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POTENTIAL PETROLEUM RESOURCES OF NORTHEASTERN UTAH AND NORTHWESTERN COLORADO

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INTRODUCTION

The area covered in this paper (fig. 1) contains more than 104,000 km^2 (40,000 mi^2). It includes the Uinta, Piceance, Eagle, North Park, Middle Park, and South Park basins.

The region is rich in hydrocarbons. Commercial production of oil and gas is obtained from strata of the Paleozoic, Mesozoic and Cenozoic Eratherms. Thick sedimentary strata are present, and source and reservoir beds are amply distributed throughout the geologic section. Because of the thickness of sedimentary rocks, the range in age of reservoir rocks, and the abundant shows of hydrocarbons in much of the geologic section, prospects for development of substantial new reserves are excellent (fig. 2).

STRATIGRAPHY

Cambrian and Ordovician

Cambrian strata are present in the subsurface throughout the area except where eroded during pre-Late Devonian and mid-Triassic periods of exposure. They crop out along the southwestern and southeastern flanks of the Uinta Mountains in Utah and along the western flanks of the Colorado Rockies. They unconformably overlie Precambrian rocks and are progressively overlapped by Upper Devonian and Mississippian strata (Robison, 1964). In northwestern Colorado, Ordovician dolomite locally lies on Cambrian strata. The Cambrian, where preserved, ranges in thickness from 60-150 m.

The Cambrian consists of a basal marine quartzite or quartzitic, glauconitic sandstone, or dolomite. The rocks normally are well indurated and tightly cemented. No known source rocks are related to the Cambrian. For these reasons, and because of the unfavorable history of exposure and erosion, the Cambrian is not considered promising for future hydrocarbon reserves.

Ordovician strata are represented by the marine Manitou Dolomite, which has very limited distribution. Like the Cambrian, it has little reservoir capacity and is given no potential for hydrocarbons.

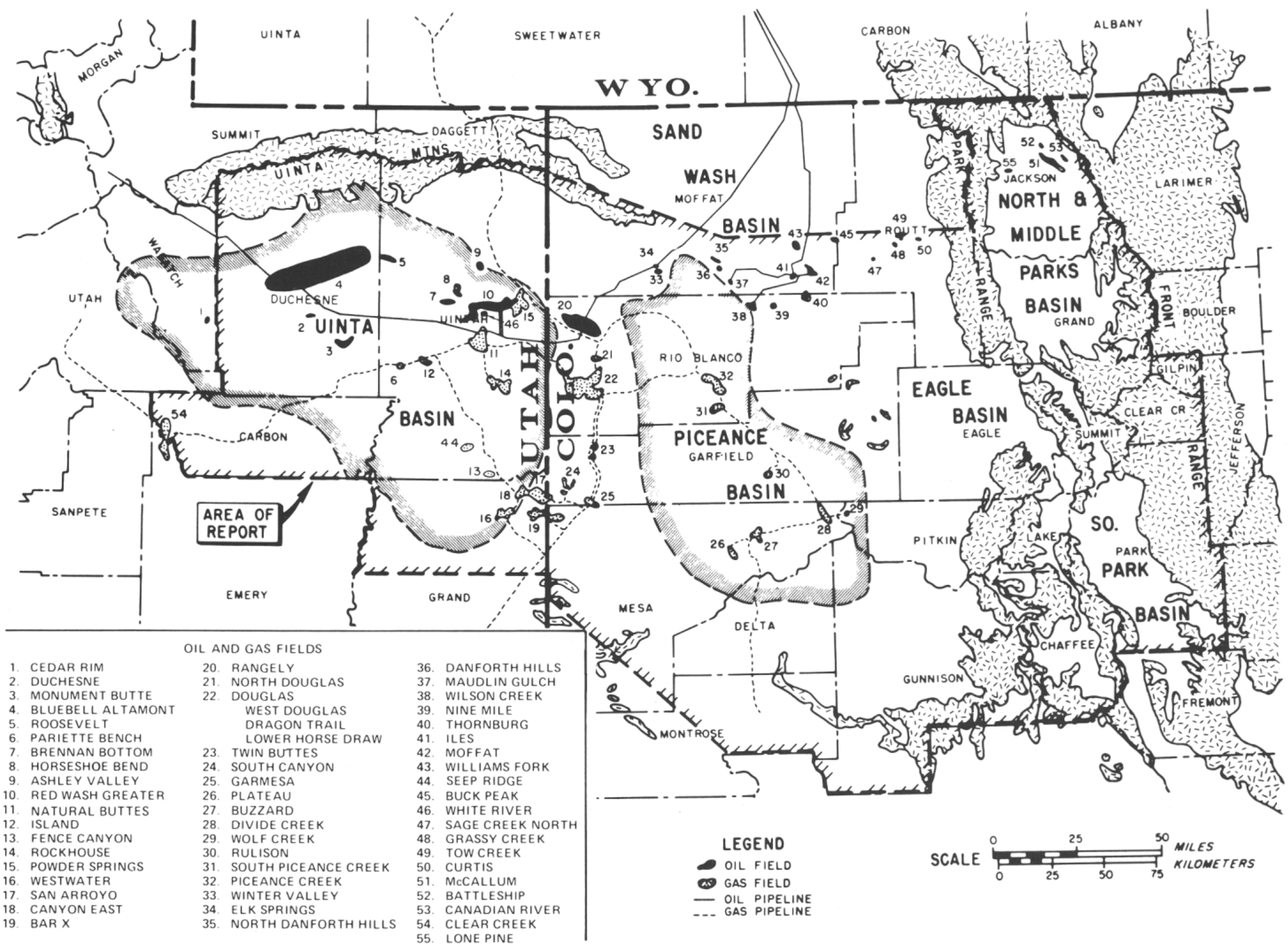

Figure 1. Index map showing principal oil and gas fields, northeastern Utah and northwestern Colorado.

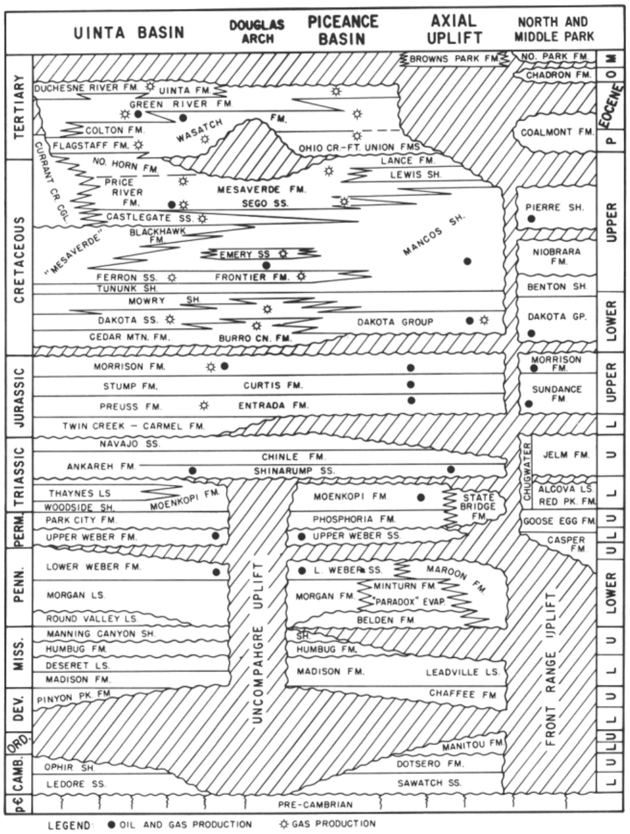

Figure 2. Correlation diagram, northeastern Utah and northwestern Colorado.

Devonian and Mississippian

After a long period of erosion, marine transgression began in Late Devonian time and continued into the Mississippian. Thus, Upper Devonian and Lower Mississippian strata progressively onlap eroded Ordovician, Cambrian, or Precambrian rocks. The Devonian of northwestern Colorado is composed of dolomite and quartzitic sandstone. Reservoir development is poor.

