) are greater than 0.6 percent R_o, except in the area of the Douglas Creek arch (Nuccio and others, 1992, their fig. 4). Johnson and Nuccio (1986) stated that the maximum burial of the lowest coal of the Mesaverde was 12,600 ft at 35 Ma. Peak generation of gas in the basin was between 36 and 20 Ma depending on location within the basin (see Nuccio and Roberts, Chapter 4, this CD-ROM). The area was uplifted beginning at about 10 Ma.

The best source rocks are within the Mowry and the basal part of the Mancos. These intervals could have started generating oil at about 76 Ma in the Piceance Basin and at about 60 Ma in the Uinta Basin (fig. 14); large parts of both the Uinta and Piceance Basins have passed through the oil window and presently the base of the Mancos has attained an R_o value greater than 1.35 percent (fig. 8).

Migration

Hydrocarbons were generated between about 76 and 9 Ma in the Uinta-Piceance Province for the Mowry and Mancos Shales, and maximum generation of gas was between 35 and 19 Ma. Fracturing of Mesaverde reservoirs, and presumably most of the Mancos associated reservoirs, took place between 40 and 36 Ma due to regional west-northwest-directed compressive stresses

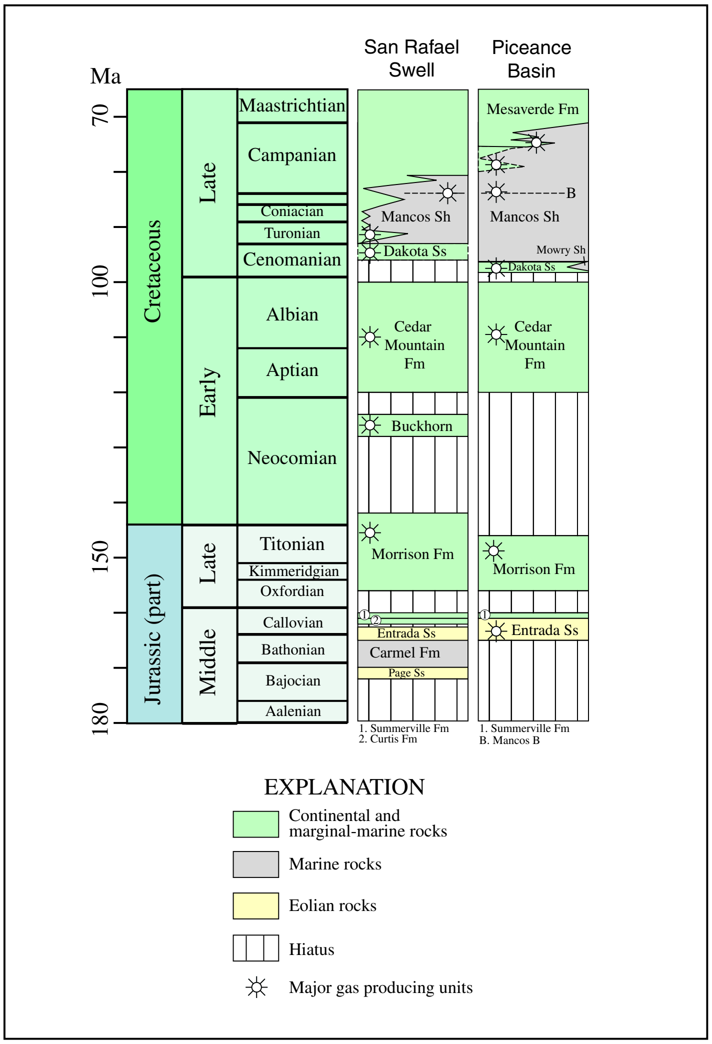


Figure 9. Columnar sections of units exposed on outcrop in the San Rafael Swell (southern Uinta Basin) and the Piceance Basin within the Mancos/Mowry Total Petroleum System. Age of units in the San Rafael Swell from Imlay (1980, his section 35) and Currie (1998) for the Jurassic, and from Currie (1998) and Roberts and Kirschbaum (1995) for the Cretaceous; age of units in the Piceance Basin from Imlay (1980, his section 39) for the Jurassic, and from Currie (1998) and Merewether and Cobban (1986) for the Cretaceous.

and high pore pressures due to the generation of hydrocarbons (Lorenz and Finley, 1991). By 36–30 Ma, horizontal compressive stress in the Mancos at the eastern margin of the Piceance Basin was mostly released by thrust faulting, and fracturing ceased at that time (Lorenz and Finley, 1991). Verbeek and Grout (1984, as cited by Barker, 1989) suggested that major fractures opened before the formation of the Grand Hogback monocline at about 34 Ma. Fractures were open to cementation throughout the maximum burial phase and microfractures likely opened and then healed near maximum burial (Barker, 1989). Shales are fractured but the fractures tend to be nonmineralized and closed (Pitman and Sprunt, 1986).

According to Brown and others (1986), all of the gas produced from the Corcoran, Cozzette, and Rollins Sandstone Members are from areas with less than 1.2 percent R_o. This suggested significant migration of gas from hotter portions of the basin, which are mainly to the northeast of the main producing fields. However, Brown and others (1986) also stated that production from the offshore siltstones of these sandstones is believed to be the result of local gas generation and accumulation from surrounding Mancos Shale. Johnson (1989) stated that some of the gas in the Corcoran and Cozzette could have been derived from the thermal cracking of oil generated from the Mancos in deeper parts of the basin where the R_o is greater than 1.35 percent (figs. 6–8). The association of abundant gas and minor oil in the Mancos B and Dakota reservoirs on the Douglas Creek arch suggests that the Mancos/Mowry generated both oil and gas, probably due to the presence of both Types II and III organic matter. Early migration of hydrocarbons into Mancos B reservoirs could have been to the south and west up depositional dip into clinoforms that are well developed in the unit (see Johnson and Finn, 1986; see pl. 1).

Reservoir Rocks

Morrison and Cedar Mountain Formations and Dakota Sandstone

The Morrison Formation (including the Tidwell, Salt Wash, and Brushy Basin Members) and Cedar Mountain Formation (including the Buckhorn Conglomerate Member) consist of fluvial and minor lacustrine deposits. The Cedar Mountain is often included in the Dakota Sandstone in subsurface studies (see Moretti and others, 1992, their fig. 2, Lower Dakota D). The units can be distinguished by the presence of coal in drill-hole samples of the Dakota, carbonate nodules in the Cedar Mountain, and variegated beds in the Morrison (fig. 15). The Dakota consists of fluvial, shoreface, and tidally influenced deposits. The fluvial channels in all these units have paleocurrent directions generally to the northeast in the southern part of the Piceance Basin (Currie and others, 1999), but channels in the upper Salt Wash and middle to upper Brushy Basin Members have paleocurrent directions to the east-southeast in the northern part of the Uinta Basin near Vernal, Utah (Currie, 1998). The Buckhorn and the Dakota fluvial systems are partly confined to paleovalleys incised into older fluvial deposits (Currie, 1998; Currie and others, 1999). The Buckhorn valley fill is present on the San Rafael Swell and extends into the Uinta Basin in a northeasterly direction. The Dakota has two valley-fill systems separated by a broad interfluvial area present between the San Rafael Swell and the vicinity of Grand Junction. One valley-fill system is exposed on

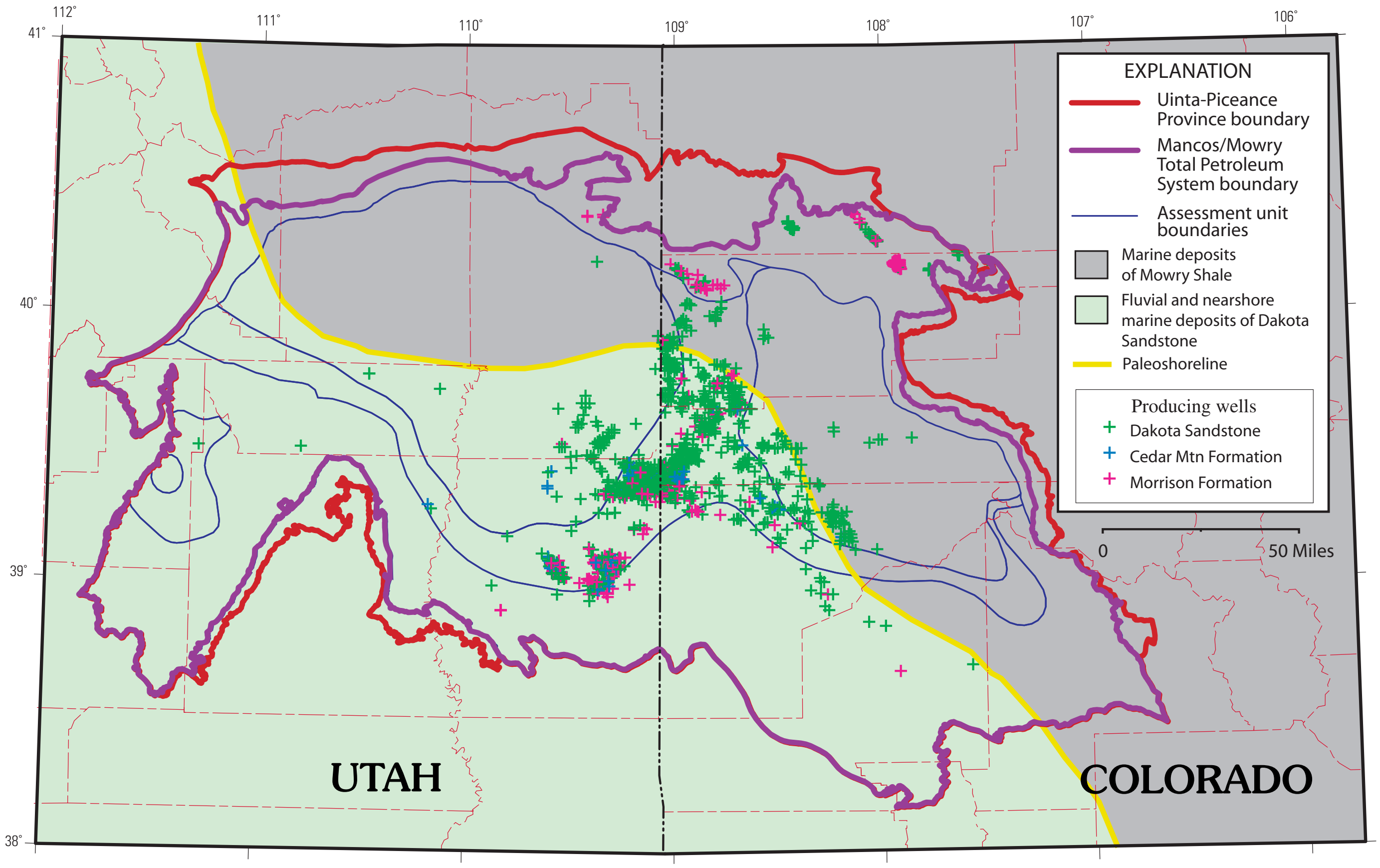


Figure 10. Paleogeographic reconstruction of the shoreline during Dakota/Mowry time (*Neogastroplites americanus*) after Cobban and others (1994), and location of producing wells from Morrison Formation, Cedar Mountain Formation, and Dakota Sandstone reservoirs. Assessment unit boundaries in purple (see fig. 23).

the west side of the San Rafael Swell (fig. 16) and extends in a northeasterly direction into the Uinta Basin. The other system is exposed in western Colorado (figs. 17, 18) and extends northeasterly into the Douglas Creek arch. Another possible valley-fill unit is contained in the upper Cedar Mountain (Dakota?) on the San Rafael Swell and consists of conglomerate and conglomeratic sandstone that extend into the Uinta Basin in a northeasterly direction.

The Morrison, Cedar Mountain, and Dakota produce predominantly gas (96 percent gas based on 1986 data, from Johnson and Rice, 1990, their table 1) from closed structures and stratigraphic/structural traps in the southwestern and northeastern parts of the Piceance Basin and from the Douglas Creek arch between the Uinta and Piceance Basins (Johnson and Rice, 1990). The valley-fill systems are underexplored for hydrocarbons.

There is conflicting evidence whether these formations contain conventional or continuous gas accumulations. Despite the classification uncertainty, the formations were assessed as a conventional accumulation by the USGS in 1995 to avoid double counting of the fields (Spencer, 1995). However, a number of lines of evidence suggests that these units are mainly a continuous accumulation with sweet spots and some minor conventional traps (see section on Traps and Seals). Most of the available data shows that the Morrison, Cedar Mountain, and Dakota are low-permeability (tight) reservoirs (Noe, 1993b) (table 1). However, two groups of fields are not considered tight: small domal structures superimposed on the crest of the Uncompahgre uplift, including Greater Cisco, Agate, and Seiber Nose fields; and fields on the southern plunge of the Douglas Creek arch, including Stateline, Westwater, East Canyon, and San Arroyo fields (table 1). The first group of fields was found to contain Phosphoria-sourced oils and probable mixed unknown Paleozoic oil and Mancos gas (Lillis and others, Chapter 3, this CD-ROM) and are included in the Phosphoria Total Petroleum System (Johnson, Chapter 9, this CD-ROM). Sparse drill-stems tests from the Morrison, Cedar Mountain, and Dakota reservoirs show various pressure conditions, but indicate mostly underpressuring with respect to normal hydrostatic pressures (table 2). Subnormal and overpressured conditions are reported for the Piceance Basin in the Niobrara-Frontier-Dakota part of the section (Wilson and

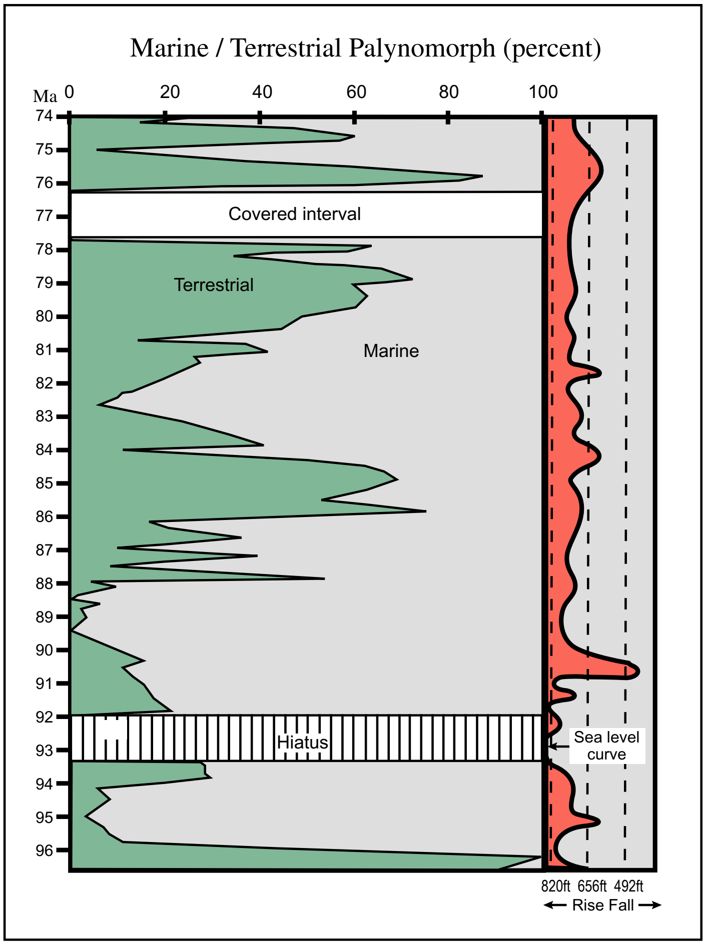


Figure 11. Distribution of marine (gray) versus terrestrial (green) palynomorphs in a section of the Mancos Shale near Delta, Colo. Collected and analyzed by Cushman (1994, his figure 18). Rise and fall of sea level during deposition of the Mancos also shown.

others, 1998). Spencer (1987) showed a zone of overpressuring in the Uinta Basin in the Dakota from an analysis of drilling mud weights from the Moncrief 14-1 Marsing well in T. 5 S., R. 6 W.

The largest gas fields (>20 wells) in the Morrison, Cedar Mountain, and Dakota reservoirs are Bar X, Baxter Pass, Bridle, Bryson Canyon, Cisco Dome, Greater Cisco, Cisco Townsite, Douglas Creek, Douglas Pass, Hells Hole, Rangely, San Arroyo, South Canyon, Trail Canyon, and Westwater, but the greatest cumulative production is from the Wilson Creek, Maudlin Gulch, and Danforth Hills fields (Johnson and Rice, 1990). Oil is produced from the Morrison, Cedar Mountain, and Dakota mainly from three fields: at the Greater Cisco field oil is produced from the Morrison, Cedar Mountain, and Dakota with about one-half the producing wells being completed in the early 1980's; oil is produced from the Morrison and Dakota at the Maudlin Gulch field with most wells being completed in the mid-1960's; and oil in the Wilson Creek field is mainly from drilling spread out between 1937 and 1997 in the Morrison with lesser production from the Dakota (data from Petroleum Information /Dwights LLC, 1999).

