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CRETACEOUS AND TERTIARY HISTORY AND RESOURCES OF THE PICEANCE CREEK BASIN, WESTERN COLORADO*

RONALD C. JOHNSON and C. WILLIAM KEIGHIN
U.S. Geological Survey
Denver, Colorado 80225

INTRODUCTION

The Piceance Creek Basin is a Late Cretaceous and Tertiary age sedimentary basin in west-central Colorado. It is bounded on the southeast by the Sawatch uplift, on the east by the White River uplift, on the north by the Uinta uplift, on the southwest by the Uncompahgre uplift, and on the west by the Douglas Creek arch (fig. 1). It is part of a larger complex of Laramide-age basins, including the Uinta Basin to the west and the greater Green River Basin to the north, which hold vast lacustrine oil-shale deposits of Eocene age. This paper is a general overview of the development of the Piceance Creek Basin starting in the Early Cretaceous time. Oil shale, and other resources, are discussed briefly.

GEOLOGIC HISTORY

Late Cretaceous

The Cretaceous epicontinental sea transgressed generally from northeast to southwest across the Piceance Creek Basin area in the Early Cretaceous, depositing about 60 to 90 m of marginal marine fluvial and paludal sediments of the Dakota Sandstone (called Dakota Group by Haun, 1959). As much as 1,700 m of marine Mancos Shale was deposited before the next marine regression, represented by the Castlegate Sandstone (fig. 2), reached the westernmost part of the area in the Campanian (Zapp and Cobban, 1960). A mixed sequence of marine, marginal marine, and paludal sediments comprise the next 210 to 600 m of section (fig. 3), as the shoreline regressed slowly across the area from northwest to southeast. This overall regressive sequence was interrupted by several relatively minor transgressions, but the Cretaceous seaway had retreated east of the area before the end of the Campanian (figs. 2, 4). At this time the Piceance Creek Basin did not exist, as such, because the surrounding Laramide uplifts that define the basin did not begin to rise until somewhat later. The area presently occupied by the Piceance Creek Basin was located along the western side of a seaway that extended from the Arctic Ocean to the Gulf of Mexico (fig. 5). Figure 2 shows an isopach of the interval from the top of the Dakota Sandstone to the top of the Rollins Sandstone member of the Mount Garfield Formation (west)-Trout Creek Sandstone Member of the Iles Formation (east), the youngest basinwide regressive marine sandstones. The interval thickens to the northeast, away from both the Uncompahgre uplift and the Douglas Creek arch. There is no evidence that either uplift was a positive area at this time, but that subsidence rates appear to have been influenced by the Uncompahgre and the Douglas Creek arch nonetheless. This sediment-thickening trend is similar to that found in younger sediments when the Uncompahgre uplift, as well as other uplifts, were actively rising.

Following the retreat of the Cretaceous seaway, more than 1,200 m of late Campanian, and possibly Maestrichtian age nonmarine sediments were deposited in the area (figs. 3,6). During this time interval, only one marine transgression, the Lewis transgression, migrated as far west as the Piceance Creek Basin area (fig. 1), and this transgression extended only to the northeast corner of the basin (Handcock, 1925; Zapp and Cobban, 1960). The Lion Canyon Sandstone Member of the Williams Fork Formation, west of Meeker, was deposited during this transgression or during the regression that followed.

The Sawatch uplift, southeast of the basin (fig. 1), began to rise during deposition of the nonmarine Cretaceous section (Obradovich and others, 1969; Tweto, 1975). The effects of this uplift on Cretaceous sedimentation are unknown. Chert pebbles, common in the upper part of the nonmarine Cretaceous section in the southern part of the basin, may have come from the rising Sawatch uplift, but overall, the section in the southeastern part of the basin near the uplift is similar to the section for the rest of the basin. The nonmarine Cretaceous section thickens toward the uplift at its nearest preserved exposure, about 15 to 25 km west (fig. 6). Apparently the uplift did not affect subsidence rates in the adjacent Piceance Creek Basin.