Rigby (1959) states that, in the western Uinta basin, "most Devonian sediments associated with the unconformity surface hold little possibility of petroleum production. In areas, however, where sands have been well washed there is a possibility of production." Devonian and Mississippian strata range in thickness from zero to more than 900 m (fig. 3). Lithology is predominantly carbonate capped by dark shale. Some sandstone is present at the base and overlying the carbonate rocks. Much of the carbonate rock is dolomite which locally contains intercrystalline to vugular porosity. The sandstone commonly is cemented by carbonate and has limited porosity. Some of the carbonate rock and the overlying black shale facies are probably petroleum-generative strata. Shows of oil are common in the Mississippian, and noncommercial gas was produced from a sandstone lens in an upper shale bed in western Carbon County, Utah. Early Pennsylvanian emergence (Sadlick, 1957) resulted in widespread development of a karst surface on thin Lower Pennsylvanian strata or on eroded Mississippian strata. This history suggests that preservation of indigenous hydrocarbons is unlikely in much of the region. However, in the Uinta basin, and particularly in the western part where the section is thicker, the chance of preservation of hydrocarbons is somewhat better. Elsewhere, porous reservoir rocks would have to be charged from younger source strata by downward or lateral migra-

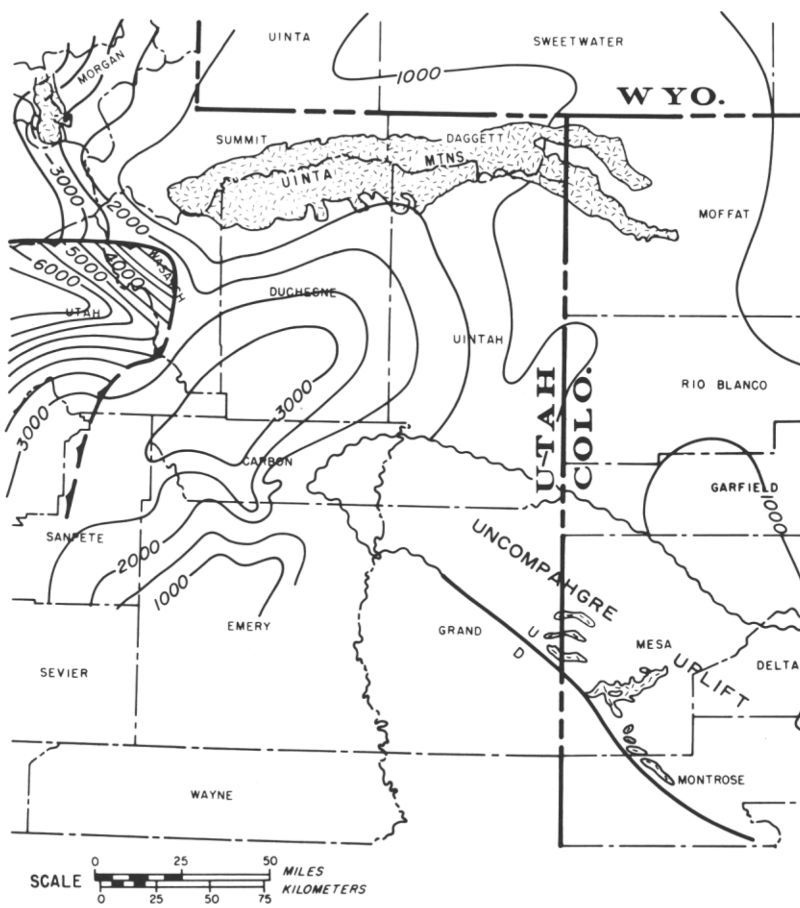

Figure 3. Isopach map of Mississippian and Devonian S

tion. Because Mississippian strata are 4750 m or deeper in half the area, the risk and cost of exploration are greatly increased.

Among the exploratory wells drilled, fewer than 20 have penetrated Mississippian strata. Largely because of the depth and unknown characteristics of reservoir rock, the Devonian-Mississippian interval has been given rather small future reserve potential.

Pennsylvanian and Permian

The Pennsylvanian and Permian are considered together because the source beds and reservoir rocks are interrelated. This section, which ranges in thickness from zero to more than 3000 m, was deposited during a period of great tectonic activity (fig. 4). Its complex geologic history is indicated by at least three, and probably four, major unconformities (fig. 2). The rising Ancestral Rockies shed large quantities of clastic sediment. In addition, considerable amounts of sand were transported into the area. The section is predominantly sandstone and arkose; interbedded carbonate is present locally, principally in northwestern Colorado (Murray, 1958). Also in northwestern Colorado, Lower Pennsylvanian rocks contain interbedded dark-gray organic shale and limestone, above which an evaporite basin developed locally (fig. 2). The evaporites are mostly gypsum and anhydrite (Katich, 1958; Lovering and Mallory, 1962). Some halite has been reported in the subsurface. These evaporites and related strata are of the same age as, and are similar in lithology to the Paradox evaporites of the Paradox basin, to the southwest. Because of this similarity, many geologists prefer to use the term "Paradox Formation" in northwestern Colorado. The strata contain excellent hydrocarbon source beds and numer 257 ous shows have been recorded in them, but no reservoir rocks have been found associated with them. However, the environment of deposition suggests that patch "reefs" or similar carbonate buildups may be present in the subsurface, and reef-like organic carbonate buildups have been reported on the surface. In addition, sandstone strata overlying and laterally equivalent to these beds may contain reservoir-quality porosity and permeability. Sandstone, very prevalent in this unit, is of two types—mature quartzose sandstone and arkose. The arkose lies in thick wedges adjacent to the Precambrian granitic blocks of the Ancestral Rockies, which were the source for these beds (Mallory, 1958). Of the quartzose sandstone strata, the uppermost or Weber Sandstone is the most important economically, although some of the lower sandstone beds may hold future reserves. The Weber Sandstone of Pennsylvanian and Permian age is the producing formation in the giant Rangely field, from which more than 600 million barrels (95 billion liters) of oil have been produced. The Weber Sandstone ranges in thickness from zero at the eastern pinchout to more than 600 m at the western edge of the study area. It is well-sorted, mature sandstone of dominantly very fine to fine grain size (Bissell, 1964). Although the Rangely structure is a large Laramide (Late Cretaceous to early Tertiary) fold, the original trap appears to have been stratigraphic. It is probable that large undiscovered reserves are present in this formation, which has a subsurface extent of more than 34,000 km' (13,000 mil.

Overlying the Weber is the Upper Permian Park City or Phosphoria Formation, a marine cyclic deposit rich in hydrocarbons (Cheney and Sheldon, 1959). This unit is not productive in the