The Dakota produces gas and minor amounts of oil from fluvial and shoreface strata in the Hells Hole field (Moretti and others, 1992); the fluvial rocks are interpreted as valley-fill complexes (Currie and others, 1999) (pl. 4). Gas and minor oil are produced from fluvial units of the Cedar Mountain Formation, including the Buckhorn Conglomerate Member. The Morrison produces gas and minor oil from fluvial channels in the Salt Wash and Brushy Basin Members (Morgan, 1999) (fig. 15). The oil from Cisco field is brownish black, and has a 33.8 gravity API and a pour point of < 5°F and is now thought to represent oil, in part, from the Phosphoria (Lillis and others, Chapter 3, this CD-ROM). The gas is 82.1 percent CH_4, 2.5 percent C_2H_5, and 1.4 percent wetter gases (Morgan, 1999). The Harley Dome field produces gas from the Entrada, Morrison, and Dakota from stratigraphic and stratigraphic/structural traps (Bon, 1999). The Agate, Cisco Dome, Cisco Springs, Cisco Greater, Cisco Townsite, Gravelpile, and Seiber Nose fields have Phosphoria or unknown Paleozoic oil, have characteristics that suggest conventional accumulations, and were assessed in the Paleozoic-Mesozoic Assessment Unit 50200402 of the Phosphoria TPS (Johnson, Chapter 9, this CD-ROM). The well spacing for Morrison, Dakota, and Cedar Mountain reservoirs is between 60 and 640 acres, with numerous fields at 320-acre spacing (Noe, 1993b).

Frontier Formation

Eight wells produce oil and gas from the Frontier Formation in the Piceance Basin. The Frontier consists of silty sandstones representing distal shoreface deposits (pl. 4).

Mancos Shale

The Mancos Shale consists of dark-gray to black calcareous and bentonitic shales, and relatively smaller amounts of siltstone and sandstone (pl. 1). The reservoirs are of two types: (1) those that produce oil, mainly from fractured shale in Niobrara equivalent strata on the Rangely anticline (93 percent of oil produced from the Mancos excluding Mancos B) and (2) those that produce gas and traces of associated oil from fields in and around the Douglas Creek arch area. Only one oil well has been completed in the Mancos from the Rangely field since 1989. The Mancos contains the Coon Spring Sandstone Bed in its lower part on the San Rafael Swell (pl. 1).

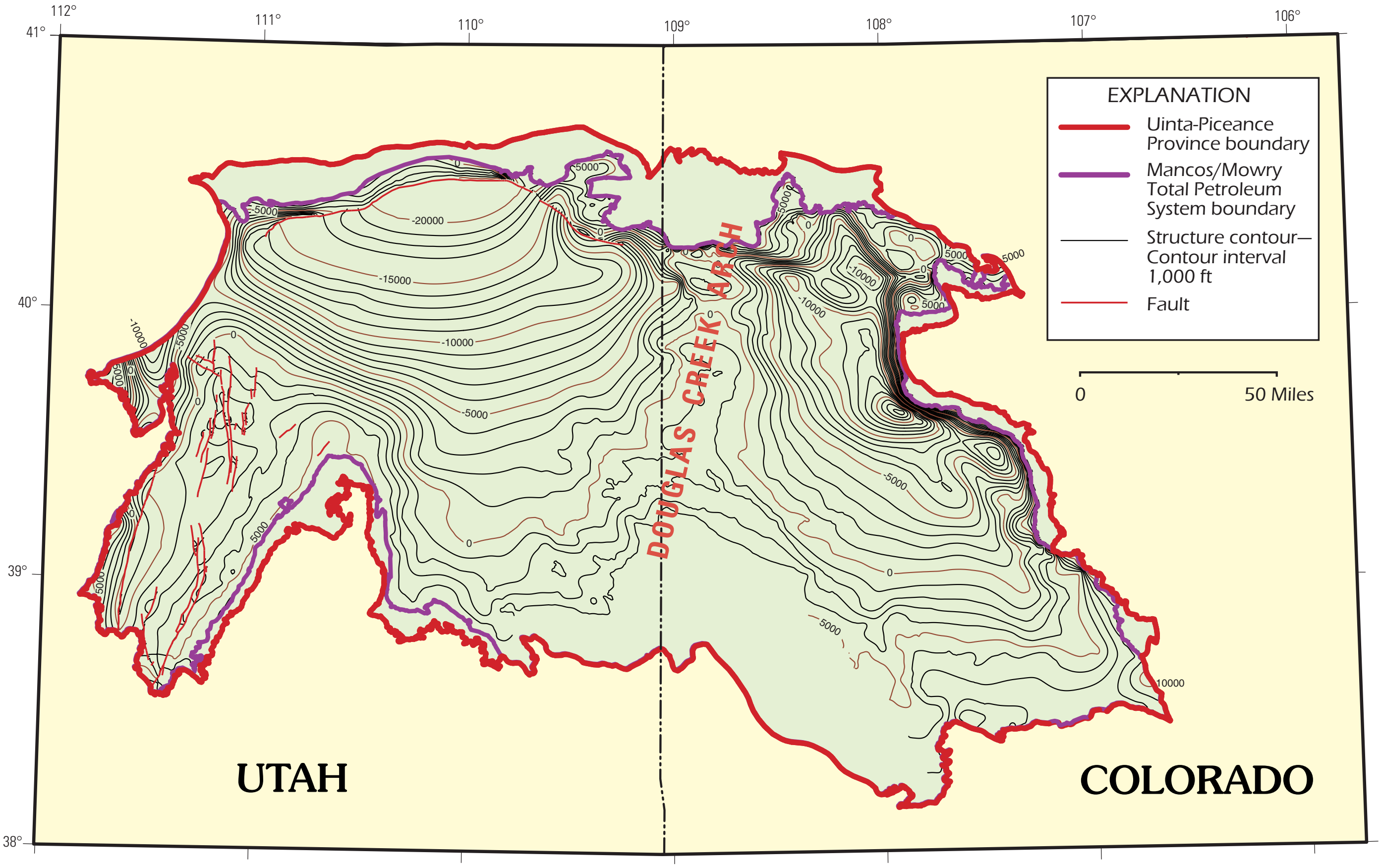


Figure 12. Structure contour map on the top of the Dakota Sandstone in the Uinta-Piceance Province (from Roberts, Chapter 16, this CD-ROM). For fault names see figure 13.

Mancos B/Emery Sandstone

The Mancos B or Emery Sandstone (included in the Prairie Canyon Bed of the Bluegate Member of the Mancos Shale by Cole and others, 1997) consists of 500–1,000 ft of interbedded sandstone and laminated mudrock that was apparently deposited on a depositional ramp/shelf during the Santonian and early Campanian (fig. 9). Two sets of clinoform-bounded units can be mapped in the subsurface, one prograding from southwest to northeast, and the other from northwest to southeast (Johnson, Chapter 11, this CD-ROM, his fig. 4). These clinoform-bounded units built up topographic highs and also formed corresponding lows in which successively younger units accumulated (Kellogg, 1977; Johnson, Chapter 11, this CD-ROM). The sandiest part of the facies is in the Douglas Creek arch area (Kellogg, 1977) and may represent distal lowstand shorelines corresponding to the valley incisions described by Hampson and others (1999; fig. 19). Proximal parts of the lowstand shorelines may have been removed during ravinement. Clinoform topsets contain erosional scours filled by heterolithic strata interpreted to be tidally influenced valley-fill deposits (fig. 19) (Hampson and others, 1999).

The Mancos B has porosities that range from 1 to 11 percent and an average permeability of 0.7 millidarcy (mD) (Kellogg, 1977). Production is mainly from fractures. Three major fields producing from the Mancos B are the Cathedral, Douglas Creek, and Dragon Trail (more than 100 producing wells) with lesser activity (20-70 producing wells) in Lower Horse Draw, Philadelphia Creek, Rangely SW, and Trail Canyon fields (Petroleum Information/Dwights LLC, 1999). Only 50 out of about 975 producing wells in both basins (as of December, 1998) have produced oil from the Mancos B/Emery, although Kellogg (1977) thought a significant oil column may be present beneath the gas cap on the Douglas Creek arch. The oil is about 40°API gravity and green in color, has a moderately high pour point, and appears to be similar to the Mancos oil produced from the Rangely anticline (Kellogg, 1977). J.W. Schmoker (USGS, written commun., 2000) studied four samples of sandstones and siltstone from the Mancos B in the Greater Douglas Creek area and stated that the best porosities range from 5.6 to 7.3 percent. Coalson and others (1982) calculated porosities of 9–12 percent from logs and 10–11 percent from cores and calculated permeabilities of less than 0.1

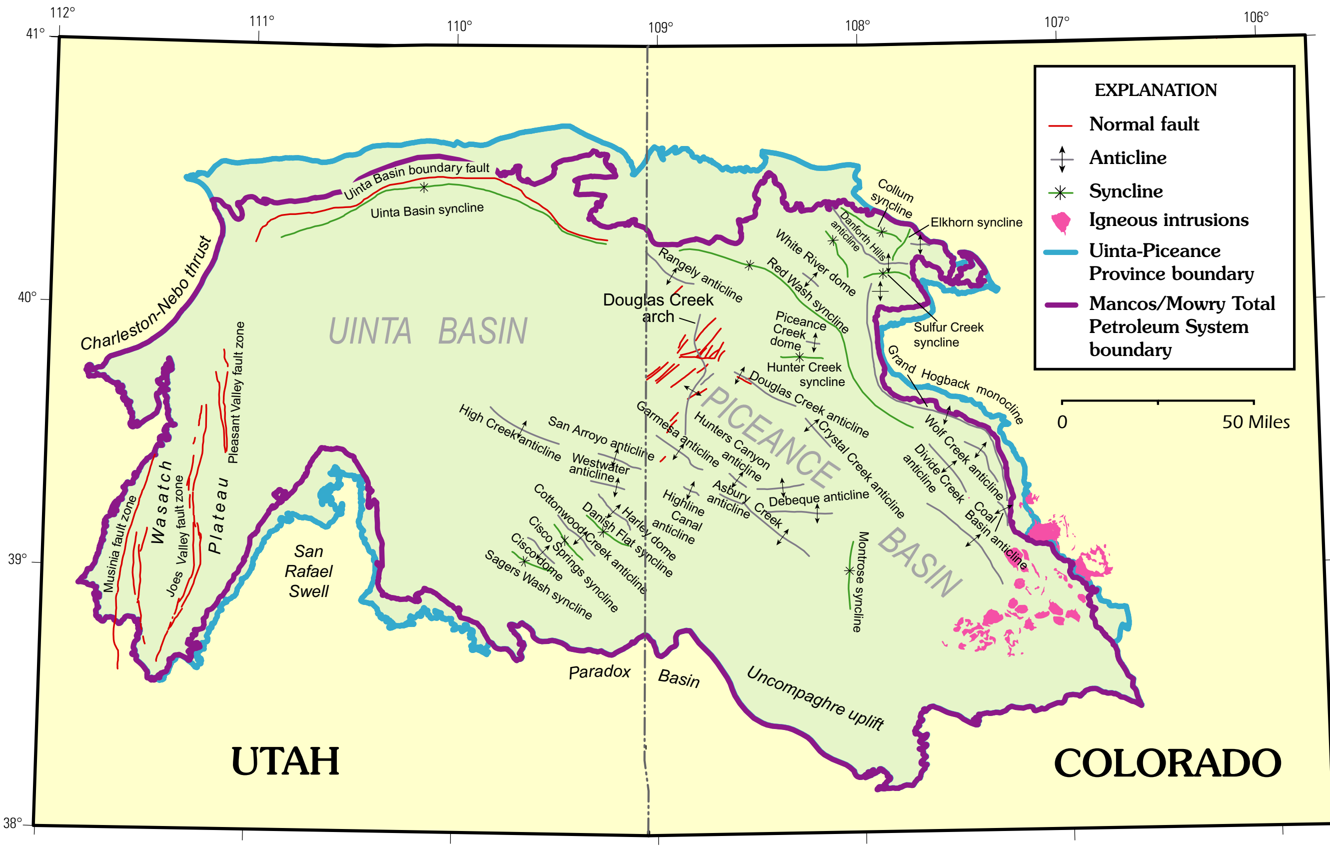


Figure 13. Major structural features and igneous intrusions in the Uinta-Piceance Province (from Roberts, Chapter 16, this CD-ROM).

mD in the Mancos B interval. Spacing for Mancos B wells is 160 acres for all the main fields (Noe, 1993a).

Rollins, Cozzette, Corcoran, Castlegate, Sego, and Morapos Sandstones

These sandstone units consist of proximal to distal shoreface deposits and associated tidally influenced valley-fill deposits (Kirschbaum and Hettinger, 1998; Van Wagoner and others, 1990). The shoreface sandstones are very fine grained to medium grained, arranged in overall coarsening upward successions, and are hummocky to trough cross stratified or horizontal laminated (pl. 2). Tidal facies are commonly indistinguishable from the shoreface facies on geophysical logs unless there is significant mud in the tidal deposits, which shows up as a break in the usual prominent upward decrease in the gamma ray log. On outcrop and in core, the tidal facies consists mostly of trough crossbedded sandstone or wavy/lenticular bedding with mud or carbonaceous laminae and inclined wavy/lenticular bedding (pl. 3). Paleoshoreline trends were generally southwest to northeast (fig. 20) except during Sego time when shorelines were probably more east-west, and during Rollins time when they were north-south (Zapp and Cobban, 1960; Johnson, 1989).

Most gas production is from tight or nearly tight sandstone reservoirs (Johnson and Rice, 1990). The sandstones have diagenetic quartz overgrowths, calcite cements, and authigenic clays that cause microporosity and low permeabilities (Brown and others, 1986). Properties calculated from log analysis indicate porosities of 5.9–6.7 percent and permeabilities averaging 0.2–0.3 mD in the Corcoran, and porosities of 7.0–7.5 percent and permeabilities of 0.29–0.42 mD in the Cozzette (Kukal, 1987). Based on petrographic data (courtesy J.K. Pitman, USGS, written commun., 1999), measured porosities are 10.1–13.1 percent for sands in the Cozzette and 11.0–12.4 percent for the Corcoran, and permeabilities are 0.05–0.21 mD for the Cozzette and 0.08–0.49 md for the Corcoran in the 1-21 Horseshoe well (pl. 2). Corcoran, Cozzette, and Rollins water saturation ranges from 45 to 65 percent (Nelson, 2002). Studies from the MWX site, located about 5 mi southwest of Rifle, Colo., suggest that the permeabilities are too low to account for the observed production from these units leading to the conclusion that fracture permeability is required (Nelson, Chapter 15, this CD-ROM).