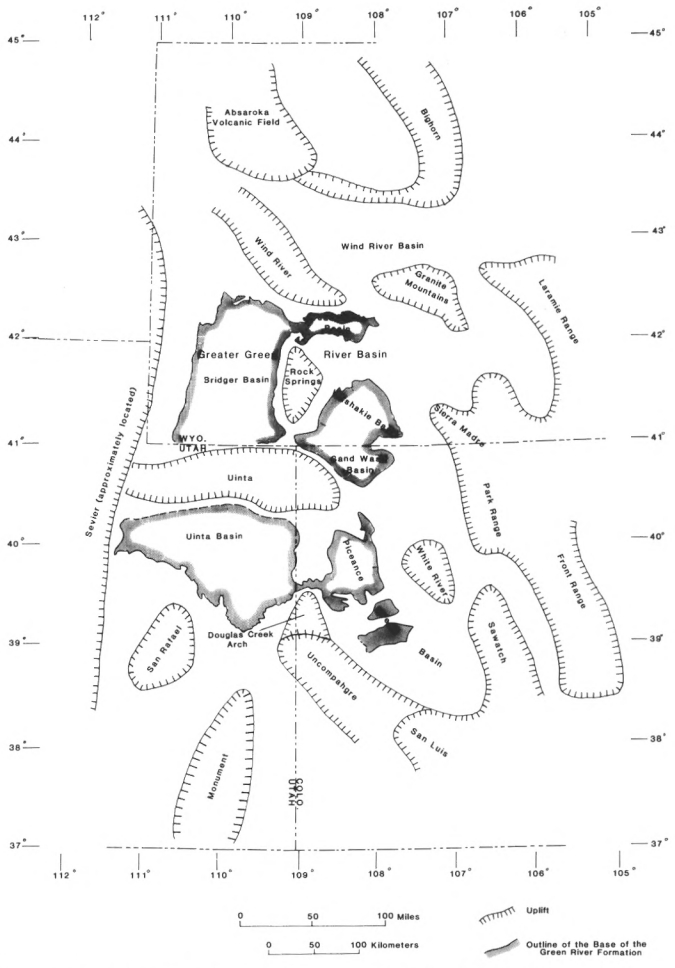


Figure 1. Map showing basins that contain Green River oil shale. Approximate extent of uplifts in Late Cretaceous and early Tertiary time are also shown.

*Part of this work was prepared in cooperation with the U.S. Department of Energy, Western Gas Sands Project.