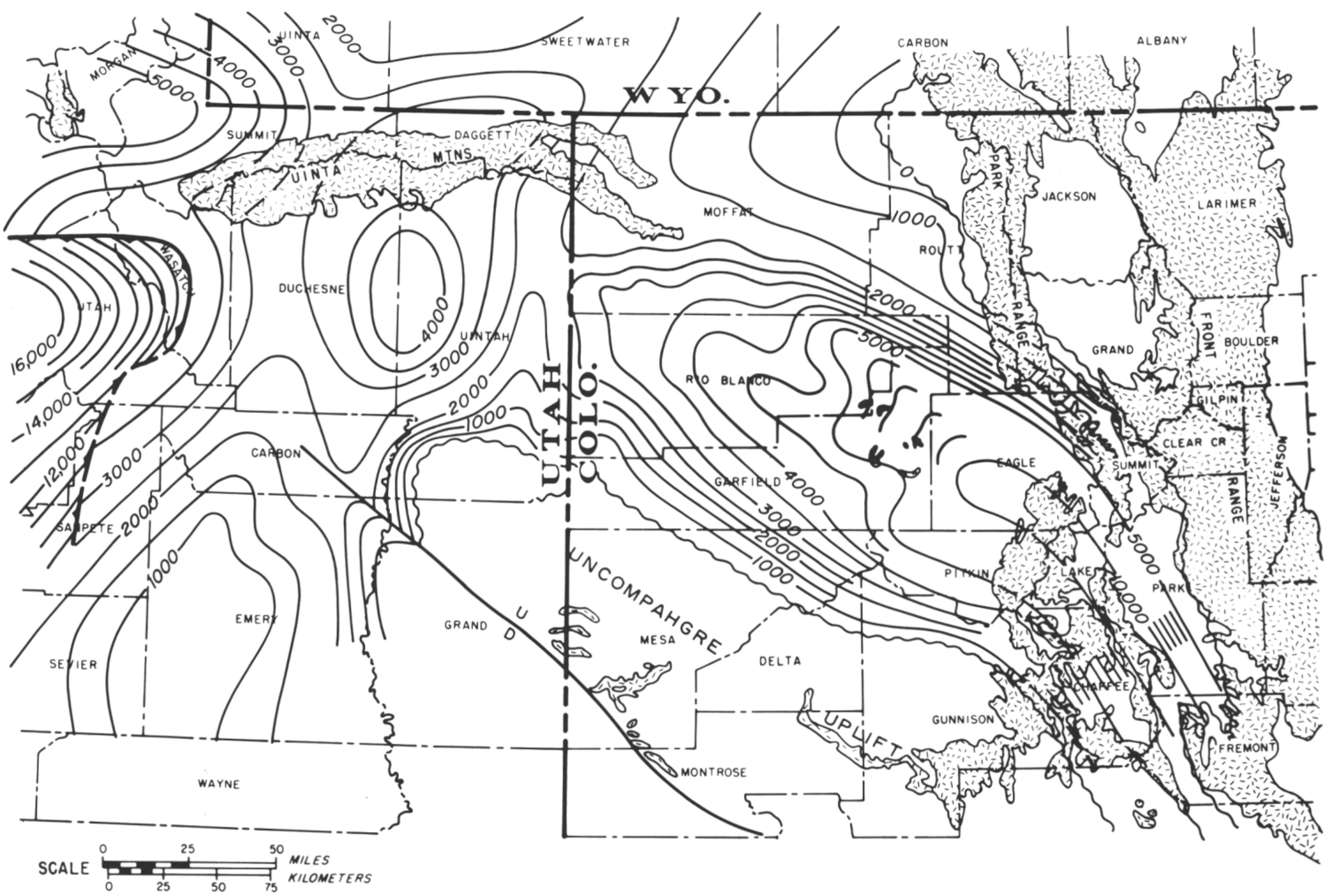

Figure 4. Isopach map of Permian and Pennsylvanian Systems. CI = 500 ft (152 m).

study area, but is a good potential source bed. These rocks are considered by many geologists to be the source of the oil in the Weber Sandstone at Ashley Valley field in Utah and Rangely field in Colorado. In Wyoming, several fields produce oil from the Phosphoria Formation. The reservoir rocks are pelletal and algal dolomites formed along an ancient strandline. Similar facies are present in the subsurface along a broad band extending northeasterly across the study area. In the Uinta Basin the top of this facies is mainly deeper than 4500 m. However, the possibility of finding an oil-filled reservoir in this formation must be considered.

Jurassic and Triassic

The Jurassic and Triassic are considered together because of similar histories. This section is composed of grossly interlayered marine and continental strata. Total thicknesses range from 150 to 1800 m (fig. 5). Three marine cycles of deposition are represented in the section, enclosed in envelopes of red and varicolored continental shale and red, orange, and white fluvial and eolian sandstone. Reservoir rock is mainly nonmarine sandstone. The Shinarump, Navajo, and Entrada strata (fig. 2) include regionally well-developed porous sandstones. Each provides reservoirs for several small fields of oil and (or) gas and one large field (Wilson Creek) in the area of this report. At Wilson Creek, more than 30 million barrels of oil have been produced from the Entrada Sandstone. In addition, the basal member of the Morrison Formation, the Salt Wash Member, is a good sandstone reservoir at Wilson Creek from which more than 60 million barrels (9.5 billion liters) of oil and 55 BCF (1.6 billion m^3) of gas have been produced.

The Shinarump, Navajo and Entrada sandstones tend to be blanket deposits and require closed structures for accumulation. The Salt Wash Member of the Morrison changes thickness and varies laterally in lithology from interbedded nonmarine shale and tight thin fluvial sandstone to thicker porous sandstone. The potential for stratigraphic entrapment in the Salt Wash is good.

Cretaceous

Rocks of Cretaceous age are the most extensive in the study area; they cover more than 80,000 km^2 (31,000 mi^2). Thickness ranges from 1800 to more than 3000 m (fig. 6). The section is characterized by complex interfingering of marine and continental strata. The environment was mainly marine in the eastern part and mainly continental in the western part. Nine principal transgressions and regressions are recognized in Cretaceous sedimentation (Hale and Van deGraaf, 1964). The seas were principally transgressive in Early and early Late Cretaceous time and predominantly regressive throughout the rest of Late Cretaceous. The complex intertonguing relations were described by Haun and Weimer (1960), Lane (1963), Walton (1957), Warner (1964), and Young (1959).

Substantial amounts of gas have been found in the Cretaceous in this area, and ultimate reserves are estimated to be about 2 trillion ft^3 (57 billion m^3). However, to date, the comparatively small amount of oil found in these rocks has come mainly from frac-

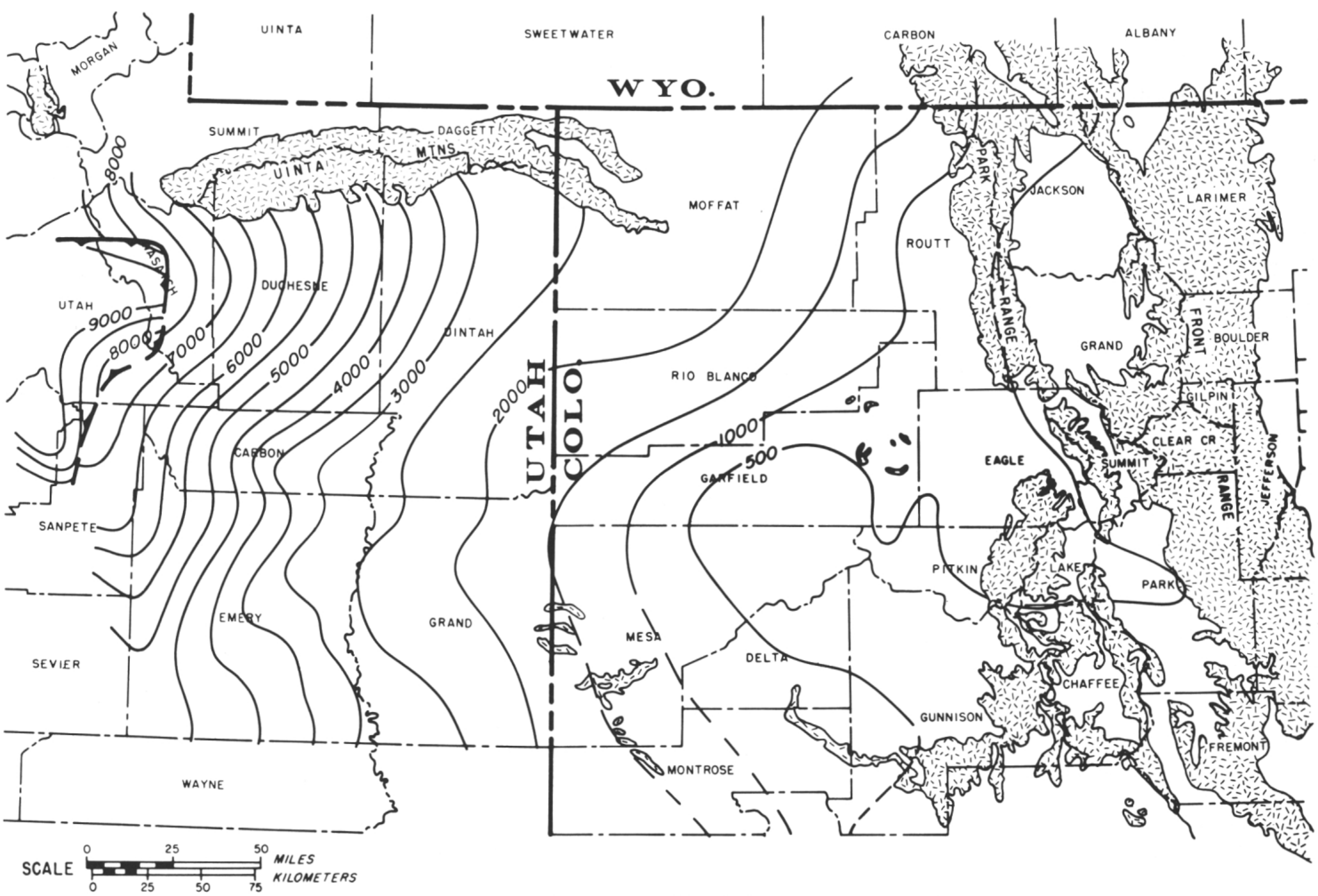

Figure 5. Isopach map of Jurassic and Triassic Systems. CI = 500 ft (152 m).