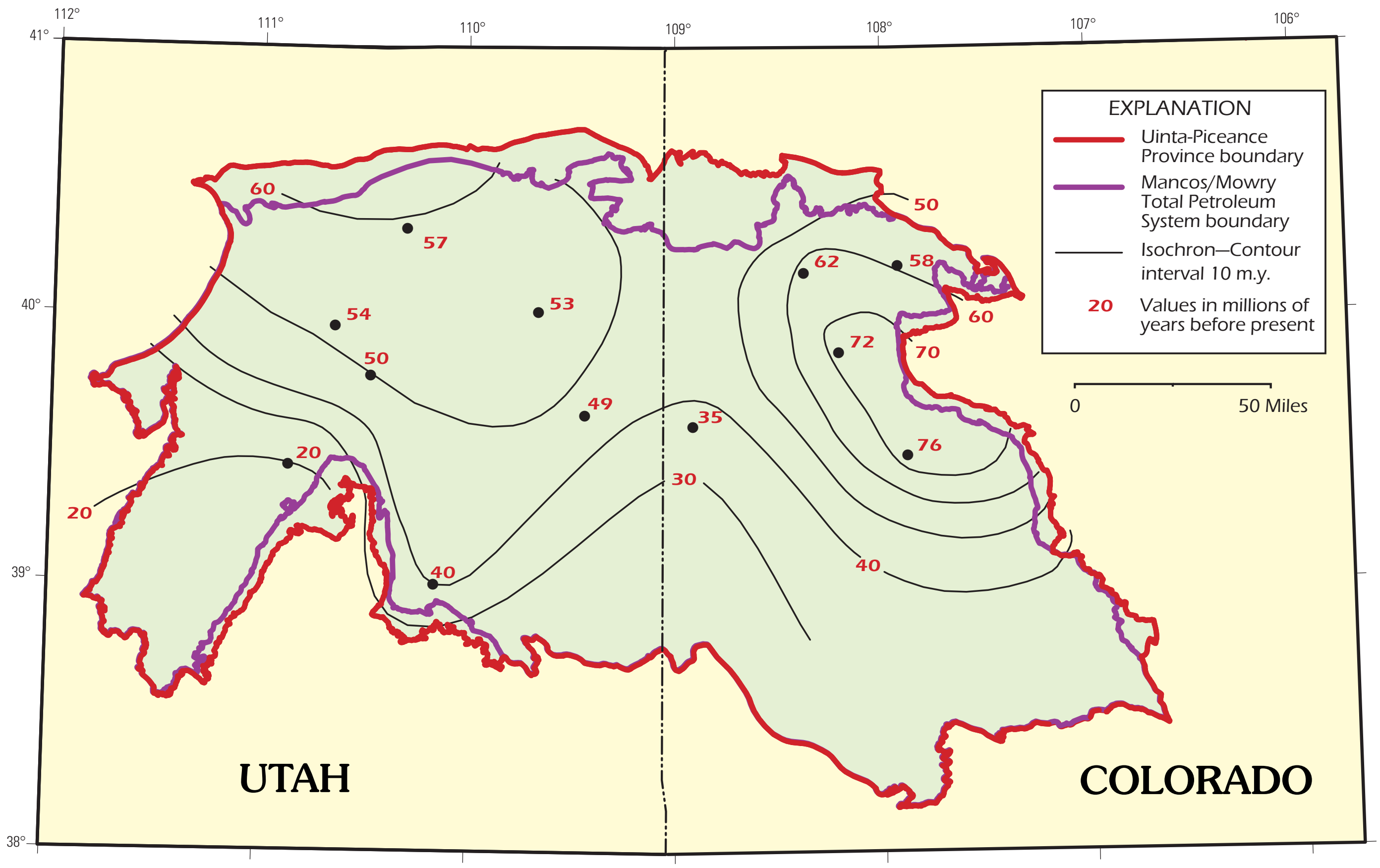


Figure 14. Timing of hydrocarbon generation for the base of Mancos/Mowry Shales (Nuccio and Roberts, Chapter 4, this CD-ROM).

As of 1998, 268 wells produced hydrocarbons from the Corcoran, Cozzette, and Rollins Sandstone Members (fig. 21) (Petroleum Information/Dwights LLC, 1999). The Plateau and Shire Gulch fields have the greatest number of producing wells, but average cumulative production, as of 1981, was highest in Divide Creek and Buzzard fields (fig. 22) (Brown and others, 1986). The Castlegate, sometimes referred to as the Mancos A, has about 60 producing wells in the province, mainly from the Greater Douglas Creek (23 percent), Taiga Mountain (15 percent), and Westwater (15 percent) fields. Both oil and gas are produced from the Castlegate; 18 percent of the producing wells are oil, mainly from the Taiga Mountain field. The Castlegate is a very fine grained to fine-grained orthoquartzite with an original porosity of about 33 percent. Two episodes of cementation, first by silica and the second by carbonate, have restricted both the porosity and permeability of the rocks (Munger, 1965). Minor production is from the Sego and Morapos Sandstones. The reservoirs tend to be from late highstand, lowstand, or early transgressive system tracts probably because they are encased in nonpermeable and nonfractured marine shale.

Traps and Seals

Morrison and Cedar Mountain Formations and Dakota Sandstone

There is conflicting evidence as to whether the oil and gas accumulations in the Morrison, Cedar Mountain, and Dakota are continuous or conventional. Gas/water contacts are unknown or absent in many of these reservoirs as reported in Hill and Bereskin (1993), except at Park Mountain where a map by Lipinski (1993b) showed shut-in gas wells outside of the main producing channel sandstone that have a gas/water contact suggestive of a more conventional accumulation. The Hells Hole field is reported to have a gas column of 1,800 ft in the Dakota interval with no known gas/water contact. Moretti and others (1992) considered the trap at Hells Hole field as a high-angle reverse fault with structural closure of 100 ft at the Dakota level. However, according to Lipinski (1993a), who was an author in the previously cited report, there is no structural closure at the Dakota level and below, even though it was drilled as a structural play. In the San Arroyo field, the gas column was reported to be 3,000 ft thick with an

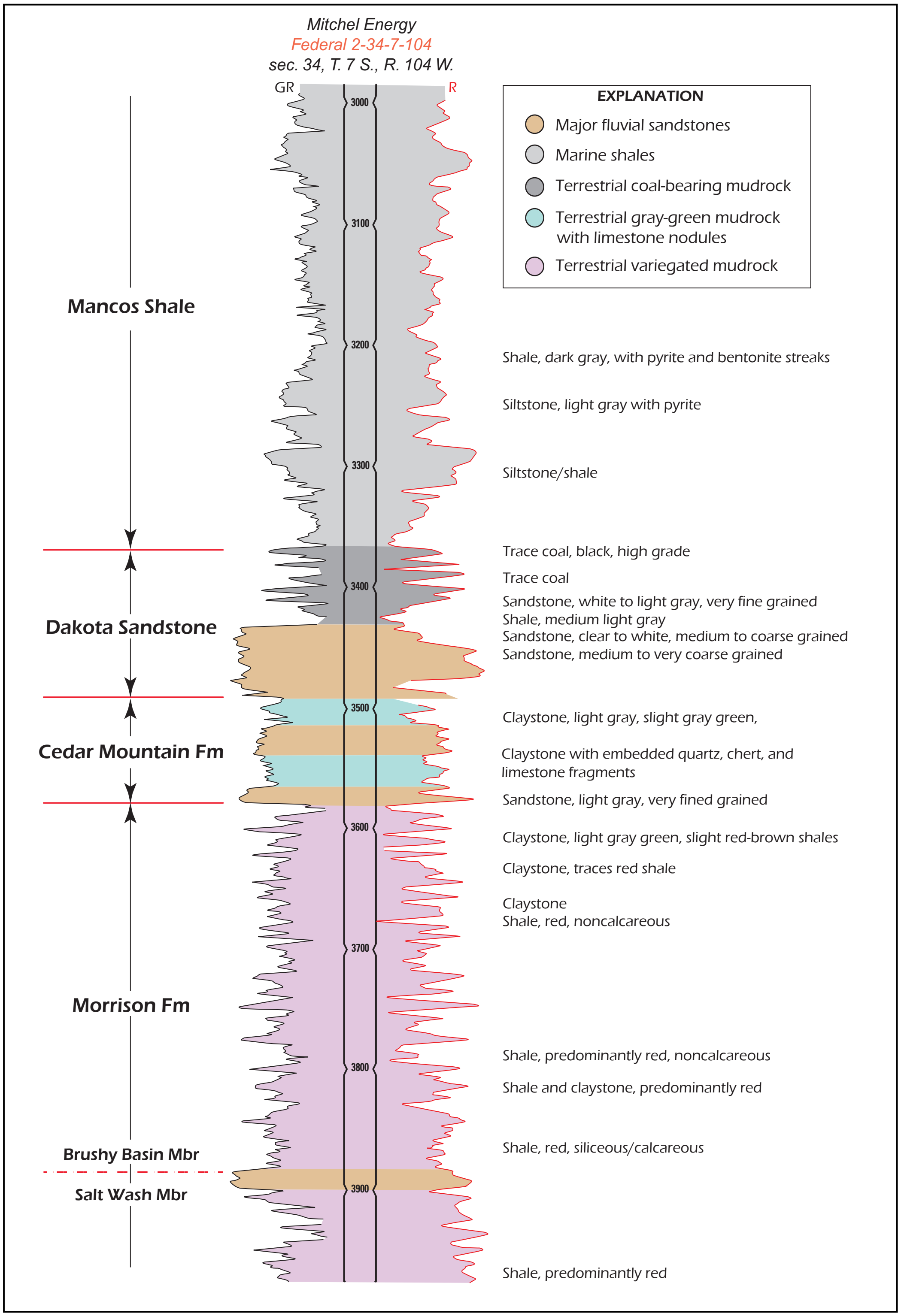


Figure 15. Well-log traces (GR, gamma ray; R, resistivity; depth in feet) and selected AMSTRAT lithologic descriptions for the Dakota Sandstone and Cedar Mountain and Morrison Formations for an area of the southern Douglas Creek arch. Mudstones can be characterized in the Dakota by the presence of coal, in the Cedar Mountain by limestone fragments or gray-green color, and in the Morrison by red beds.

Figure 16. Amalgamated fluvial sandstones near Mesa Butte, Utah, preserved within valley-fill deposits in the Dakota Sandstone on the southwestern part of the San Rafael Swell.

Figure 17. Upper part of Morrison Formation (red) in lower part of photograph, Cedar Mountain mudstones (gray) in center of slope, and caprock of fluvial sandstones in the Dakota Sandstone at Agate Wash, eastern Utah. Note the incised valley. Person (circled) for scale.

Figure 18. Variegated mudstones of the Morrison Formation, green-gray mudstone of the Cedar Mountain Formation, and amalgamated sandstones of the upper part of the Cedar Mountain Formation and the Dakota Sandstone at Westwater Canyon, eastern Utah. Sandstones form reservoirs in much of the southernmost extent of the Dakota.

Figure 19. Mancos B incised valley fill from the Cisco oil field of Hampson and others (1999, their section 19, called Prairie Canyon Formation).

upper water contact, but no known lower water contact (Quigley, 1960), which would imply a continuous accumulation. Stateline field has mainly gas production from the Dakota/Cedar Mountain but also small amounts of water and oil (Stowe, 1979). Most of the fields that produce from the Dakota, Cedar Mountain, and Morrison are classified as tight, a criterion for continuous accumulation. Pressure data from drill-stem tests in the Conoco 22-1 well, located in sec. 22, T. 9 S., R. 22 E. in the Uinta Basin, showed overpressured conditions from all units below the Mancos B, which is underpressured. The deeper units that were tested include: the lower Mancos, Dakota/Cedar Mountain, Nugget Sandstone(?), Entrada Sandstone, and Madison Limestone. Spencer (1987) showed overpressuring in the Mancos, Dakota, and lower units based on analysis of mud weights from the Marsing 41-1 well located in sec. 14, T. 5 S., R. 6 W. (See Multiwell Experiment for evidence of overpressuring in the Iles sandstones, Nelson, Chapter 15, this CD-ROM.) Based on the preceding discussion, the traps are probably continuous for these reservoirs with sweet spots and some conventional accumulations where the reservoirs are undersaturated.

Some wells have initial production with oil, gas, and water indicative of conventional accumulations. A drill-stem test from the Argo 4-26-A well in the Baxter Pass field yielded a pressure of 0.3 psi/ft, and recoveries included gas-cut mud, water-cut mud, and highly gas-cut saltwater. The Coseka 2-15-1S-103 well from Banta Ridge field had initial production of 15 barrels of oil per day (BOPD), 2,000 thousand cubic feet of gas per day (MCFGD), and 9 barrels of water (BW); the Chorney 3 Banta Ridge well had initial production of 2 BOPD and 87 BW. The Pease Willard 1 Federal well in Lower Horse field produced 1,097 ft saltwater.

Seals in the Dakota are formed by the overlying impermeable Mowry or Mancos intraformational shale and mudstone. Presumably, the seals in the Morrison are intraformational mudstones of floodplain origin and seals in the Cedar Mountain are nodular carbonate rich mudstones also of floodplain origin.

Mancos/Niobrara/Frontier

Fractured sandstone and siltstone within the Mancos related to proximity to structures form internal traps for oil and gas accumulations. The main Mancos production is oil from the Rangely anticline, an anticline associated with a south-directed blind thrust (Stone, 1986). The seals for the trapped oil are the overlying shales in the Mancos.

Morapos/Castlegate/Sego/Corcoran /Cozzette/ Rollins Sandstones

There are two main types of traps within the sandstones of the Iles Formation (Corcoran, Cozzette, and Rollins Members): closed anticlinal structures and basin-centered accumulations (Brown and others, 1986). Stratigraphic traps are only important in the offshore equivalents of these sandstones (Brown and others, 1986). Anticlinal structures include Divide Creek, Coal Basin, White River Dome, and Wolf Creek (fig. 13); basin-centered accumulations are represented by the Shire Gulch, Plateau, and Rulison fields (Brown and others, 1986). Based on their analysis of subsurface geology and remote sensing techniques, Hoak and Klawitter (1995) concluded that trends of production from fractures are controlled by subsurface structures, many of which are reactivated basement faults. Seals are mainly the overlying and underlying unfractured (or resealed fractures) marine shale tongues of the Mancos (unnamed shale tongues sealing the Iles and Morapos, and Buck and Anchor Mine Tongues sealing the Castlegate and Sego, respectively). These seals may be especially important in preserving the gas in tight reservoirs following uplift and erosion during which the invasion of surface waters and the escape of gas could occur. The Rollins is water wet with minimal production probably because of recharge from outcrop (R.C. Johnson, USGS, oral commun., 1999). Also, the lack of a good seal probably allowed the escape of hydrocarbons from the Rollins. The Rollins is overlain by mudrock and coals of coastal plain origin.

Resource Assessment

There are three assessment units (AU) for hydrocarbons generated from the Mowry or Mancos Shales (fig. 23)—Piceance Basin Continuous Gas AU (AU50200361), Uinta Basin Continuous Gas AU (AU50200362), and Uinta-Piceance Transitional and Migrated Gas AU (AU 50200363). The highest total organic carbon (TOC) is within the Mowry and near the base of the Mancos, although organic matter is present throughout the entire 4,000–5,000 ft interval of marine shale that is present in the province. Reservoir units are located below, within, and above the main source-rock interval and are grouped according to accumulation type. The highest TOC and earliest generation of hydrocarbons were from the Mowry and lowermost Mancos. Vitrinite reflectance isolines constructed on the base of the Mancos are used as a guide to show the boundaries between gas-saturated zones, transition zones, and conventional accumulations based on observations in several Rocky Mountain basins. Gas-saturated, overpressured, continuous accumulations are generally found in areas >1.1 percent R_o, and transitional accumulations are found in areas between 0.75 and 1.1 percent R_o. The Mancos/Mowry Total Petroleum System is summarized in events charts of each assessment unit (figs. 24–26).