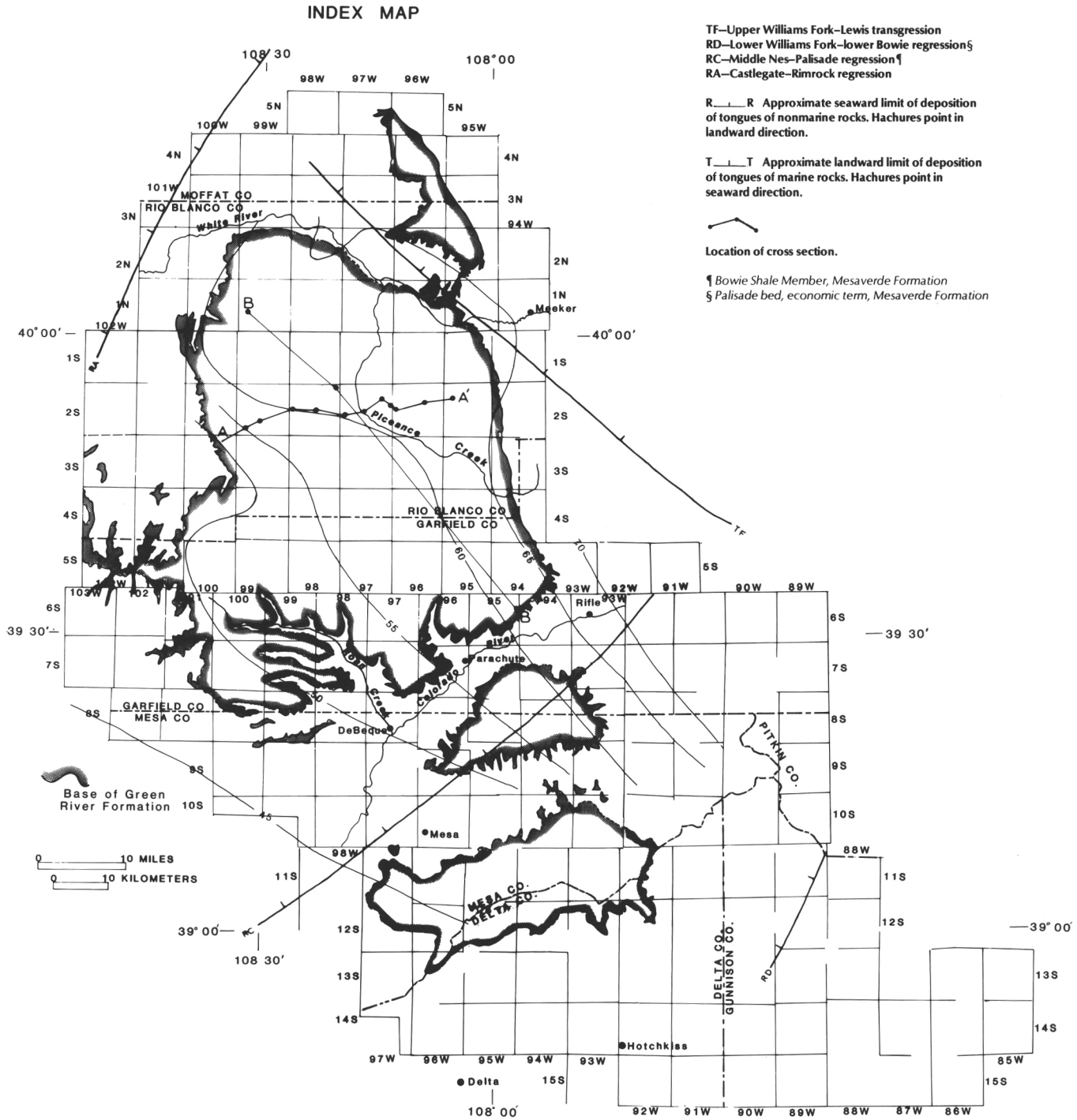


Figure 2. Index map showing the location of cross sections A-A′ and B-B′, the limits of selected Late Cretaceous transgressions and regressions (Zapp and Cobban, 1960), and a generalized isopach of the interval from the top of the Dakota Sandstone to the top of the Rollins Sandstone Member-Trout Creek Sandstone Member. Contour interval, 500 ft (152 m).