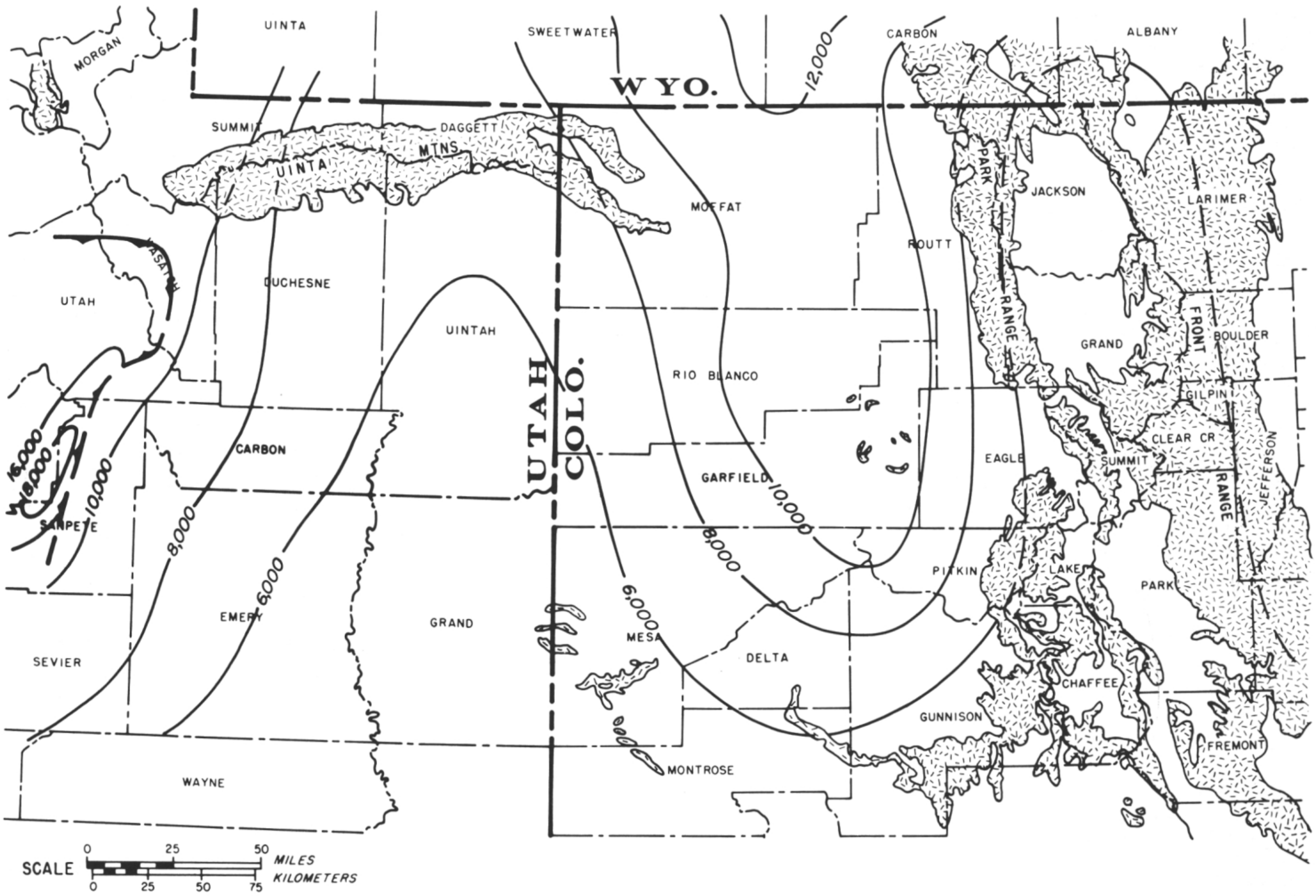

Figure 6. Isopach map of Cretaceous System. CI = 2,000 ft (610 m).

tured marine shale and the Dakota Sandstone. Reservoirs are sandstone developed as bar or beach deposits along the fluctuating strandline and as fluvial channel sands in the continental sediments. The Mancos Shale is a likely source for oil, and the carbonaceous beds in the lagoonal areas may be the source for gas.

Although great thicknesses of sandstone of Cretaceous age are present, effective porosity appears to be limited. The sandstone is either clay-filled or tightly cemented in much of the section. Thus, the main problem in exploration of the Cretaceous is locating effective porosity in trap position. There are enormous reserves of gas in these low-permeability reservoir rocks. Any technologic advance in production of gas Prod this tight sandstone will increase available reserves very substantially. It is not expected that very large accumulations of oil will be discovered, although one or two fields with reserves of 100 million barrels (16 billion liters) are possible. Most of the undiscovered hydrocarbons are expected to be in stratigraphic traps.

Tertiary

Potential hydrocarbon bearing Tertiary strata in this area are confined to the Paleocene and Eocene Series. Younger Tertiary nonmarine strata are present in part of this area, primarily on or near the surface and are not considered prospective for hydrocarbon accumulation. Paleocene and Eocene strata are nonmarine and range in thickness from 600 to more than 3300 m (fig. 7). This sequence is one of the most petroliferous deposits in the world, con taining great quantities of gas, liquid petroleum, solid petroleum, "oil shale," and bituminous sand. Although the present evaluation excludes the last three types of accumulation, the Tertiary rocks in the Uinta and Piceance Basins stand high in potential for future oil and gas reserves.

An important oil-bearing formation, the Green River Formation, is a complex suite of lacustrine deposits which is enclosed in an envelope of fluvial-floodplain and interbedded lacustrine deposits. The underlying part of the envelope is the Wasatch Formation and equivalents, and the overlying strata are the Uinta and Duchesne River Formations. Green River sediments have yielded more than 130 million barrels (20 billion liters) of oil and 400 BCF (11 billion m^3) of gas.

The Wasatch Formation is also important for hydrocarbon production. More than 100 million barrels (16 billion liters) of oil and 300 BCF (8.5 billion m^3) of gas have been produced from these strata. The greater part of the oil has been produced since the discovery of Altamont field in 1970. The Wasatch Formation is Paleocene and Eocene in age. The basal part is equivalent to the Flagstaff Formation in the southwest part of the Uinta basin. The Wasatch Formation contains sediments deposited in lacustrine, fluvial, floodplain and lagoonal environments. The strandline of lacustrine deposition is the most important belt for the location of hydrocarbon reservoirs in both the Green River and Wasatch Formation.