Piceance Basin Continuous Gas Assessment Unit (AU 50200361)

This assessment unit consists of a continuous gas accumulation in the Piceance Basin and is estimated to be present where the vitrinite reflectance is greater than 1.1 percent R_o at the

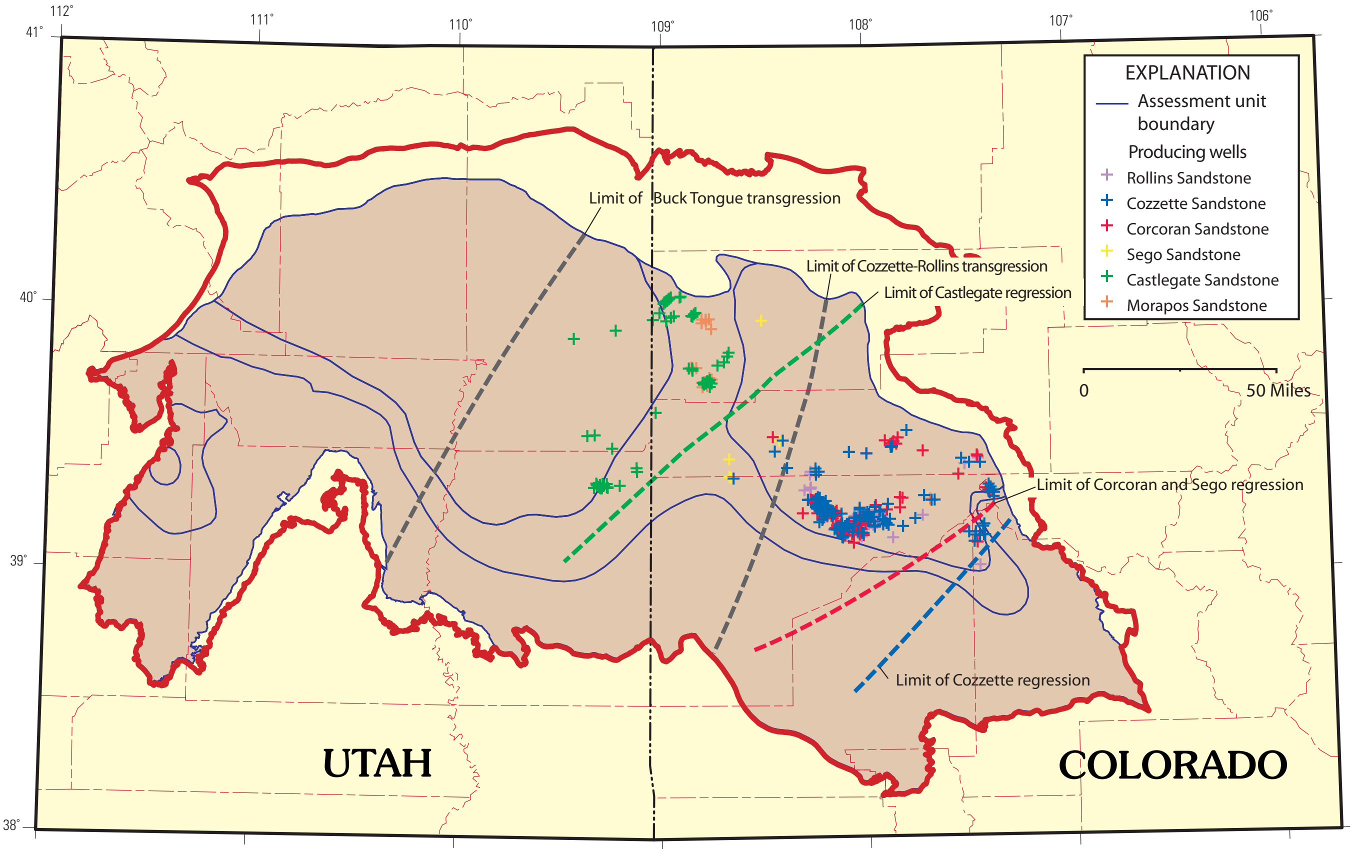


Figure 20. Paleogeographic shorelines and limits of marine transgressions for upper reservoir units of the Mancos Shale in the Uinta-Piceance Province (shorelines after Johnson, 1989), and producing wells for upper sandstone reservoirs of the Mancos Shale. Assessment unit boundaries in purple (see fig. 23).

base of the Mancos (Appendix A). It includes three groups of reservoirs: (1) a lower group consisting of units in the Morrison Formation (including Salt Wash and Brushy Basin Members), Cedar Mountain Formation, and Dakota Sandstone (fig. 3); (2) a middle group consisting of units in the Frontier Formation, Mancos Shale, and Mancos B (fig. 3); and (3) an upper group consisting of units in the Sego Sandstone, Morapos Sandstone Member and sandstones of the Iles Formation or equivalents (Corcoran, Cozzette, and Rollins Sandstone Members, pl. 2). Reservoirs in this assessment unit are usually tight and may be overpressured.

In the 1995 USGS assessment (Gautier and others, 1996), reservoirs included in this assessment unit were assessed, in part, as conventional accumulations in Plays 2003 (Upper Cretaceous Conventional) and 2004 (Cretaceous Dakota to Jurassic), and, in part, as a continuous accumulation in Play 2010 (Tight Gas Piceance Mesaverde Iles). In the current assessment, even though there are numerous reservoir units, most are similar in their depositional setting (see fig. 4) and production is dependent on fracture permeability.

There are 402 wells producing from reservoir units of the Mancos/Mowry Total Petroleum System (table 3). A total of 329 wells are thought to have tested the Mancos/Mowry, but are not producers (that is, dry holes). Some of the 329 nonproductive wells may have had hydrocarbon shows but were completed in more favorable intervals in the overlying Mesaverde reservoirs. Of the 402 producing wells, 98.5 percent terminated within a reservoir unit of the Mancos/Mowry TPS and 32 percent of the wells terminated in the same unit that has the production.

Determining the success ratio of producers versus dry holes requires some assumptions: (1) holes with a final class of 0 (dry) or 8 (junked and abandoned) (in Petroleum Information/Dwights LLC, 1999) are assumed to be dry holes for the Mancos/Mowry TPS if they terminated within a Mancos/Mowry reservoir; (2) holes that terminate within Mancos/Mowry reservoirs, but produce from a stratigraphically higher petroleum system (for example, Mesaverde), are assumed to have tested the bottom-hole unit because nearly all (98.5 percent) producing wells actually did terminate within a targeted Mancos/Mowry reservoir; and (3) holes that penetrate older units below Mancos/Mowry reservoirs

Table 1. Permeability and porosity data for selected fields and reservoirs in the Mancos/Mowry Total Petroleum System.
[Abbreviations: Kd, Dakota Sandstone; Kcm, Cedar Mountain Formation; Kcmb, Buckhorn Conglomerate Member; Jm, Morrison Formation]

Field	Unit	Porosity (percent)	Permeability (Millidarcies)	Reference
Bar X	Kd	13.5	NA	Stowe (1979)
	Kcmb	13		
	Jm	13		
Baxter Pass	Kd	17	0.1	Noe (1993b)
Bridle	Kd	11	0.1	Noe (1993b)
Douglas Creek	Kd	13	28.6	Noe (1993b)
Evacuation Ck; Park Mtn	Kd	26max; 21.5 average	0.15-44	Lipinski (1993b)
Fence Canyon	Kd, Kcmb, Jm	10-16	NA	Osmond (1993a)
Hells Hole	Kd	14-18	0.1-1.0	Moretti and others (1992) Lipinski (1993a)
Hells Hole	Kd	16	0.5	Noe (1993b)
Maudlin Gulch	Kd	17	4.8	Gibbs, 1982
	Jm	12-20	83	
Pine Springs	Kd	12-18	Estimated <1	Osmond (1993b)
	Jm	10-13	Estimated <1	
San Arroyo	Kd	15	50.0	Noe (1993)
San Arroyo	Kd	10-12	NA	Suek/Miller (1993)
	Kcm	12-20		
	Jm	13-18		
Seep Ridge	Kd/Kcmb/Jm	10-15	NA	Osmond (1993c)
Shire Gulch	Kd	8	0.05	Noe (1993b)
South Canyon	Kd	11	0.1	Noe (1993b)
	Jm	12	3.32	
Trail Canyon	Kd	11	0.1	Noe (1993b)

Table 2. Selected pressure data from drill-stem tests in the Uinta-Piceance Province.
[Note that the Marshal Leon well in the Agate field had 188 ft water-cut mud, 188 ft mud-water, and 1,350 ft salt water, and the Morrison from Seiber Nose field had 15 ft oil and 1,205 ft salt water suggesting a more conventional accumulation. Abbreviations: ISIP, initial shut in pressure; FSIP, final shut-in pressure; Kd, Dakota Sandstone; Kcm, Cedar Mountain Formation; Kcmb, Buckhorn Conglomerate Member; Jm, Morrison Formation]

Well	Unit	Location/Field	Pressures	Depth	Gradient
Argo 4-26-A Baxter Pass	Kd	Sec. 26, T. 4 S., R. 103 W. Baxter Pass Field	ISIP 1,915 (30 min.) FSIP 1,880 (30 min.)	6,294 ft.	0.30 psi/ft
Continental Oil 5-7 Government	Kd	Sec. 5, T. 3 S., T. 101 W. Douglas Creek Field	ISIP NA FSIP 1,400 (1 hr.)	4,437 ft.	0.31 psi/ft
Chorney Oil 1-Banta Ridge	Kd	Sec. 8, T. 1 S., R. 103 W. Banta Ridge Field	ISIP 1,869 (30 min.) FSIP 2,644 (1 hr.)	7,140 ft.	0.37 psi/ft
Chorney Oil 1-9 SW Rangley	Kd	Sec. 9, T. 1 S., R. 103 W. Rangley SW Field	ISIP 1,638 (30 min.) FSIP 3,105 (1 hr.)	7,466 ft.	0.42 psi/ft
Humble Oil 8 Peters Point	Kcmb	Sec. 34, T 12 S., R. 16 E. Peters Point Field	ISIP 1,567 (NA) FSIP 2,488 (4 hrs.)	9,004 ft.	0.27 psi/ft
Mountain Fuel Supply 1-Muddy Creek	Kd	Sec. 16, T. 21 S., R. 6 E. Wasatch Plateau	ISIP 1,745 (NA) FSIP 1,617 (1 hr.)	4,421 ft.	0.39 psi/ft
Marshal Leon 1 Marshal-Federal	Jm	Sec. 9, T. 20 S. R. 24 E. Agate Field	ISIP 541 (NA) FSIP 582 (41min.)	1,426 ft.	0.41 psi/ft
Continental Oil 22-1 Conoco-Federal	Kd?/ Kcm	Sec. 22, T. 9 S., R. 20 E. Natural Buttes	ISIP 10,057 (NA) FSIP 8,206 (NA)	15,800 ft.	0.64 psi/ft

Figure 21. Marine Mancos Shale (lower slope-forming unit), continuous shoreface and tidal sandstones of the Corcoran, Cozzette, and Rollins Sandstone Members of the Mount Garfield Formation (Iles Formation equivalent) (middle cliff-forming unit), and fluvial rocks of the Mesaverde Group (upper slope-forming unit to skyline) in the Book Cliffs north of Grand Junction, Colo.

are also assumed to be Mancos/Mowry tests. There are 107 wells listed in the database as dry holes or junked and abandoned, plus 345 wells that terminate in Mancos/Mowry reservoir units or below, minus 123 that terminate in the Rollins, which is normally water wet, for a total of 329. Total evaluations in Mancos/Mowry reservoirs are 731 wells (or cells) (402 producers plus 329 dry holes), making the success ratio 55 percent.

A minimum total recovery per cell of 0.02 billion cubic feet of gas (BCFG) was used to calculate resources based on estimated ultimate recovery (EUR) distributions from historical production data (IHS Energy Group, 2000). Of the 402 producing wells, 354 (88 percent) are above this minimum value. The elimination of the wells below the minimum results in a truncated EUR distribution that is used in the assessment (fig. 27). The total recovery by thirds (dividing production into three equal time periods) provides some indication of the maturity of an assessment unit and is determined from the truncated EUR distributions (for a detailed explanation of EUR see Cook, Chapter 23, this CD-ROM). This assessment unit has been producing since the late 1950's and so has relatively short time intervals included in the thirds (figs. 28, 29).

The total area of the Piceance Basin Continuous Gas Assessment Unit is about 2,000,000 acres with uncertainties of 5 percent (103,000 acres) for a minimum and 10 percent (206,000 acres) for a maximum. The uncertainty in area is from not knowing the exact edge of the gas-saturated zone nor the extent of lower group reservoirs below a buried thrust whose surface expression is the Grand Hogback monocline (fig. 13). The area per cell (drainage area) for all reservoirs in the assessment unit is based on current well-spacing information and the effective drainage areas of wells in similar depositional environments of the Denver Basin (D.K. Higley, USGS, written commun., 2000). The assessment area is between 94 and 98 percent untested.

The total area that has potential for additions to reserves in the next 30 years is most likely in areas of current production and is mostly limited to the lower (Morrison, Cedar Mountain, and Dakota) and upper (Iles sandstones) reservoir groups. The best potential comes from: (1) areas that have concentrated active and historical production, and from isolated sweet spots in the Rulison, Divide Creek, Wolf Creek, Coal Basin, and Ragged Mountain fields; (2) areas where there are stacked fluvial reservoirs in the Morrison, Cedar Mountain, and Dakota; (3) shoreface or valley-fill strata in the Dakota that were deposited landward of the (Mowry) paleoshoreline (fig. 10); (4) infill drilling in the Mancos B; and (5) infill drilling and recompletions from the upper group of reservoirs of the Iles and its equivalents. Historical production is located in areas where drilling depths are less than 10,000 ft to the lower reservoirs and less than about 6,000 ft to the upper reservoirs.

The minimum area that fulfills these requirements, a conservative scenario, was estimated to be about twice as large as the area of current production—an area of about 80,000 acres or 4 percent of the untested area. A median area that fulfills the above requirements is estimated at 360,000 acres. Of these acres, 160,000 acres have potential in lower reservoirs, about 20,000 acres have potential from the Mancos B, and about 180,000 acres have potential from the upper reservoirs. The maximum area or best-case scenario, about one-half of the total untested area, or 49 percent of the total assessment unit, is considered to have potential from one of the reservoir groups. About 500,000 acres of the total 2,000,000 acres in the assessment unit are not considered to have potential over the next 30 years because drilling depths are greater than 15,000 ft for the lower reservoirs and greater than 11,000 ft for the upper reservoirs, which are currently below the maximum drilling depths for these units (fig. 30). A value of 0.25 BCFG is used for the median total recovery per cell, which is slightly higher than the median value of 0.22 BCFG found in the EUR distributions (fig. 27), and a value of 10 BCFG per cell is used as the maximum, which is slightly higher than the estimated maximum of 7.5 BCFG. These values are based on the fact that the assessment unit is not maturely explored and we assume that the best well (cell) has not yet been found.

Uinta Basin Continuous Gas Assessment Unit (AU 50200362)

This assessment unit consists of continuous accumulations of gas in the Uinta Basin and encompasses the area where the vitrinite reflectance is greater than 1.1 percent R_o for the base of the Mancos (Appendix B). The area contains reservoirs in the Morrison Formation (including some identified in the Salt Wash and Brushy Basin Members), Cedar Mountain Formation

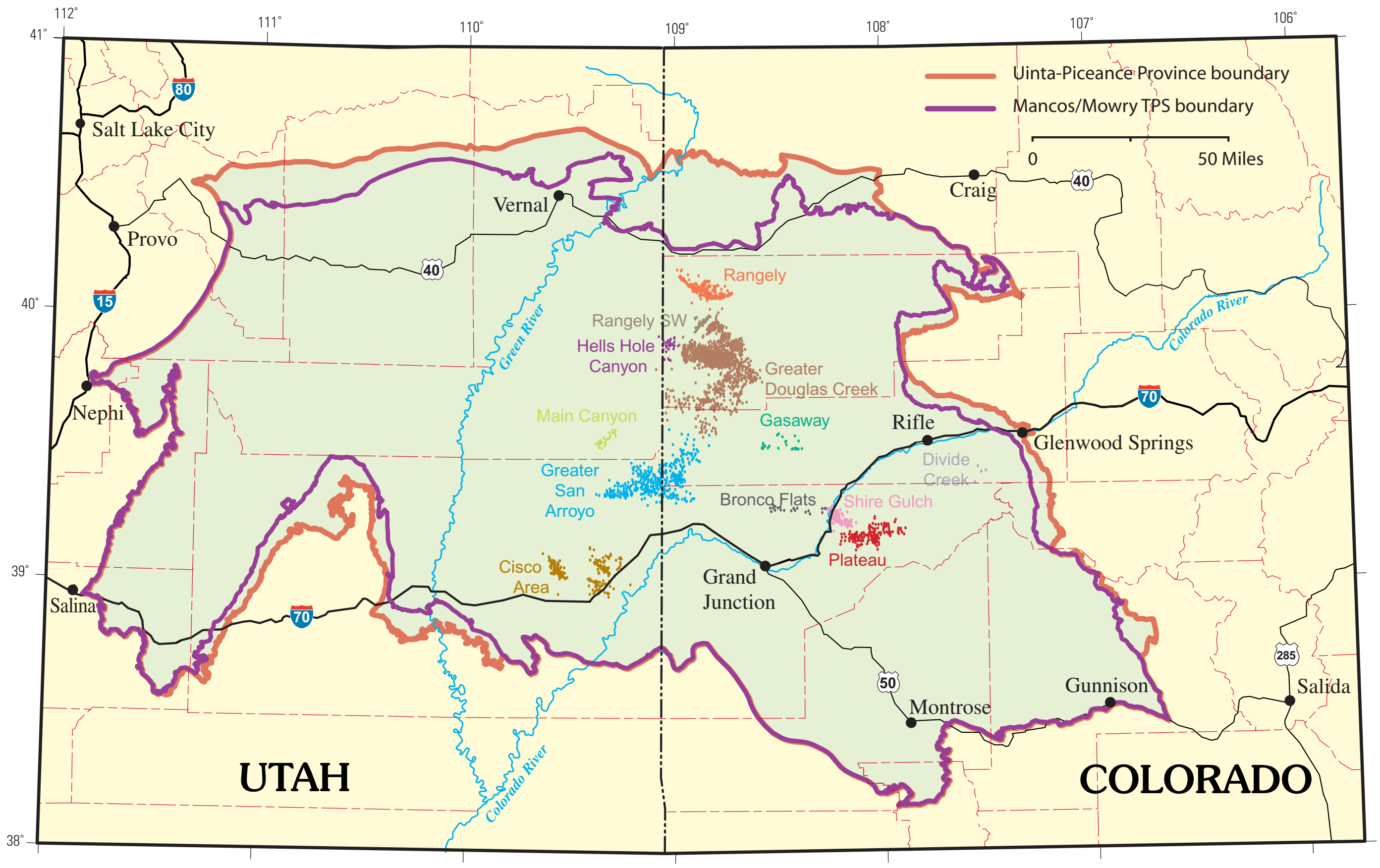


Figure 22. Selected major fields producing hydrocarbons from reservoirs sourced from the Mancos/Mowry Shales. The Cisco area fields are partly sourced from the Phosphoria Total Petroleum System, but are included because of discussion in text.