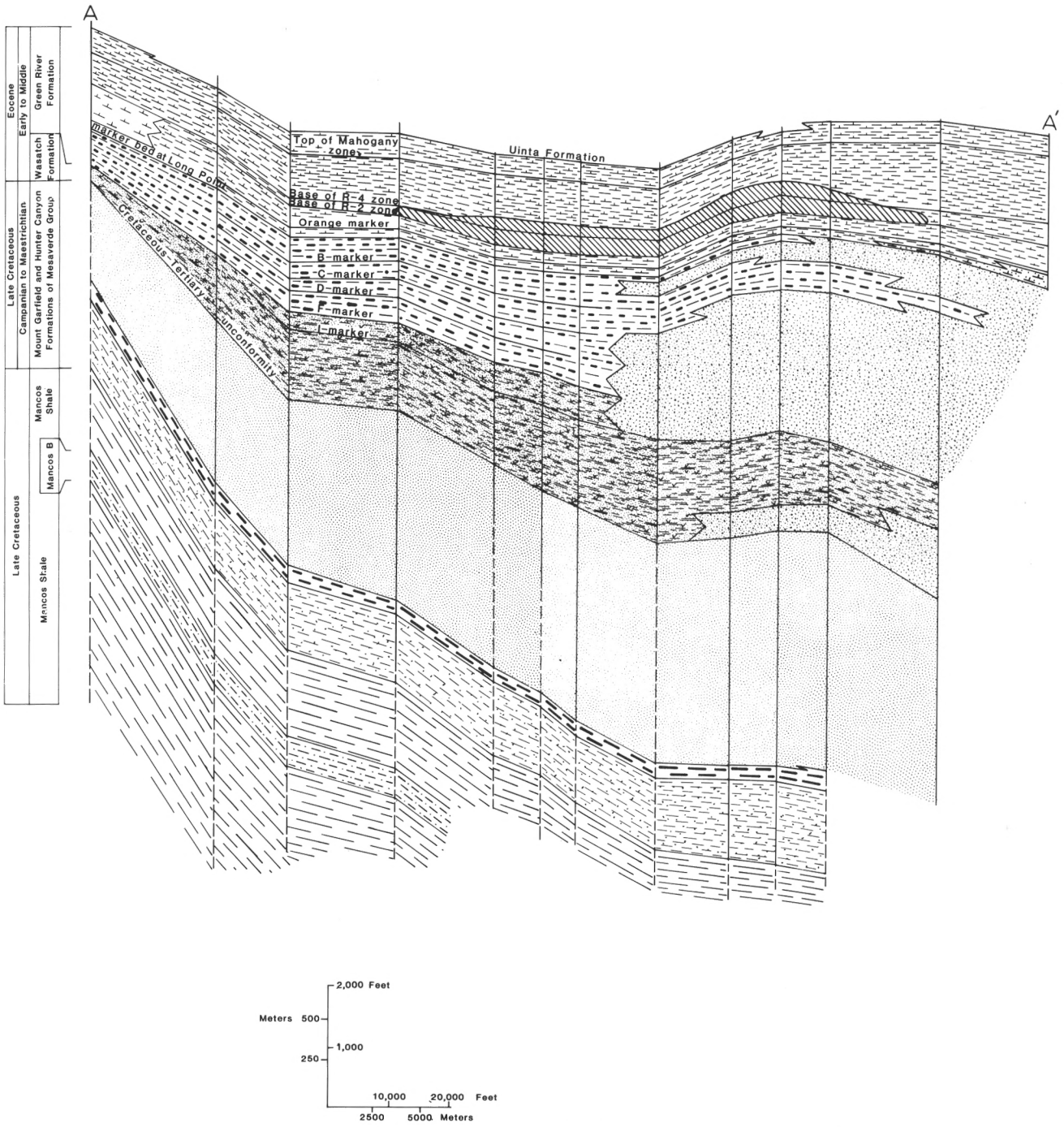
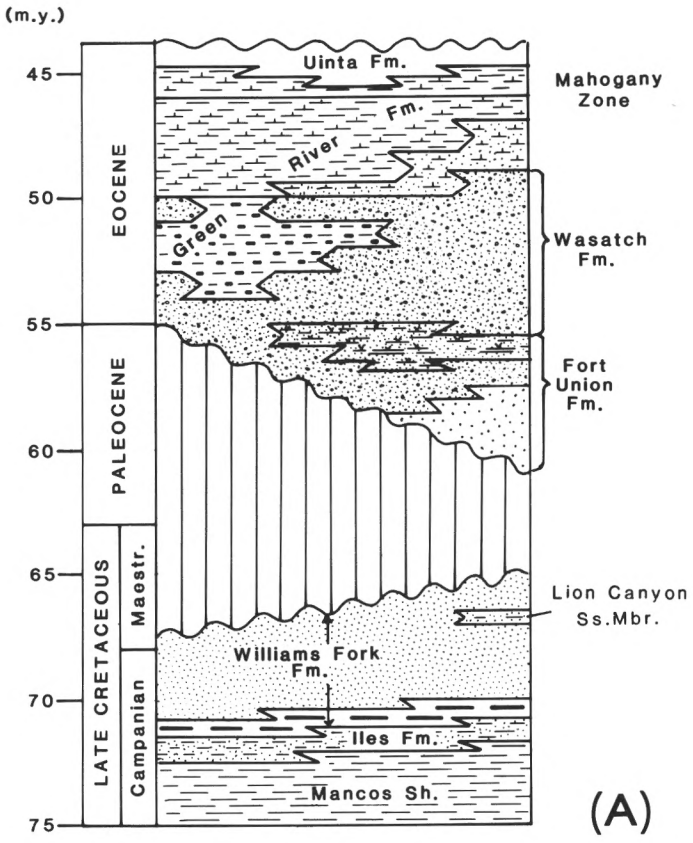


Figure 3. Generalized east-west cross section through the central part of the Piceance Creek Basin; modified from Johnson (1979). Key for cross section and correlation diagrams.