During early Tertiary time, the present Uinta Mountains began to

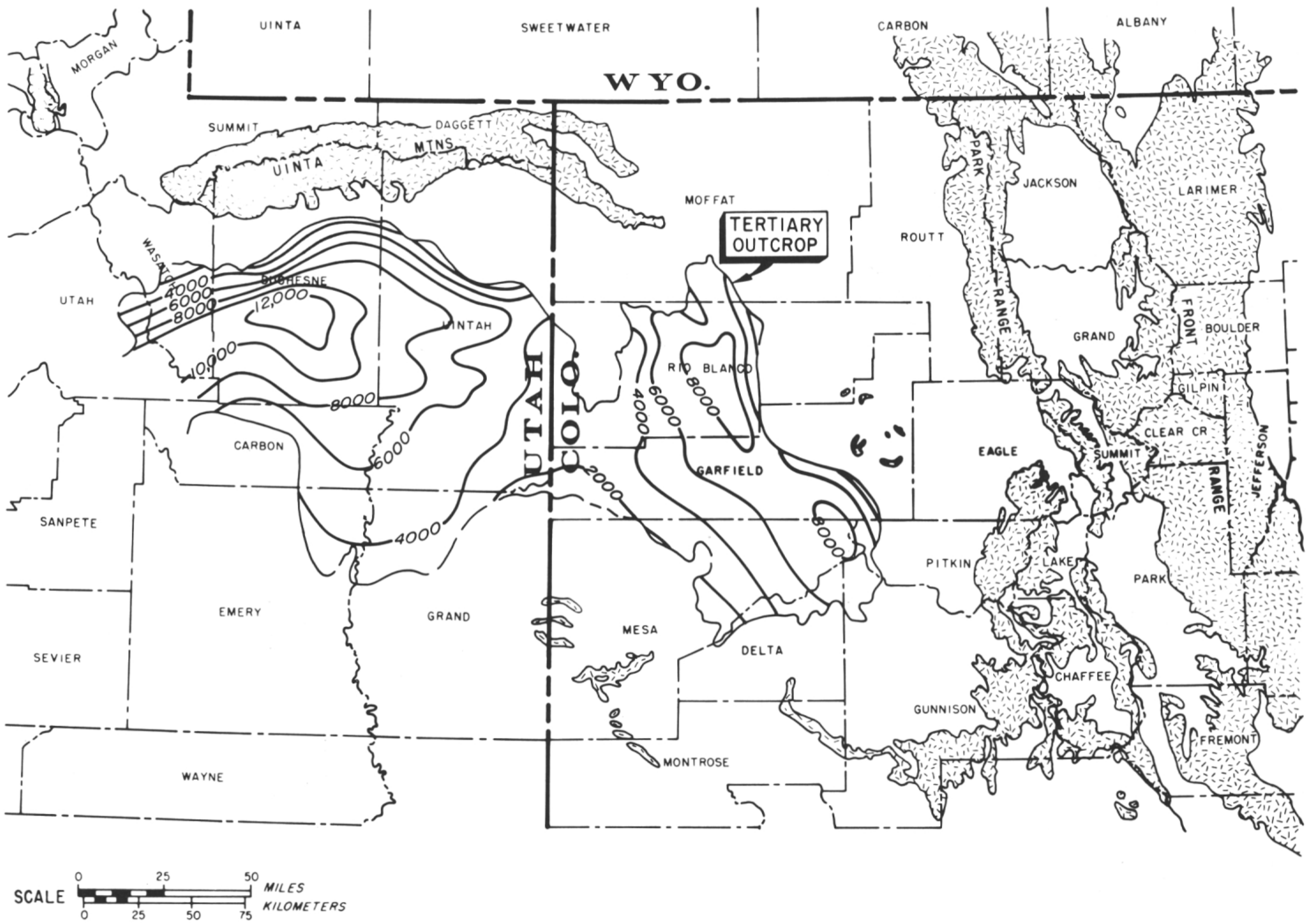

Figure 7. Isopach map of Tertiary strata (Paleocene and Eocene). CI = 2,000 ft (610 m).

rise, dividing the Tertiary basin into two parts; the southern part is the Uinta basin. Concurrently, the north-trending Douglas Creek arch (fig. 8) began to rise separating the Uinta basin from the Piceance basin. On the south, the Uncompahgre highland again became positive. Clastic material was contributed to the two Tertiary basins from these three positive features. By the end of Wasatch deposition, the Douglas Creek arch had been overlapped by red shale. The Douglas Creek arch, later covered by thin Green River sediments, was not subject to erosion during the rest of Eocene time.

Clastic sediments for the Green River Formation were derived from the Uinta Mountains on the north and the Uncompahgre highland on the southeast. Bar, beach, and deltaic sands were deposited along a rapidly fluctuating strandline. The central part of the lake received fine-grained clastic material augmented by a rain of orthochemical sediment and rich organic debris derived from the abundant biota of this unusual lake.

The resulting reservoir rocks are marginal lacustrine sands pinching out basinward into organically rich fine-grained sediments—a remarkable setting for the development of stratigraphic traps. The subsequent shifting of the basinal axis to the north gave the north-source sands an updip, southward pinchout into impermeable lacustrine fine-grained sediments (fig. 9).

The Red Wash field produces from multiple stratigraphic traps formed in an ancient delta complex. Production was at first believed to be confined to the Red Wash nose, a westerly dipping structure (fig. 8). Later a substantial accumulation was found in and south of the southerly syncline at the southwestern edge of the Red Wash feature. The area, the Wonsits Valley Unit, is a stratigraphic accumulation on northerly regional dip. The Wonsits Valley area and the Red Wash field are referred to as Red Wash Greater field.

Hydrocarbon production in the Bluebell-Altamont field is from reservoirs in marginal lacustrine strata from both Green River and Wasatch beds. Production is mainly confined to the area of the fluctuating strandline in dominantly fine siliceous clastics and carbonate strata. Porosity and permeabiltiy are greatly enhanced by intrastratal fracturing. Fracture production has become a substantial part of Tertiary production. Future reserves in the Uinta Basin Tertiary strata are expected to be very substantial.

Tertiary production in the Piceance basin is almost entirely gas. The Green River strata are thin, and the high pour point of the lacustrine oil, about 100°F (38°C), precludes production from strata shallower than about 1000 m. The Wasatch Formation, 30-1500 m thick, contains sandstone beds that produce gas in large amounts at Piceance Creek field.

Elsewhere in this basin smaller fields are producing from the Tertiary and additional gas discoveries are expected.