(including the Buckhorn Conglomerate Member), Dakota Sandstone, Frontier Formation, Mancos Shale, Mancos B/Emery (Prairie Canyon Formation), Castlegate Sandstone, and hypothesized accumulations in sandstones of the Blackhawk Formation and valley fills of the Buckhorn and Dakota. Reservoirs in this assessment unit are usually tight and may be overpressured.

There are 211 wells producing from reservoirs of the Mancos/Mowry TPS in this assessment unit (table 4). A total of 188 wells are considered to be dry holes. Total evaluations in reservoirs of this assessment unit are 399 (211 producers plus 188 dry holes), giving a success ratio of 53 percent. Some of the wells classed as dry holes with respect to Mancos/Mowry reservoirs may have had shows, but were completed in more favorable intervals in the overlying Mesaverde TPS. Based on the available data (Petroleum Information/Dwights LLC, 1999), determining the number of evaluated cells that are dry holes requires some assumptions: (1) 116 holes are assumed to be dry because they have a final class of 0 or 8 (dry or junked and abandoned) in the Petroleum Information/Dwights LLC database and they terminated within a Mancos/Mowry reservoir unit (all but 9 of the 211 producing wells did not terminate within a reservoir unit of the Mancos/Mowry TPS); (2) 57 wells are included as dry holes because they terminated within reservoir units of the Mancos/Mowry TPS, but produce from the overlying Mesaverde system—we assume that if the operator drilled to a certain unit it must have been a target and therefore is included as a test (however, wells that terminated in the Mancos/Mowry in the Altamont/Bluebell fields are eliminated because they barely penetrated the Mancos/Mowry); and (3) another 30 wells had deep penetrations below the Mancos/Mowry, but do not produce from the system. One-half of these 30 wells produced from the Mesaverde or Wasatch Formations, mainly in the Altamont-Bluebell fields, and are assumed to have been deep tests that intended to complete in the Mesaverde or Wasatch, but the other 15 wells are assumed to have tested reservoir units in the Mancos/Mowry and are included in the total 188 nonproducing wells.

A minimum total recovery per cell of 0.02 BCFG was used to calculate reserves based on EUR distributions from historical production data (Petroleum Information/Dwights LLC, 1999). Of the 211 producing wells, 179 (85 percent) of the wells have

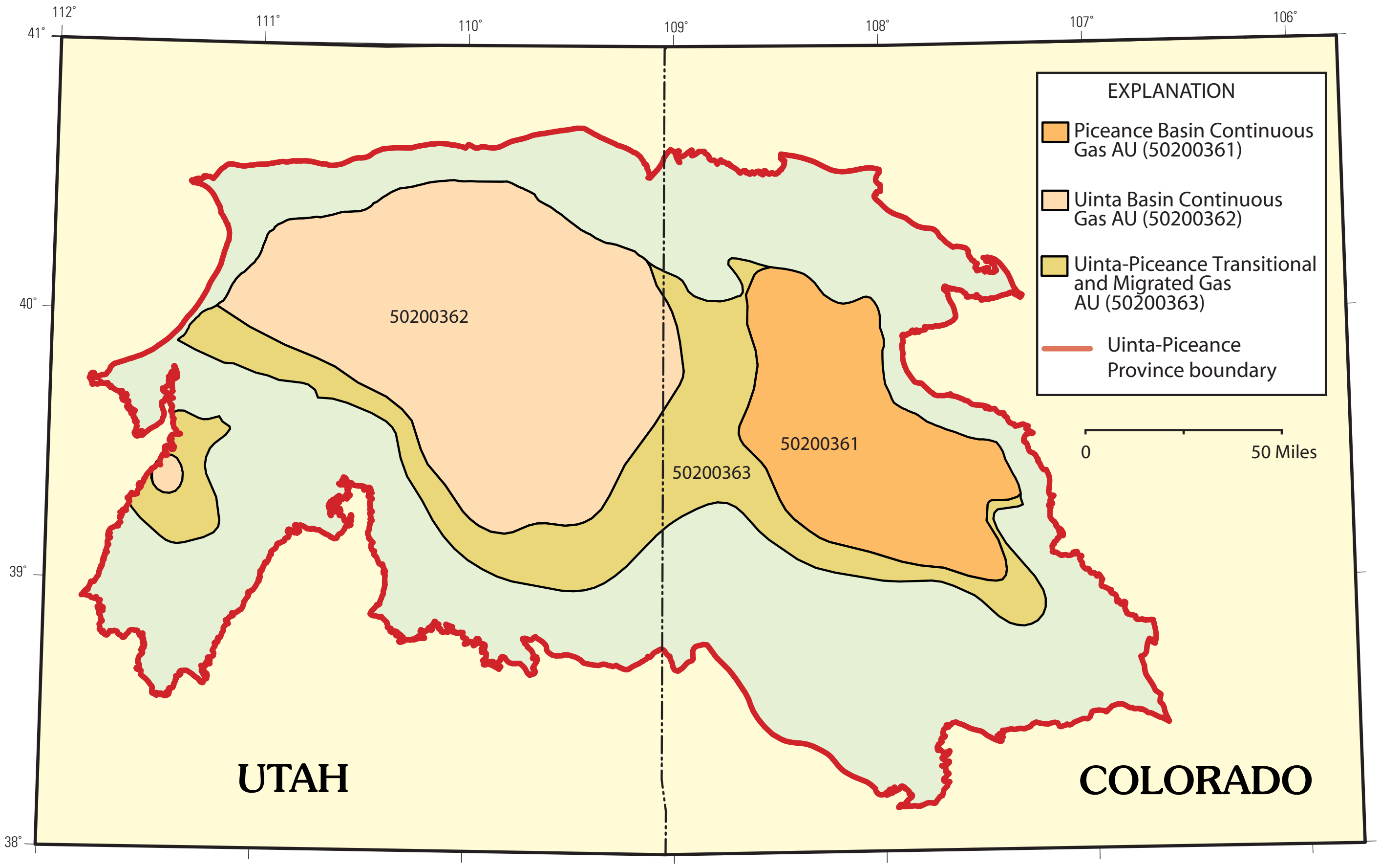


Figure 23. Distribution of the three assessment units of the Mancos/Mowry Total Petroleum System in the Uinta-Piceance Province.

EUR's above this minimum value. The elimination of the wells below the minimum results in a truncated EUR distribution that is used in the assessment (fig. 31). The total recovery by thirds provides some indication of the maturity of an assessment unit and is determined from the truncated EUR distributions (fig. 32). This assessment unit has been producing since the 1950's (fig. 33).

The total area of the assessment unit is 4,217,000 acres, with uncertainties of plus or minus 5 percent (211,000 acres). The uncertainty comes from not knowing the exact boundary of the gas-saturated zone nor the exact area of continuous accumulation present in the footwall of the Uinta Basin boundary fault. The area per cell (drainage area) for all reservoirs in the assessment unit is based on current well spacing and the effective drainage areas of wells in similar depositional environments of the Denver Basin (D.K. Higley, USGS, written commun., 2000). The assessment area is almost totally untested (between 98 and 99.9 percent).

The most conservative approach to calculating the total area that has potential for additions to reserves in the next 30 years would be close to historical and current production in the Dakota and Mancos B, which involves about 200,000 acres or 6 percent of the untested assessment area. An 85 percent success ratio is used for this minimum untested area. The median area having potential is estimated to be 500,000 acres in the Dakota and 275,000 acres in the Mancos B, or about 9 percent of the untested assessment area. These 775,000 acres have some past production where drilling depths are less than 10,000 ft, and the acreage is in areas near faults where fracturing is more intense and could be potential sweet spots. A success ratio of 75 percent is assumed for this less maturely explored area. The maximum area having potential for addition to reserves in the next 30 years would include all areas less than 10,000 ft or about 800,000 acres (18 percent of the untested assessment area) and includes hypothesized accumulations in valley fills in the Dakota and shoreface sandstones of the Blackhawk Formation. The maximum area is estimated to have a 50 percent success ratio based on its being a less maturely explored area.

A value of 0.5 BCFG is used for the median total recovery per cell based on the median value found in the EUR (fig. 31) and

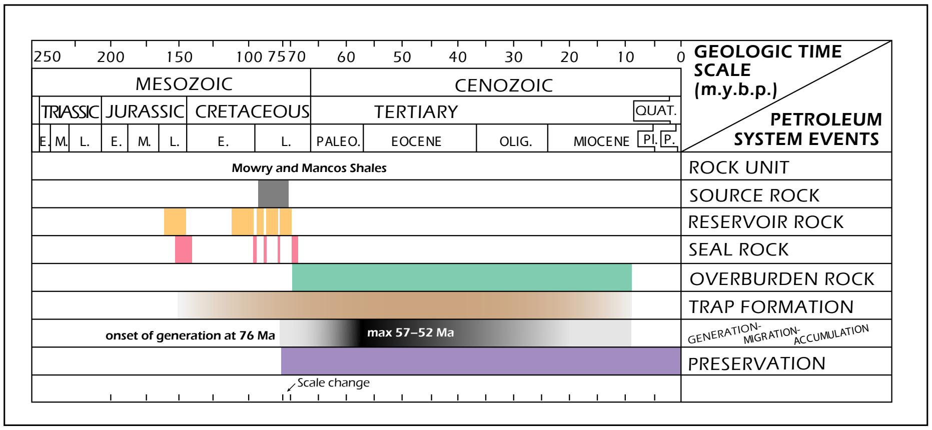


Figure 24. Petroleum system events chart for the Piceance Basin Continuous Gas Assessment Unit (AU 50200361).

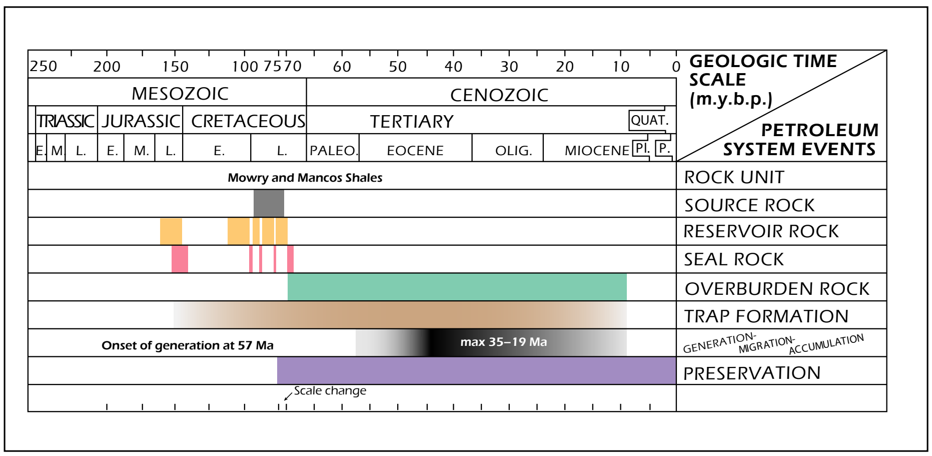


Figure 25. Petroleum system events chart for the Uinta Basin Continuous Gas Assessment Unit (AU 50200362).

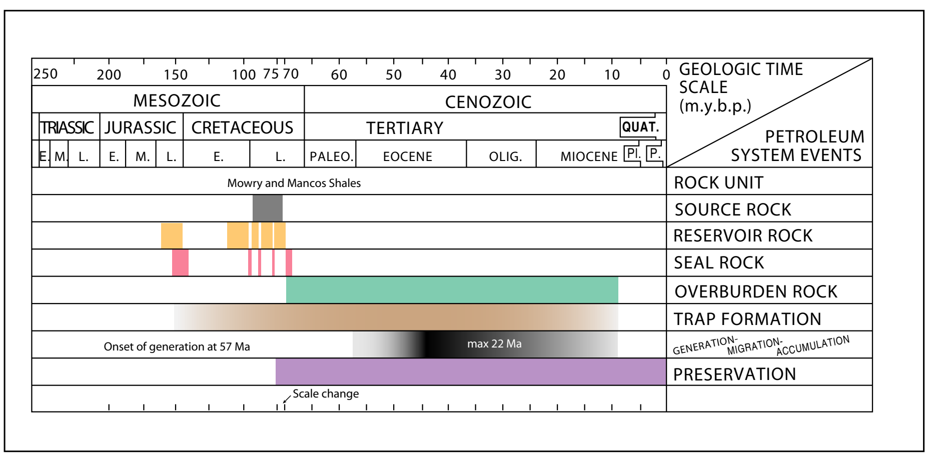


Figure 26. Petroleum system events chart for the Uinta-Piceance Transitional and Migrated Gas Assessment Unit (AU 50200363).

a value of 16 BCFG is used as the maximum cell recovery, which is near the maximum estimated in the EUR's for this assessment unit (fig. 31).

Uinta-Piceance Transitional and Migrated Gas Assessment Unit (AU 50200363)

This assessment unit consists of continuous accumulations of gas in the Uinta-Piceance Basin where the vitrinite reflectance is between 0.75 and 1.1 percent R_o for the base of the Mancos (Appendix C) and includes reservoirs in the Morrison Formation (including those reported as Salt Wash or Brushy Basin Members), Cedar Mountain Formation (including those reported as Buckhorn Conglomerate Member), Dakota Sandstone, Frontier Formation, Mancos B, Castlegate Sandstone, Sego Sandstone, Morapos Sandstone, Niobrara Formation, and hypothetical accumulations in sandstones of the Blackhawk Formation. Reservoirs may be tight and may be normally pressured or underpressured. Invasion by surface waters may have created some conventional gas/water contacts or water-saturated reservoirs.

There are about 1,655 wells producing from reservoir units of the Mancos/Mowry TPS in this assessment unit (table 5). Of the 1,655 producing wells, only 21 wells did not terminate within a reservoir unit of the Mancos/Mowry TPS. About 50 percent of the wells terminate within the same unit that has the production. Another 662 wells terminate within one of the Mancos/Mowry reservoir units. Of the 662 wells, 608 are labeled dry, junked, or abandoned (final class 0 or 8); 86 holes are in conventional fields (Agate, all the Cisco fields, Gravel Pile, and Seiber Nose) and are excluded as tests; and another 54 wells produce from other reservoir units but are assumed to have tested Mancos/Mowry reservoir units except for six coalbed methane wells, which are assumed to have terminated just in the upper part of the Mancos Shale. There are 45 deep tests that are also assumed to have tested Mancos/Mowry reservoir units. Total "dry holes" for the system are 615 wells [(608–86) labeled dry + (54–6) terminations + 45 deep tests]. Thus, there are 2,270 evaluated cells for this assessment unit, 1,655 producers and 615 "dry holes." The success ratio for this assessment unit is 73 percent (1,655 producers/2,270 evaluated cells).

A minimum total recovery per cell of 0.02 BCFG was used to calculate reserves based on EUR distributions from historical production data (Petroleum Information/Dwights LLC, 1999). Of the 1,655 producing wells, 1,489 (90 percent) have EUR's above this minimum value. The elimination of the wells below the minimum results in a truncated EUR distribution that is used in the assessment (fig. 34). The total recovery by thirds provides some indication of the maturity of an assessment unit and is determined from the truncated EUR distributions (fig. 35). This assessment unit has been producing since the 1920's (fig. 36).

The assessment unit has a total area of 2,540,000 acres, with uncertainties of plus or minus 12 percent (305,000 acres). The uncertainties result from not knowing the extent of gas saturation in this transitional continuous accumulation. The area per cell (drainage area) for all reservoirs in the assessment unit is based on current well spacing (Noe, 1993b) and the effective drainage areas of wells in the basins and in similar depositional environments of the Denver Basin (D.K. Higley, USGS, written commun., 2000). The assessment area is 82–94 percent untested.