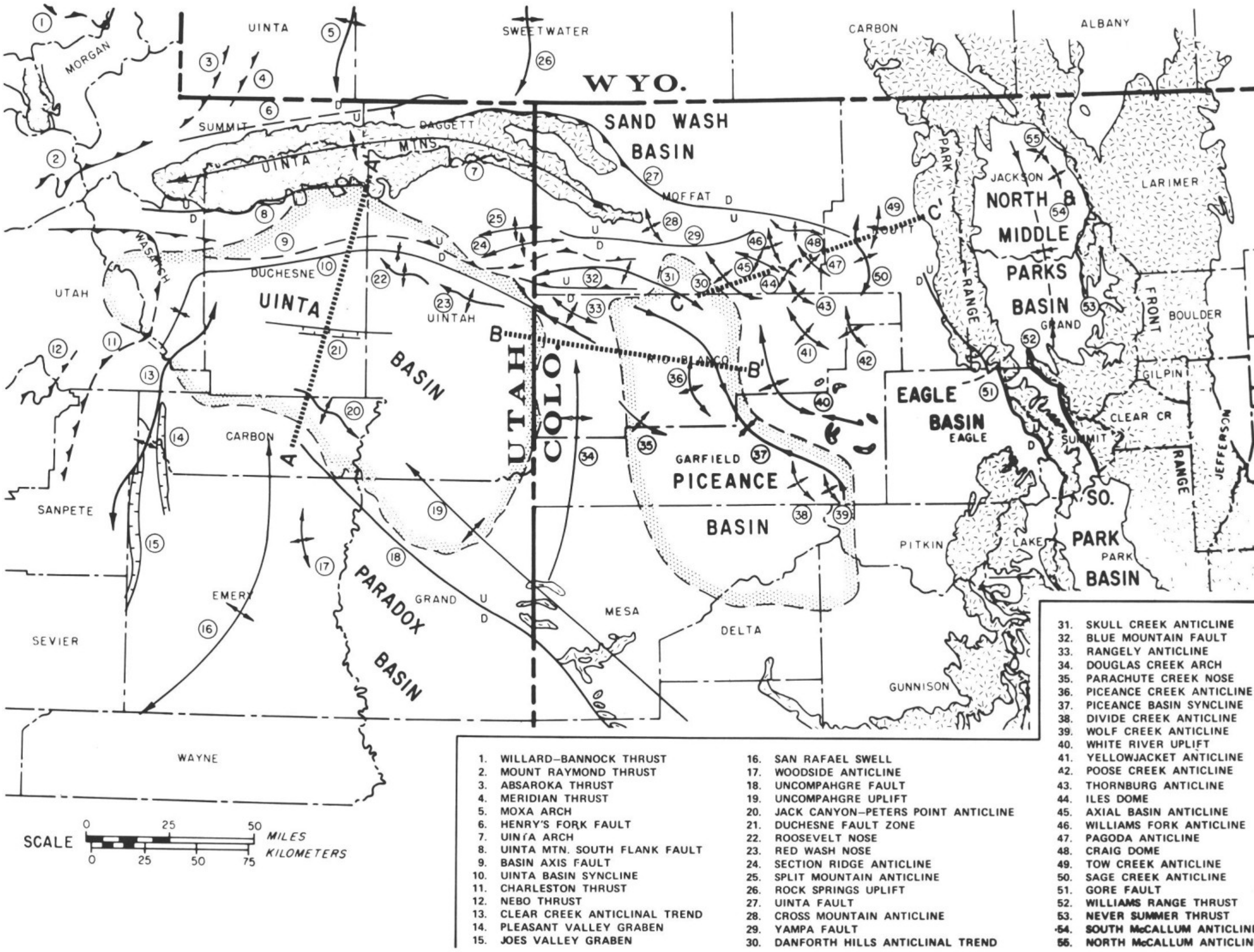

Figure 8. Tectonic map showing major or economically important features, northeastern Utah and northwestern Colorado.

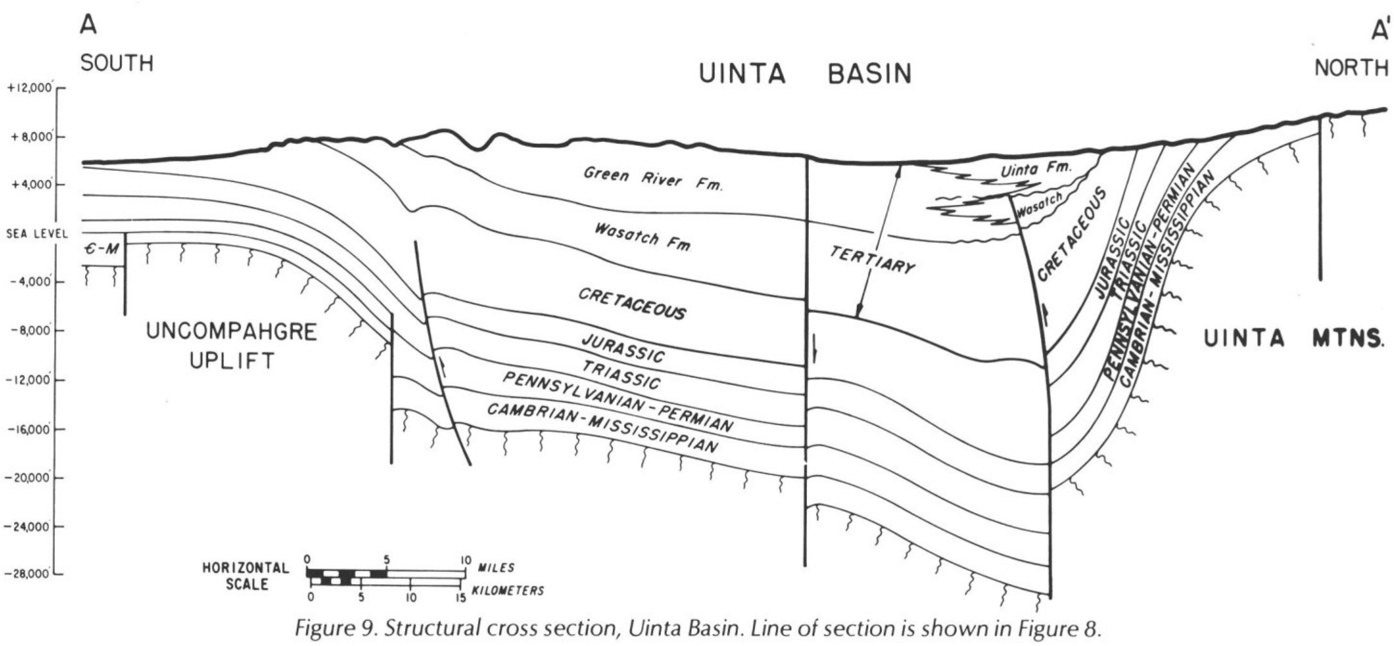

Figure 9. Structural cross section, Uinta Basin. Line of section is shown in Figure 8.

New technology may be developed to remove the substantial reserves of high pour point oil trapped in the shallow sands of the Green River Formation.

STRUCTURAL SETTING

The dominant basins in the study area are outlined by major positive features, as shown on the tectonic map (fig. 8). The form of the basins is shown on the structure map (fig. 10) and three cross sections (figs. 9,11, and 12).

Most of the structural features as now expressed are of "Laramide" (Late Cretaceous to early Tertiary) age or younger. However, where more information is available, it appears that many of the pronounced Laramide features had earlier and more subtle expression.

Most of the production is from combination structural and stratigraphic traps that have been discovered by drilling anticlinal features. Most of the exploratory drilling to date has been directed to the search for structural features. However, the Cretaceous and Tertiary intertonguing facies are ideal for stratigraphic entrapment. More stratigraphic accumulations will be found as the industry gives more attention to the search for stratigraphic traps.

PRODUCING ROCKS

As shown on the correlation chart (fig. 2), every system from Pennsylvanian through Tertiary produces oil and gas. Except for fracture reservoirs in the Tertiary and Cretaceous, the reservoirs are in sandstone strata. Some accumulations are in tabular beds but most are lenticular beds.

Gas production from the Wasatch Formation has been disappointing because of rapid decrease in productivity. The sandstone is clay-filled or tightly cemented, resulting in low effective porosity and a lower reservoir volume than might be expected. However, technologic advances may in time increase producibility of the Wasatch strata.

The high pour point of the Tertiary lacustrine oils (90-100°F; 32-38°C) presents special problems. To be transported, this oil must be heated or mixed with a low-pour point "carrier" crude. The Red Wash field Tertiary crude oil is mixed with Rangely field Pennsylvanian oil and transported by pipeline to Salt Lake City, Utah.

POTENTIAL FUTURE PRODUCTION

Future production in the area may be expected in large part from new fields and pools in the strata that are now productive. The reservoirs will be mainly lenticular sandstone bodies. It is probable that most of the new oil will be found in stratigraphic traps, inasmuch as the more readily determinable structures have been drilled. Geophysical methods will be used to locate deeper structural features, and certainly some of these structures will reward the explorer with significant new reserves.

Carbonate reservoir possibilities in the Mississippian and Penn-

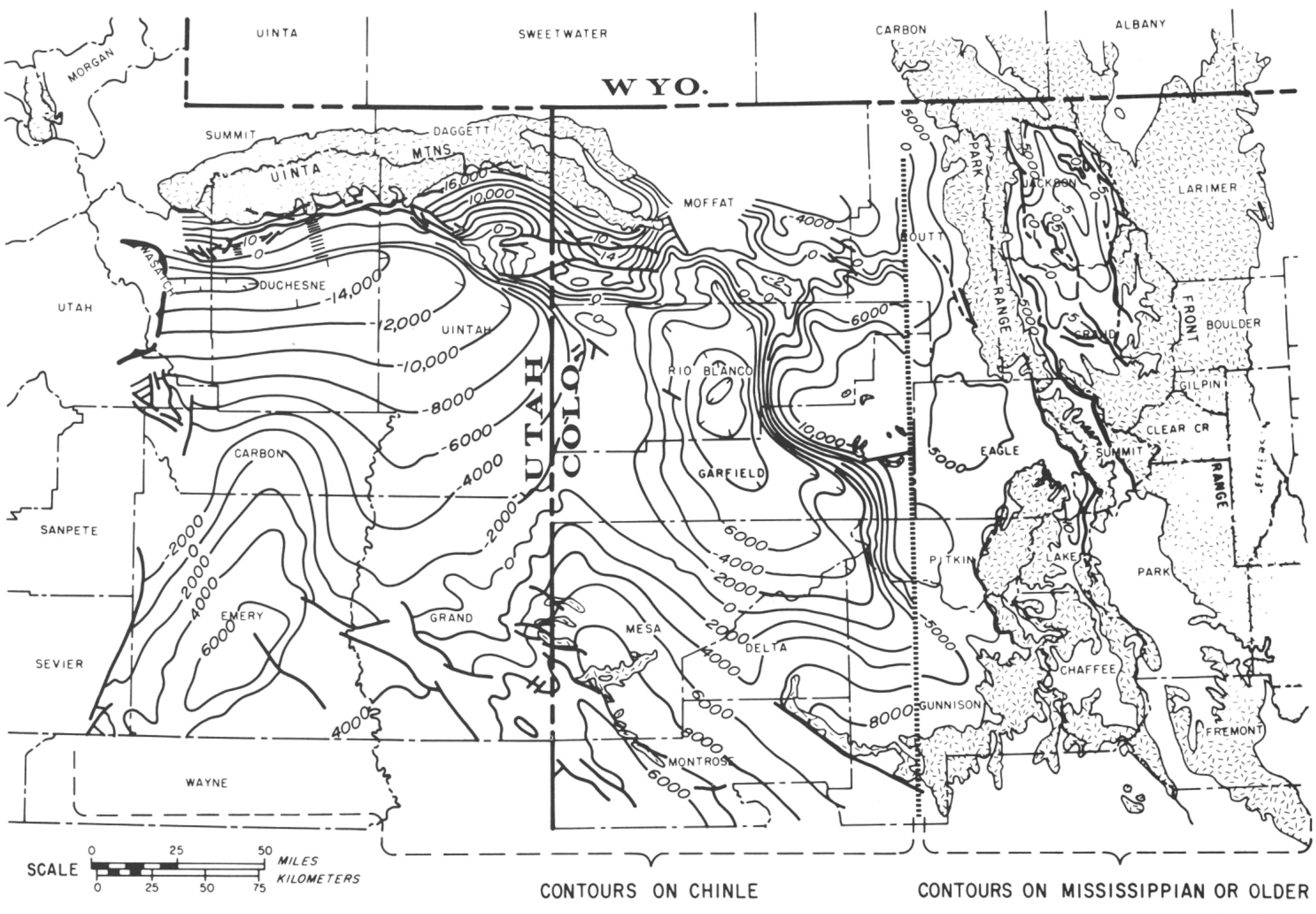

Figure 10. Structure contour map of top of Triassic Chinle Formation and Mississippian System or older rocks as indicated. Modified after Kelley (1955) and Anderman (1961). Elevation in feet from sea level.

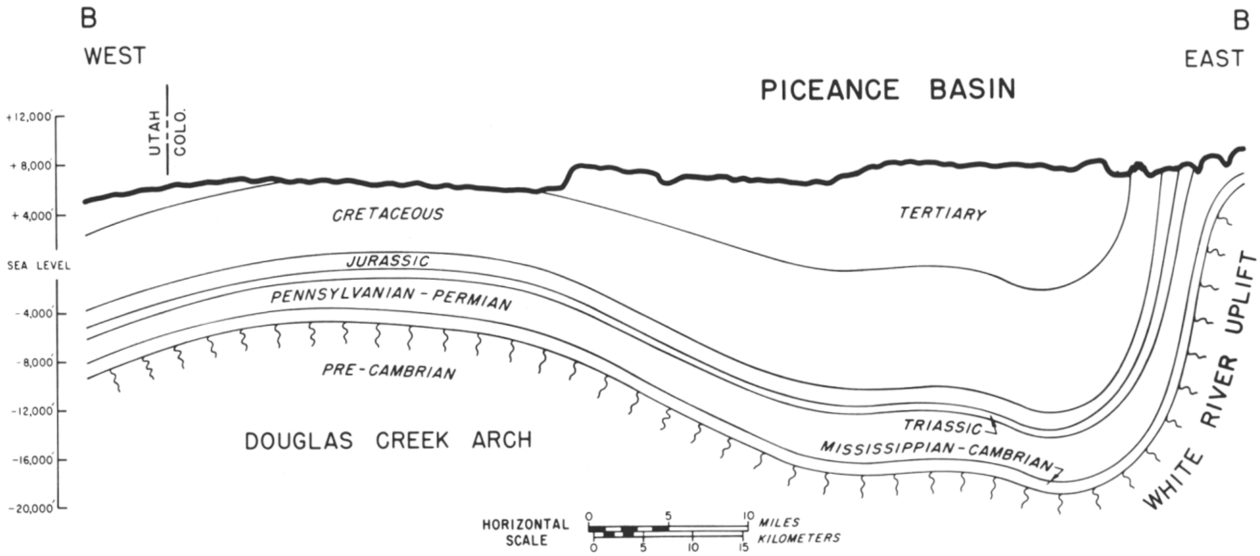

Figure 11. Structural cross section, Douglas arch and Piceance basin. Line of section is shown in Figure 8.

sylvanian are yet to be evaluated. The Mississippian has had few tests and is relatively unknown. On the average, there has been one Mississippian test for every 5000 km' (2,000 mil) in the study area.

In the Pennsylvanian the presence of reefs adjacent to evaporites has been observed on the outcrop. These reefs may be found to have porosity and reservoir capacity in the subsurface, and there is ample associated source rock.

ESTIMATION OF FUTURE RESERVES

Estimation of undiscovered reserves is a highly speculative process. However, some assumptions can be based on knowledge of regional distribution of thickness of strata, amount of porous beds characteristic of an interval, and production experience in the area. Sufficient source rocks must be available to charge the sec tion with hydrocarbons, and trapping conditions must be present. Furthermore, after a trap has been filled with hydrocarbons, structural history must be favorable for its preservation. Because we know only a few of these parameters and surmise the rest, numerical values for undiscovered reserves are conjectural at best. However, they do offer a means of comparison and they are a summation of present knowledge. Figures 13 and 14 present a graphic summary of the estimated hydrocarbon potential.

CONCLUSIONS

The area comprising the Uinta and Piceance basins and vicinity has excellent potential for future reserves. Estimated ultimate recoverable reserves of 3 billion barrels (500 billion liters) of oil and 5 trillion ft' (150 billion m^3) of gas are predicted.