The total area that has potential for additions to reserves in the next 30 years is most likely in areas of current production. The best potential comes from: (1) areas that have concentrated active and historical production; (2) areas where there are stacked fluvial reservoirs in the Morrison, Cedar Mountain and Dakota; (3) shoreface or valley-fill strata in the Dakota that were deposited landward of the (Mowry) paleoshoreline (fig. 10); (4) infill drilling in the Mancos B; and (5) infill drilling and recompletions from the upper sandstone reservoirs of the Castlegate, Sego, and Iles. Historical production is located in areas where drilling depths are less than 14,000 ft for the Morrison, Cedar Mountain, and Dakota reservoirs (averaging, for example, about 5,000 ft for the Dakota). Drilling depths to the Mancos B are as deep as 7,000 ft, but average about 3,250 ft. Upper sandstone reservoirs have drilling depths of less than 8,500 ft (averaging, for example, about 3,500 ft for the Castlegate).

The minimum area that fulfills these requirements, the most conservative scenario, surrounds historical production and includes an estimated 275,000 acres in fluvial units, 185,000 acres in marine units, and 25,000 acres in shoreface units. This total of 485,000 acres reduces to 436,000 acres (20 percent of the untested area) by using a 90 percent success ratio for this mature area [485,000 acres–(485,000 acres × 10 percent)]. The median area consists of about 850,000 acres and, using a success ratio of 75 percent, would yield an area of about 637,000 acres (28 percent of the untested area). The most liberal estimate would be about 700,000 acres from the lower reservoir group, 300,000 acres from the middle and upper reservoir groups, 100,000 acres for hypothesized valley fills in the Dakota, and 100,000 acres for shoreface sandstones of the Blackhawk. This total of 1,200,000 acres, combined with a 64 percent success ratio (assuming about one-third of the wells are water wet), yields an area of about 768,000 acres (34 percent of the untested area).

A value of 0.5 BCFG is used for the median total recovery per cell, which is higher than the average of about 0.3 BCFG found in the EUR's (fig. 34), and a 7 BCFG per cell value is used as the maximum recovery, which is higher than the maximum of about 4.5 BCFG shown on the EUR distribution (fig. 34). These increased EUR's reflect that the assessment unit is 82 percent untested and assumes that the best well (cell) has not yet been found.

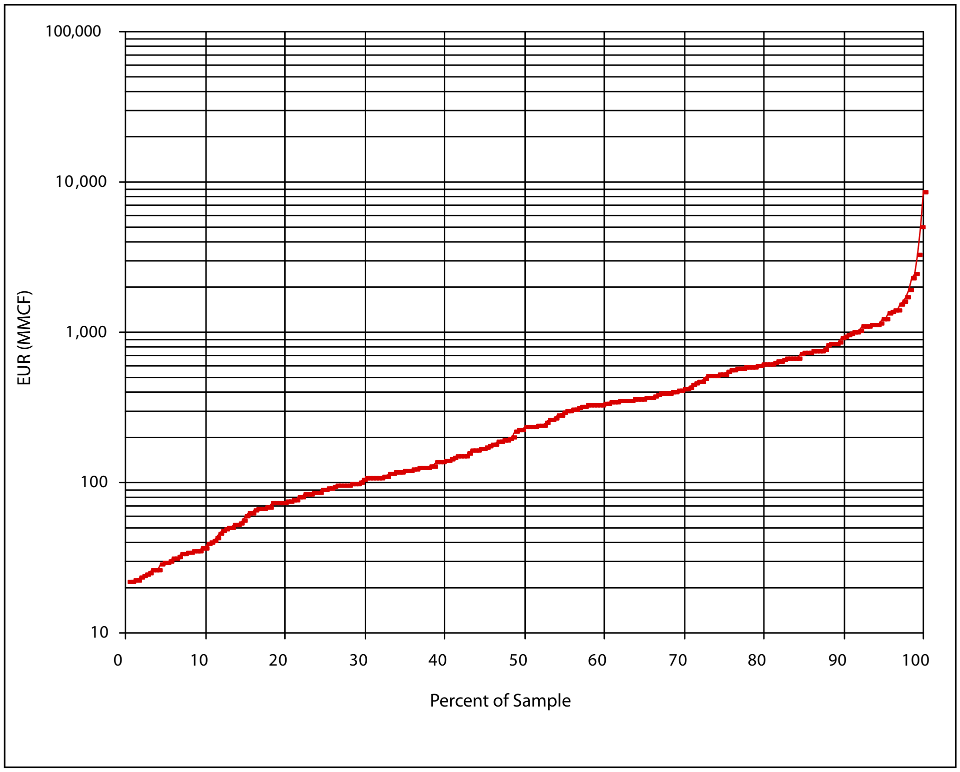


Figure 27. Truncated estimated ultimate recovery (EUR) distributions for the Piceance Basin Continuous Gas Assessment Unit (AU 50200361).

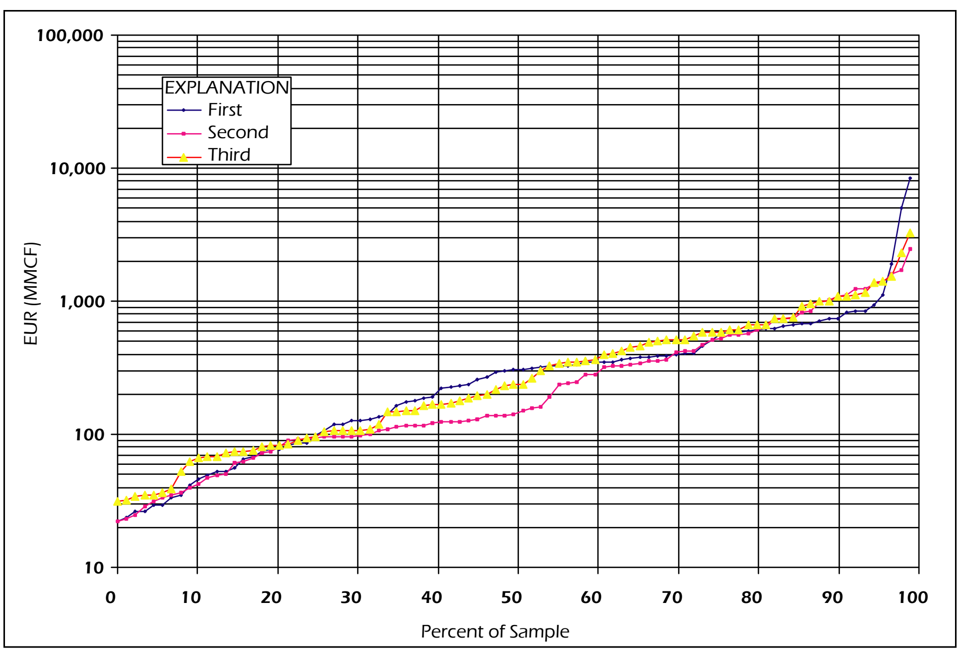


Figure 28. Estimated ultimate recovery (EUR) by thirds based on the truncated EUR distributions for the Piceance Basin Continuous Gas Assessment Unit (AU 50200361). For a discussion of EUR thirds see Cook (Chapter 23, this CD-ROM).

Table 3. Producing wells in the Piceance Basin Continuous Gas Assessment Unit (AU 50200361).
[Data from Petroleum Information/Dwights LLC, 1999]

Producing unit	Final Class			
	Oil	Gas	Multiple Gas	Total
Cedar Mountain Formation		1		1
Corcoran Sandstone	3	78	3	84
Cozzette Sandstone		114	5	119
Dakota Sandstone		97	5	102
Frontier Formation		2		2
Mancos Shale	3	28		31
Morapos Sandstone	1	1		2
Morrison Formation		3		3
Rollins Sandstone		55	1	56
Sego Sandstone		2		2
Grand Total	7	381	14	402

Assessment Results

Potential additions to reserves are reported by accumulation (conventional versus continuous), by hydrocarbon type (oil, gas, and natural gas liquids), and by assessment unit.
Within the Uinta-Piceance Province there are three continuous assessment units for gas and minor natural gas liquids (NGL) (Appendixes D, E). No oil or conventional accumulations were assessed for the Mancos/Mowry TPS because of mixing with other total petroleum systems that were assessed by Johnson (Chapter 9, this CD-ROM).

Summary

The total mean potential additions to reserves for the Mancos/Mowry Total Petroleum System in the Uinta-Piceance Province are about 6.5 TCF of gas and 0.01 TCF natural gas liquids (Appendix D).

Piceance Basin Continuous Gas Assessment Unit (AU 50200361)—This assessment unit contains a mean value of about 1.7 TCF of gas (Appendix E).

Uinta Basin Continuous Gas Assessment Unit (AU 50200362)—This assessment unit contains a mean value of about 3.1 TCF of gas (Appendix E).

Uinta-Piceance Transitional and Migrated Gas Assessment Unit (AU 50200363)—This assessment unit contains a mean value of about 1.8 TCF of gas (Appendix E).

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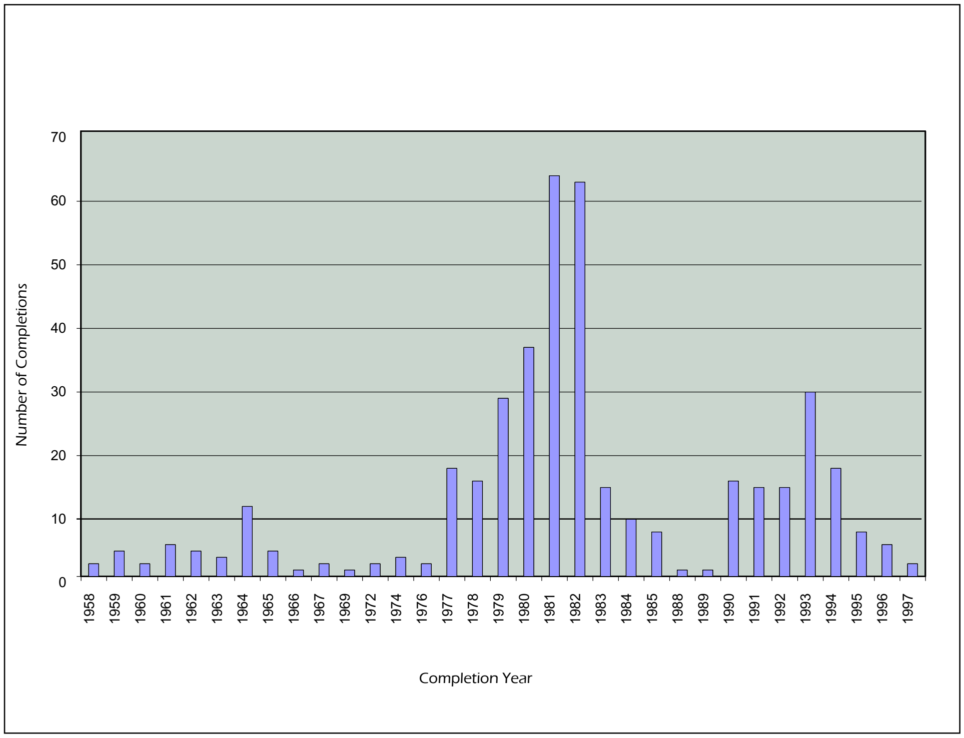


Figure 29. Histogram of number of drilling completions per year for reservoirs in the Piceance Basin Continuous Gas Assessment Unit (AU 50200361) based on data in Petroleum Information/Dwights LLC (1999).

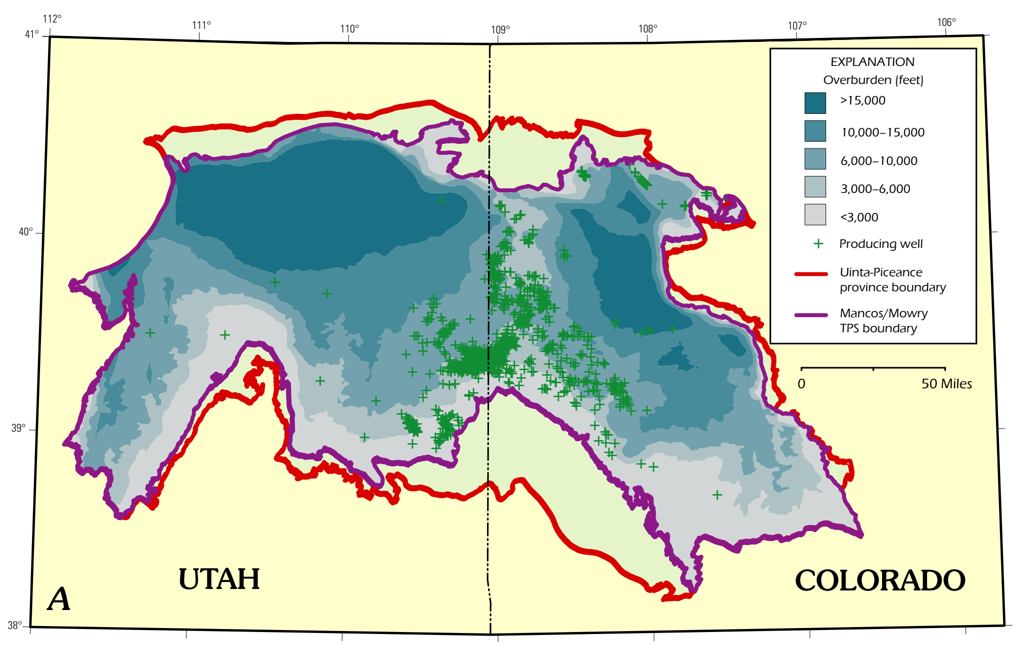


Figure 30*A*. Overburden above base of the Mancos Shale, and wells producing from Morrison, Cedar Mountain, Dakota, and Mancos B reservoirs.

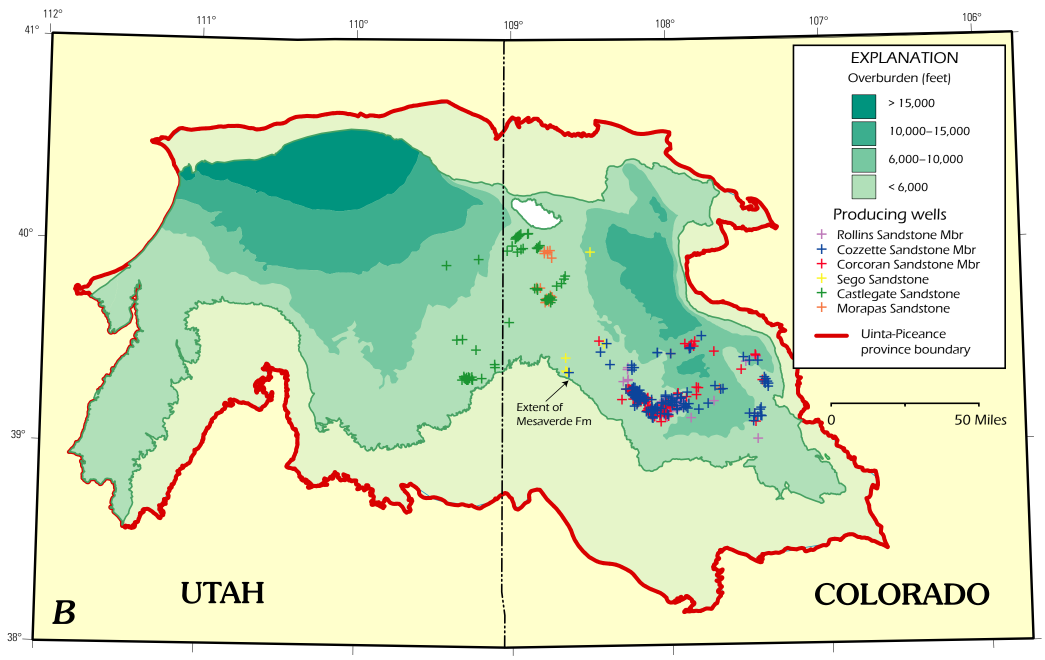


Figure 30*B*. Overburden at top of the Mancos Shale, and wells producing from reservoirs in the Morapos Member of the Mancos Shale, Castlegate Sandstone, Sego Sandstone, and Corcoran, Cozzette, and Rollins Sandstone Members of the Iles Formation and equivalents.