Potential for new oil and gas exists in Paleozoic, Mesozoic, and

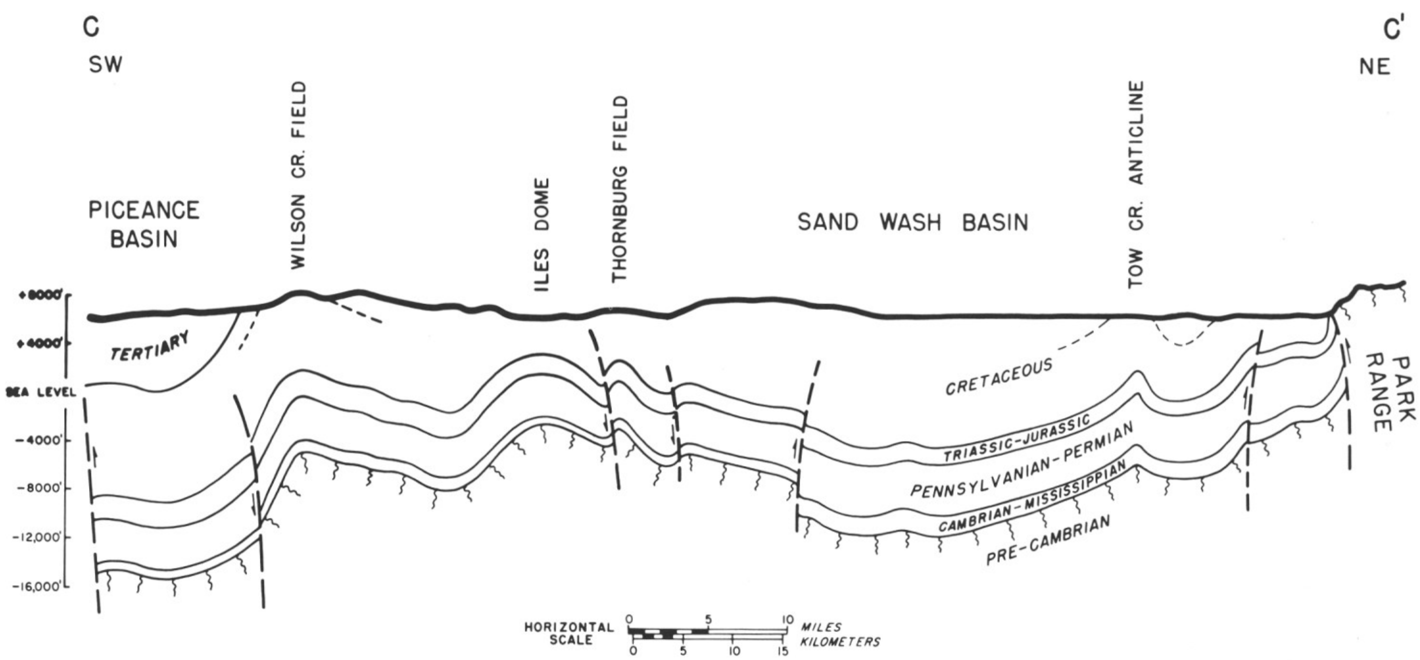

Figure 12. Structural cross section, Piceance basin to Park Range. Line of section is shown in Figure 8.

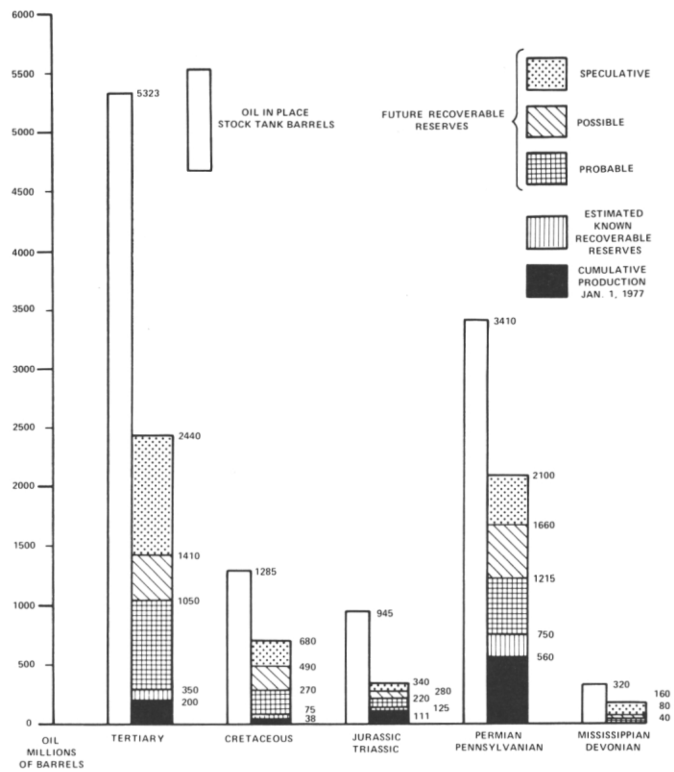

Figure 13. Present and future oil reserves, northeastern Utah and northwestern Colorado. Estimated oil in place is compared with estimated recoverable oil. Future reserves are rounded off to nearest 50 million barrels (7.95 billion liters).

Cenozoic rocks. Most of the future oil and gas reserves will be found in stratigraphic traps. The dominant reservoirs for future petroleum will be lenticular sandstone bodies.

ACKNOWLEDGMENT

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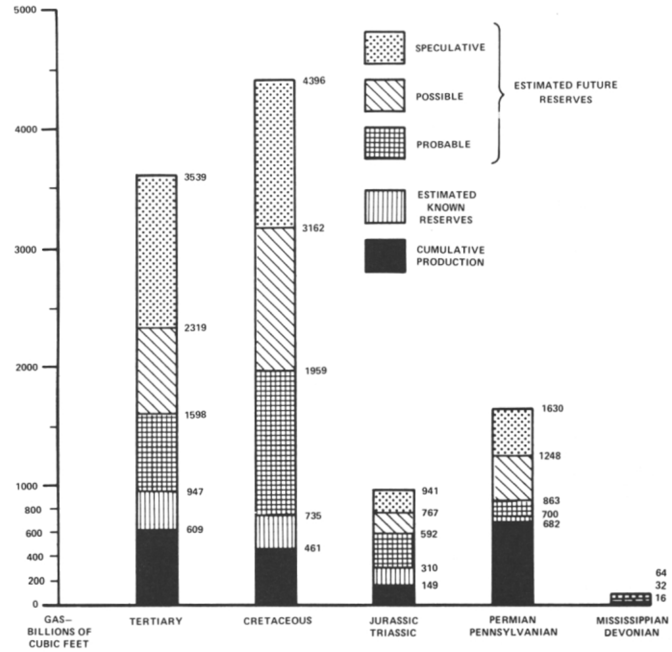

Figure 14. Present and estimated future gas reserves, northeastern Utah and northwestern Colorado. 1 BCF = 28 million m³.

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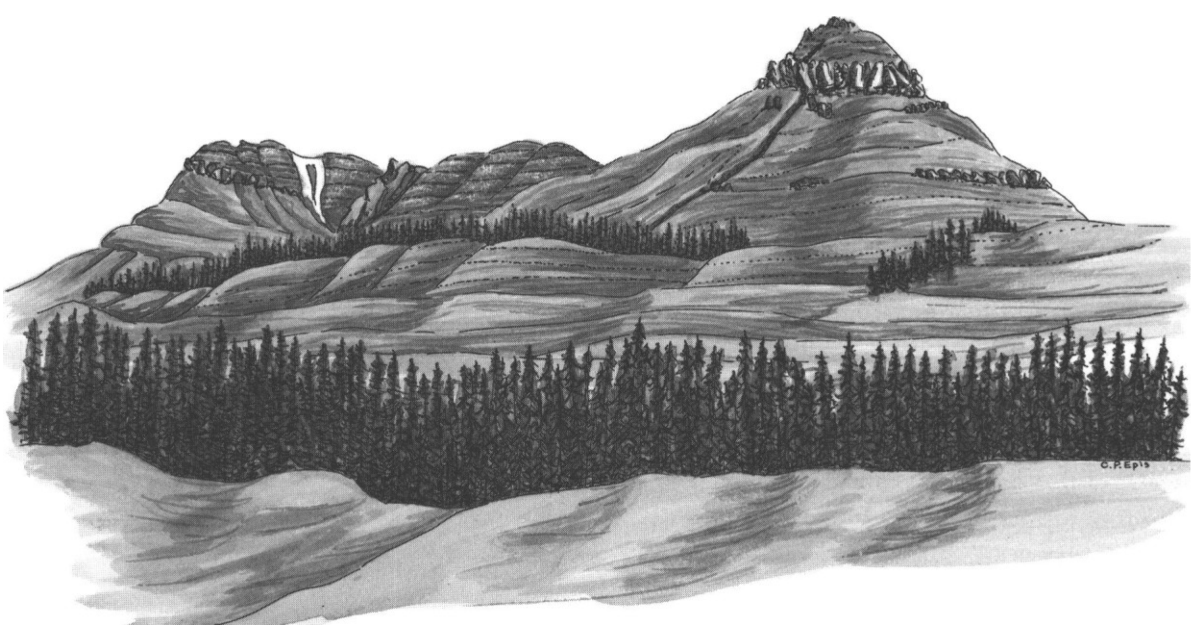

Gunnison Gorge Recreation area, Black Canyon, looking northwest from Black Ridge toward Grand Mesa on skyline.