Table 4. Producing wells in the Uinta Basin Continuous Gas Assessment (AU 50200362).
[Data from Petroleum Information/Dwights LLC, 1999]

Producing unit	Final Class			
	Oil	Gas	Other	Total
Buckhorn Conglomerate	2	11		13
Brushy Basin Member		1		1
Cedar Mountain Formation		4		4
Castlegate Sandstone	3	8	1	12
Dakota Sandstone	6	127		133
Emery Sandstone	1		1	2
Frontier Formation		2		2
Mancos Shale	4	33		37
Morrison Formation	1	5		6
Salt Wash Member		1		1
Grand Total	17	192	2	211

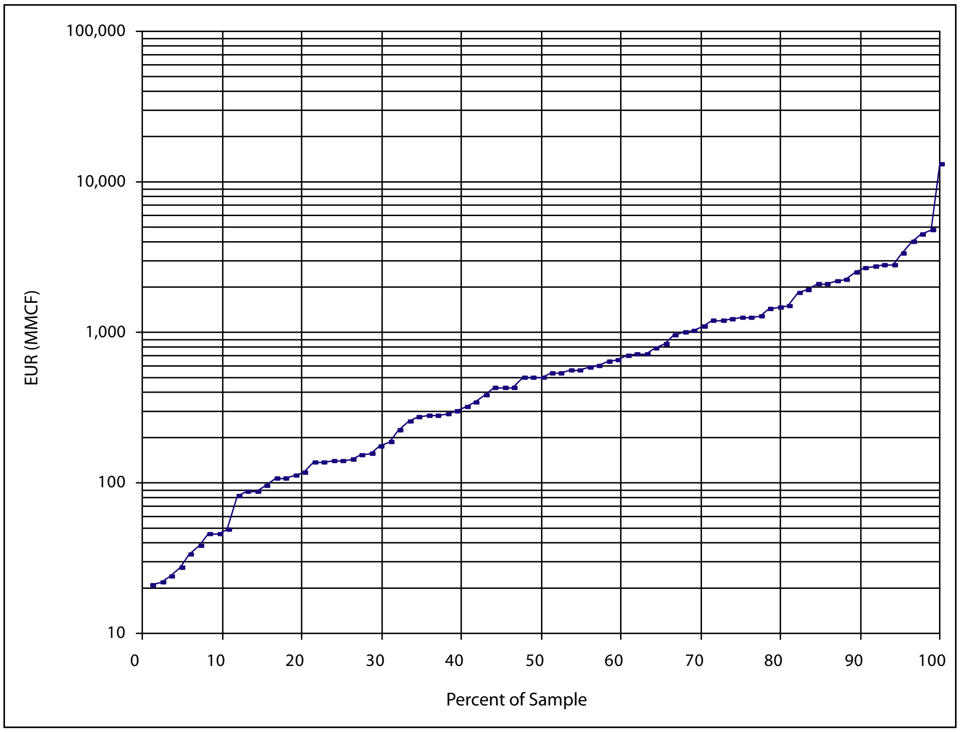


Figure 31. Truncated estimated ultimate recovery (EUR) distributions for the Uinta Basin Continuous Gas Assessment Unit (AU 50200362).

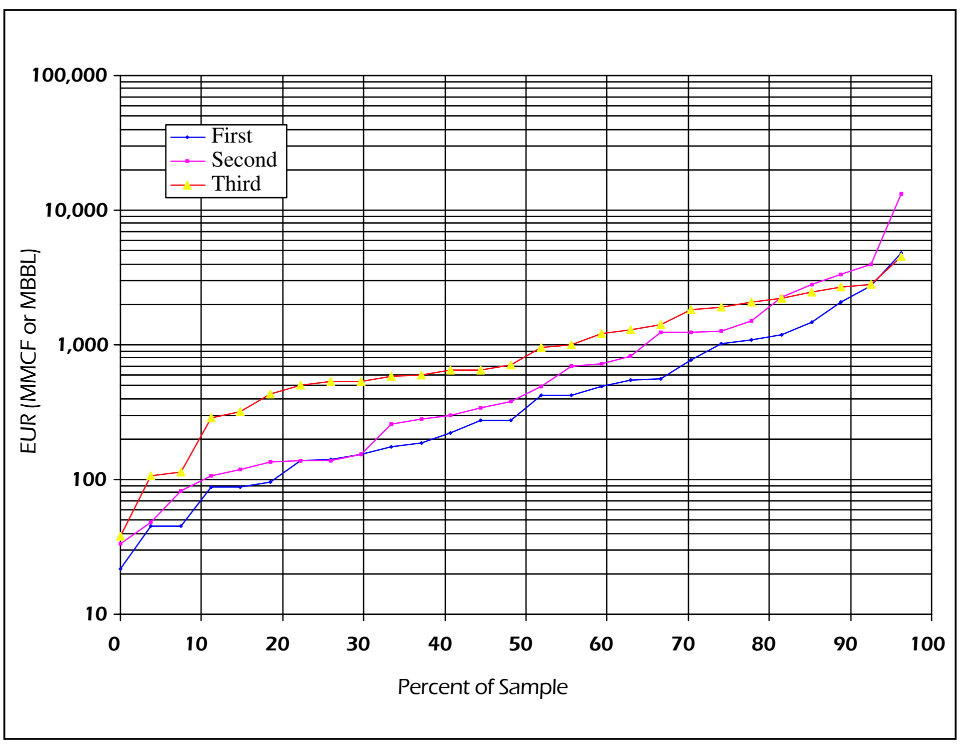


Figure 32. Estimated ultimate recovery (EUR) by thirds based on the truncated EUR distributions for the Uinta Basin Continuous Gas Assessment Unit (AU 50200362). For a discussion of EUR thirds see Cook (Chapter 23, this CD-ROM).

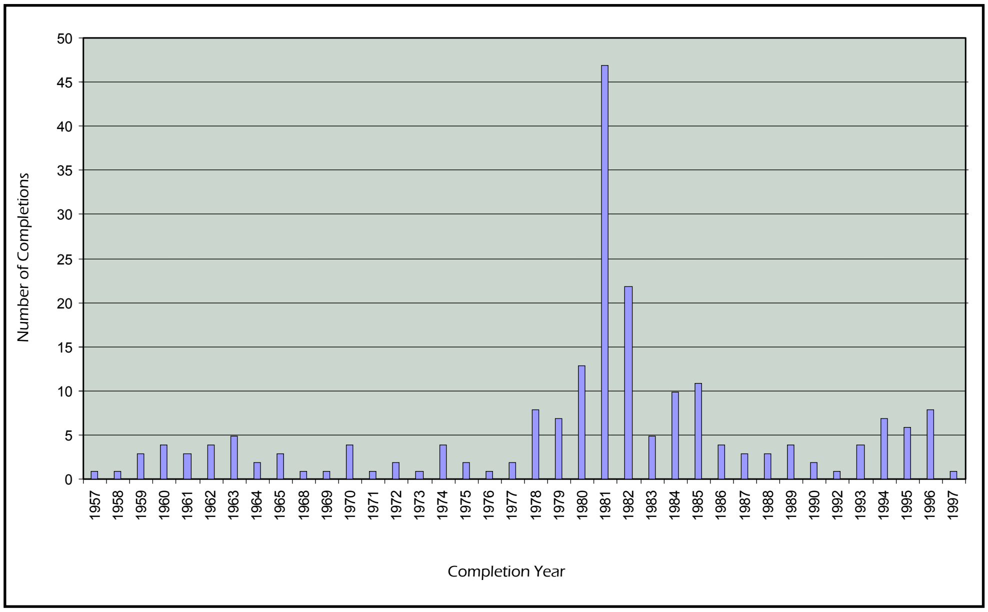


Figure 33. Histogram of number of drilling completions per year for reservoirs in the Uinta Basin Continuous Gas Assessment Unit (AU 50200362).

Table 5. Producing wells in the Uinta-Piceance Transitional and Migrated Gas Assessment Unit (AU 50200363). [Data from Petroleum Information/Dwights, LLC, 1999]

Producing unit	Final Class			
	Oil	Gas	Multiple gas	Total
Buckhorn Conglomerate		16		16
Brushy Basin Member	1	4		5
Cedar Mountain Formation	1	27		28
Corcoran Sandstone Mbr		1		1
Castlegate Sandstone	8	39	1	48
Cozzette Sandstone Mbr		7		7
Dakota Sandstone	23	514	2	539
Emery Sandstone Mbr	1	121		122
Frontier Formation		2		2
Mancos Shale	32	746	4	782
Morapos Sandstone		15		15
Morrison Formation	7	58	2	67
Niobrara Formation	2	3		5
Sego Sandstone		3		3
Salt Wash Member	2	13		15
Grand Total	77	1569	9	1655

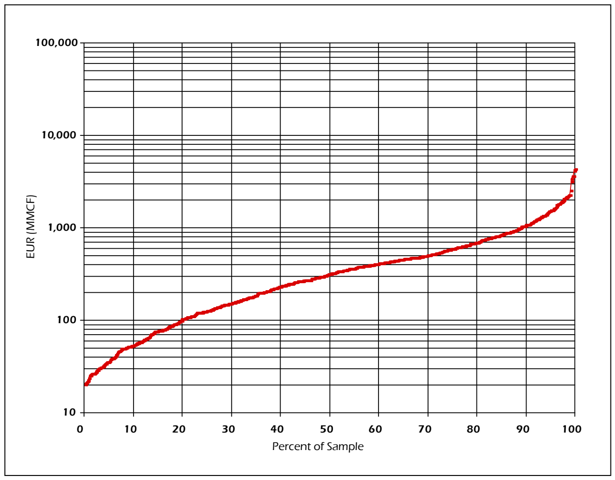


Figure 34. Truncated estimated ultimate recovery (EUR) distributions for the Uinta-Piceance Transitional and Migrated Gas Assessment Unit (AU 50200363).

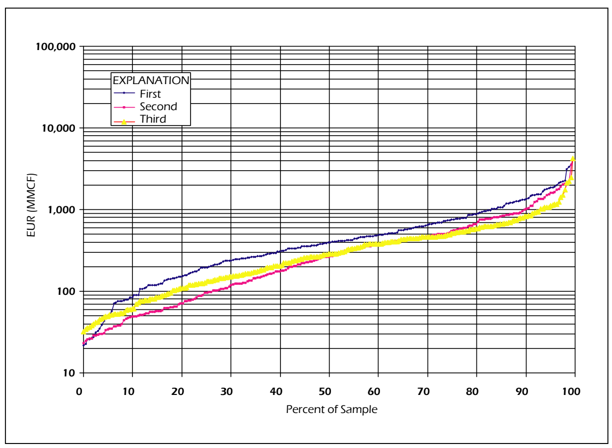


Figure 35. Estimated ultimate recovery (EUR) by thirds based on the truncated EUR distributions for the Uinta-Piceance Transitional and Migrated Gas Assessment Unit (AU 50200363). For a discussion of EUR thirds see Cook (Chapter 23, this CD-ROM).

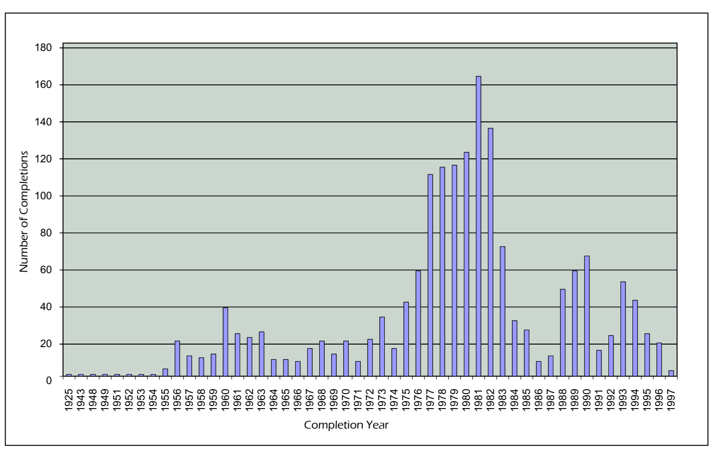


Figure 36. Histogram of number of drilling completions per year for reservoirs in the Uinta-Piceance Transitional and Migrated Gas Assessment Unit (AU 50200363).

Appendix A. Data form for the Piceance Basin Continuous Gas Assessment Unit (AU 50200361). FORSPAN assessment model for continuous accumulations—Basic Input data form (Version 4, 10-5-00).

IDENTIFICATION INFORMATION

Assessment Geologist:…	M.A. Kirschbaum	Date:	10/10/00
Region:……………………	North America	Number:	5
Province:…………………	Uinta-Piceance	Number:	5020
Total Petroleum System:.	Mancos/Mowry	Number:	502003
Assessment Unit:……….	Piceance Basin Continuous Gas	Number:	50200361
Based on Data as of:……	PI data current through third quarter 1999		
Notes from Assessor…..	Continuous gas, where base of Mancos/Mowry >1.1Ro		

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:………… 731
Number of evaluated cells with total recovery per cell ≥ minimum: …….. 354
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 0.3 2nd 3rd 0.13 3rd 3rd 0.22

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 1,955,000 median 2,058,000 maximum 2,264,000

2. Area per cell of untested cells having potential for additions to reserves in next 30 years (acres):
   (values are inherently variable) minimum 30 median 110 maximum 240

3. Percentage of total assessment-unit area that is untested (%): (uncertainty of a fixed value)
   minimum 94 median 96 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 4 median 18 maximum 49

Appendix A—Continued. Data form for the Piceance Basin Continuous Gas Assessment Unit (AU 50200361). FORSPAN assessment model for continuous accumulations—Basic Input data form (Version 4, 10-5-00).

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 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)………………..……	0.5	1	1.5

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	0.40	25.00
CO_2 content (%)……………………………..…..	0.01	2.00	6.00
Hydrogen-sulfide content (%)……………...…….	0.00	0.00	0.00
Drilling depth (m)………………………………….	700	2300	5000
Depth (m) of water (if applicable)……………….			

Appendix B. Data form for the Uinta Basin Continuous Gas Assessment Unit (AU 50200362). FORSPAN assessment model for continuous accumulations—Basic Input data form (Version 4, 10-5-00).

IDENTIFICATION INFORMATION

Assessment Geologist:…	M.A. Kirschbaum	Date:	10/11/00
Region:……………………	North America	Number:	5
Province:…………………	Uinta-Piceance	Number:	5020
Total Petroleum System:.	Mancos/Mowry	Number:	502003
Assessment Unit:……….	Uinta Basin Continuous Gas	Number:	50200362
Based on Data as of:……	PI production data current through third quarter 1999		
Notes from Assessor…..	Continuous gas, where base of Mancos/Mowry >1.1Ro		

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:………… 399

Number of evaluated cells with total recovery per cell ≥ minimum: ……... 179

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 0.33 2nd 3rd 0.42 3rd 3rd 0.81

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 4,006,000 median 4,217,000 maximum 4,428,000

2. Area per cell of untested cells having potential for additions to reserves in next 30 years (acres):
   (values are inherently variable) minimum 30 median 110 maximum 240

3. Percentage of total assessment-unit area that is untested (%): (uncertainty of a fixed value)
   minimum 98 median 99 maximum 100

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 5 median 9 maximum 18

Appendix B—Continued. Data form for the Uinta Basin Continuous Gas Assessment Unit (AU 50200362). FORSPAN assessment model for continuous accumulations—Basic Input data form (Version 4, 10-5-00).

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 16

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	2	3

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	1.30	7.40
CO_2 content (%)……………………………….…..	0.15	0.60	1.20
Hydrogen-sulfide content (%)……………...…….	0.00	0.00	0.00
Drilling depth (m)………………………………….	300	2700	6100
Depth (m) of water (if applicable)……………….			

Appendix C. Data form for the Uinta-Piceance Transitional and Migrated Gas Assessment Unit (AU 50200363).
FORSPAN assessment model for continuous accumulations—Basic Input data form (Version 4, 10-5-00).

IDENTIFICATION INFORMATION

Assessment Geologist:…	M.A. Kirschbaum	Date:	10/11/00
Region:……………………	North America	Number:	5
Province:………………….	Uinta-Piceance	Number:	5020
Total Petroleum System:.	Mancos/Mowry	Number:	502003
Assessment Unit:……….	Uinta-Piceance Transitional and Migrated Gas	Number:	50200363
Based on Data as of:……	PI production data current through third quarter 1999		
Notes from Assessor…..	Gas in area where base of Mancos/Mowry is between 0.6 and 1.1 Rc		

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:………… 2270
Number of evaluated cells with total recovery per cell ≥ minimum: ……... 1489
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 0.4 2nd 3rd 0.25 3rd 3rd 0.27

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 cel 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 2,235,000 median 2,540,000 maximum 2,845,000

2. Area per cell of untested cells having potential for additions to reserves in next 30 years (acres)
   (values are inherently variable) minimum 30 median 130 maximum 240

3. Percentage of total assessment-unit area that is untested (%): (uncertainty of a fixed value)
   minimum 82 median 88 maximum 94

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 20 median 28 maximum 34

Appendix C—Continued. Data form for the Uinta-Piceance Transitional and Migrated Gas Assessment Unit (AU 50200363). FORSPAN assessment model for continuous accumulations—Basic Input data form (Version 4, 10-5-00).

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 0.2 maximum 7

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)……………………	0.1	1.2	3.8

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	6.00	22.00
CO_2 content (%)………………………………………..	0.10	1.00	20.00
Hydrogen-sulfide content (%)……………………….	0.00	0.00	0.00
Drilling depth (m)………………………………………….	400	1200	4500
Depth (m) of water (if applicable)……………….			

Appendix D. Assessment results summary for the Mancos/Mowry Total Petroleum System, Uinta-Piceance Province.

[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]

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	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gas Fields						0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Continuous-type resources													
Oil	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gas						3,860.60	6,170.75	10,355.40	6,518.85	4.50	9.22	19.43	10.24
Total	1.00	0.00	0.00	0.00	0.00	3,860.60	6,170.75	10,355.40	6,518.85	4.50	9.22	19.43	10.24
Total resources													
Total	1.00	0.00	0.00	0.00	0.00	3,860.60	6,170.75	10,355.40	6,518.85	4.50	9.22	19.43	10.24

Appendix E. Assessment unit results summary for the Mancos/Mowry Total Petroleum System, Uinta-Piceance Province.

[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
502003	**Mancos/Mowry Total Petroleum System**													
50200361	Piceance Basin Continuous Gas Assessment Unit													
Gas	0.02	1.00					649.30	1,463.09	3,296.86	1,652.90	0.60	1.43	3.45	1.65
50200362	Uinta Basin Continuous Gas Assessment Unit													
Gas	0.02	1.00					1,781.69	2,965.07	4,934.43	3,110.69	3.16	5.81	10.67	6.22
50200363	Uinta-Piceance Transitional and Migrated Gas Assessment Unit													
Gas	0.02	1.00					1,429.61	1,742.59	2,124.11	1,755.26	0.74	1.98	5.31	2.37

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

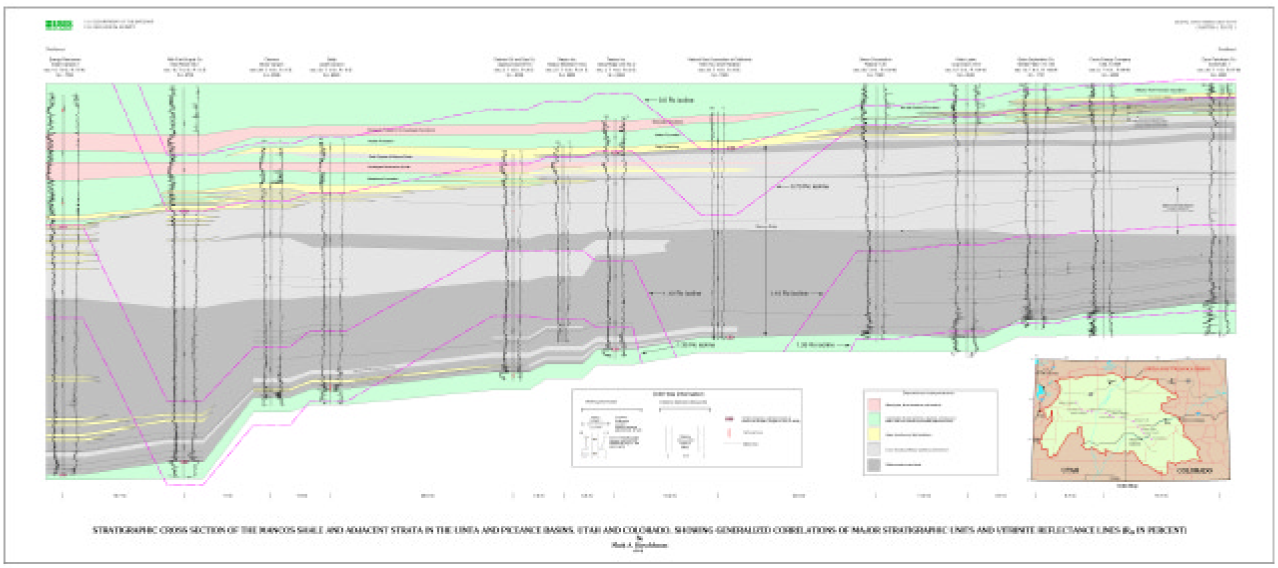


Plate 1. Stratigraphic cross section of the Mancos Shale and adjacent strata in the Uinta and Piceance Basins, Utah and Colorado, showing generalized correlations of major stratigraphic units and vitrinite reflectance lines (R_o in percent).

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

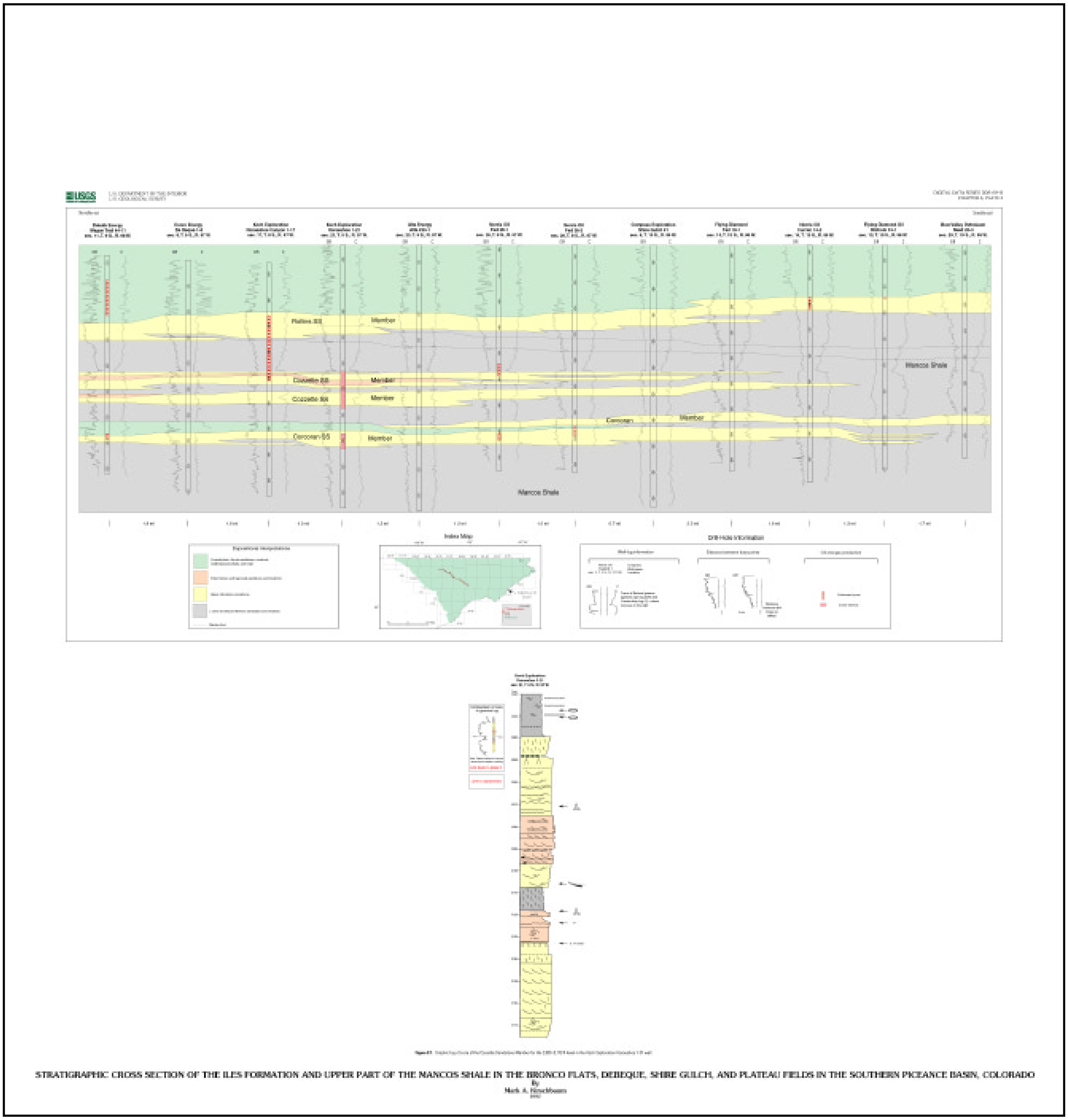


Plate 2. Stratigraphic cross section of the Iles Formation and upper part of the Mancos Shale in the Bronco Flats, Debeque, Shire Gulch, and Plateau fields in the southern Piceance Basin, Colorado.

Click on image below to bring up high-resolution image of plate 3.

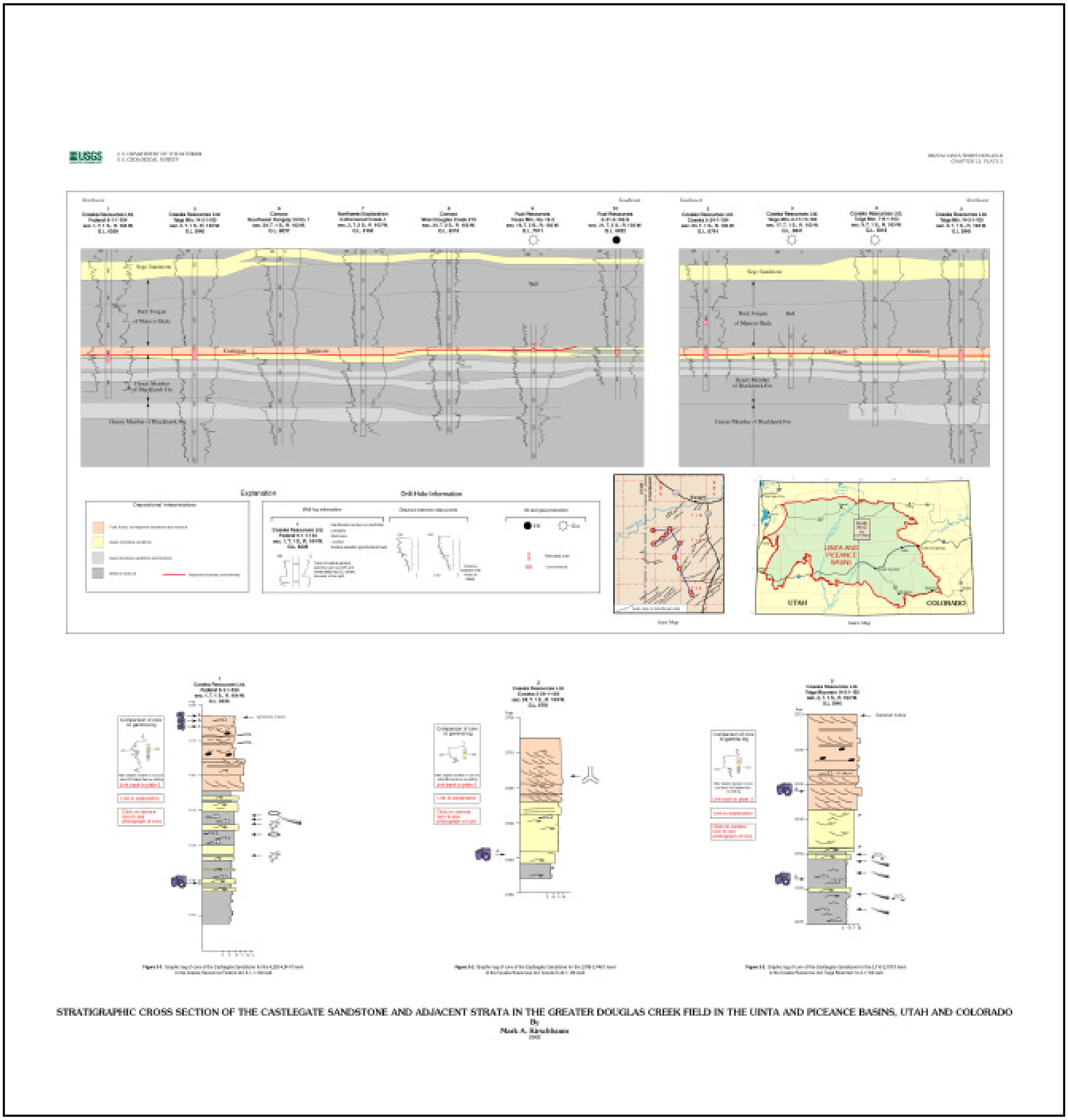


Plate 3. Stratigraphic cross section of the Castlegate Sandstone and adjacent strata in the Greater Douglas Creek field in the Uinta and Piceance Basins, Utah and Colorado.

Click on image below to bring up high-resolution image of plate 4.

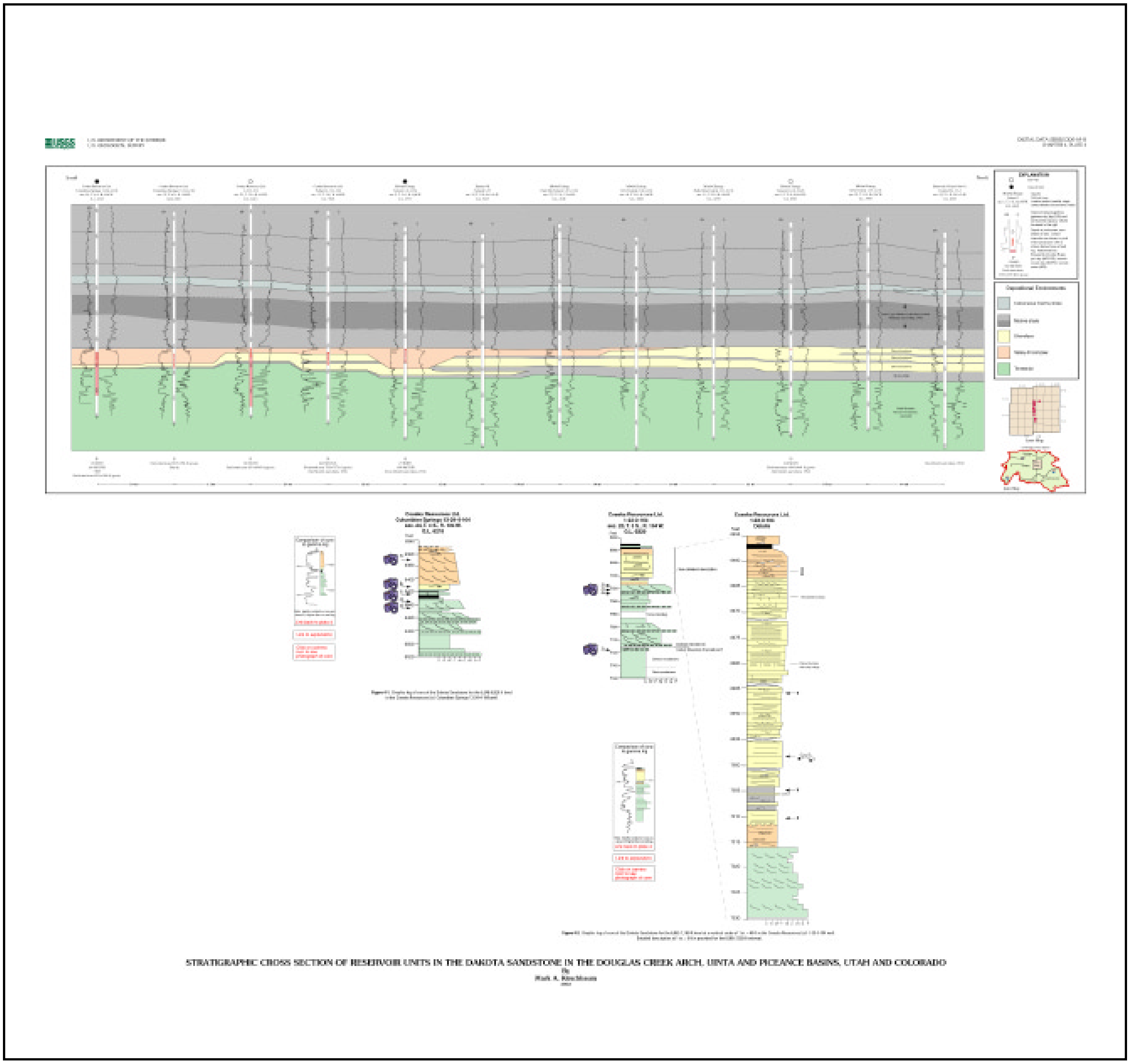
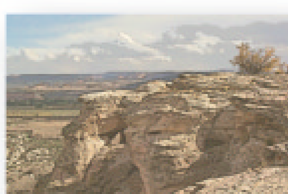


Plate 4. Stratigraphic cross section of reservoir units in the Dakota Sandstone in the Douglas Creek arch, Uinta and Piceance Basins, Utah and Colorado.



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