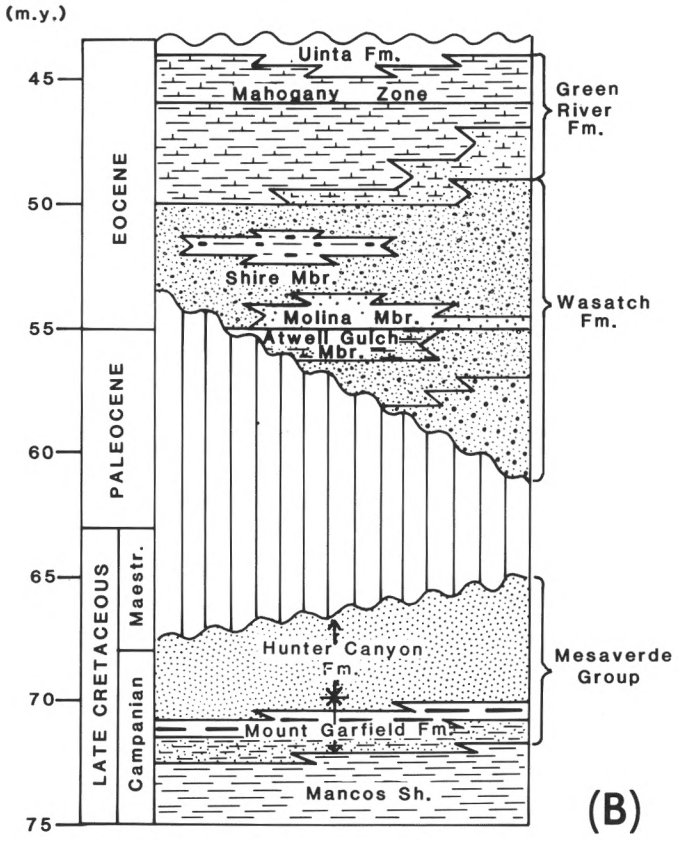


Figure 4. Correlation diagrams for the Piceance Creek Basin. **A,** *northern Piceance Creek Basin;* **B,** *southern Piceance Creek Basin.*

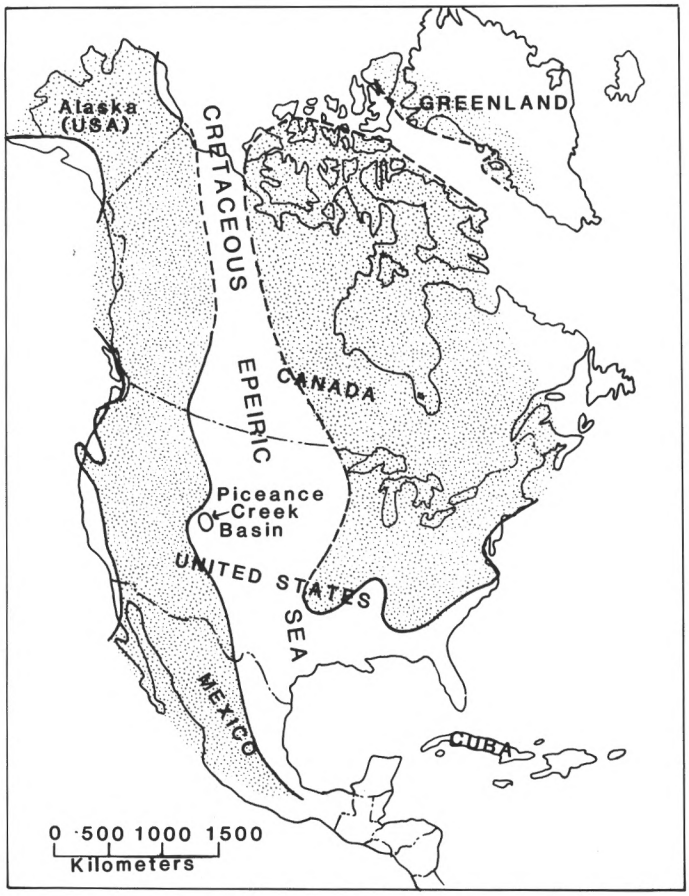


Figure 5. Approximate extent of Cretaceous epeiric sea during late Campanian time (from Obradovich and Cobban, 1976).

Cretaceous-Tertiary Unconformity

An unconformity between the Cretaceous and Tertiary sections probably is present throughout the basin. The youngest rocks below the unconformity are late Campanian to Maestrichtian (Johnson and others, 1980). The oldest rocks above the unconformity range in age from early to middle Paleocene in the northern and eastern parts of the basin (Hail, 1973; Newman, 1974), to late Paleocene and probably early or middle Eocene in the western and southwestern parts of the basin (Johnson and May, 1978). Several Laramide structures began to rise during this time, disrupting the old coastal-plain drainage system and establishing a new drainage system controlled largely by local uplifts.

The Cretaceous section beneath the unconformity is highly weathered, particularly in the southwestern part of the basin where a kaolinite-rich zone as much as 150 m thick is present (Johnson and May, 1980). Most of this weathering probably occurred prior to deposition of the unaltered overlying rocks. The amount of section removed by this period of erosion is unknown but much of the thinning of the nonmarine part of the Mesaverde from 1,400 m in the northeastern part of the basin to less than 600 m along the western margin (fig. 6) may be due to erosion at this time. Despite the evidence of intense weathering, local relief on the unconformity surface is minor, consisting only of shallow conglomerate-filled channels (Johnson and May, 1980). The kaolinitic zone formerly was called the Ohio Creek Formation and was thought to be Paleocene in age. The Ohio Creek recently was reduced in rank, its age and affiliation changed. It is a member of

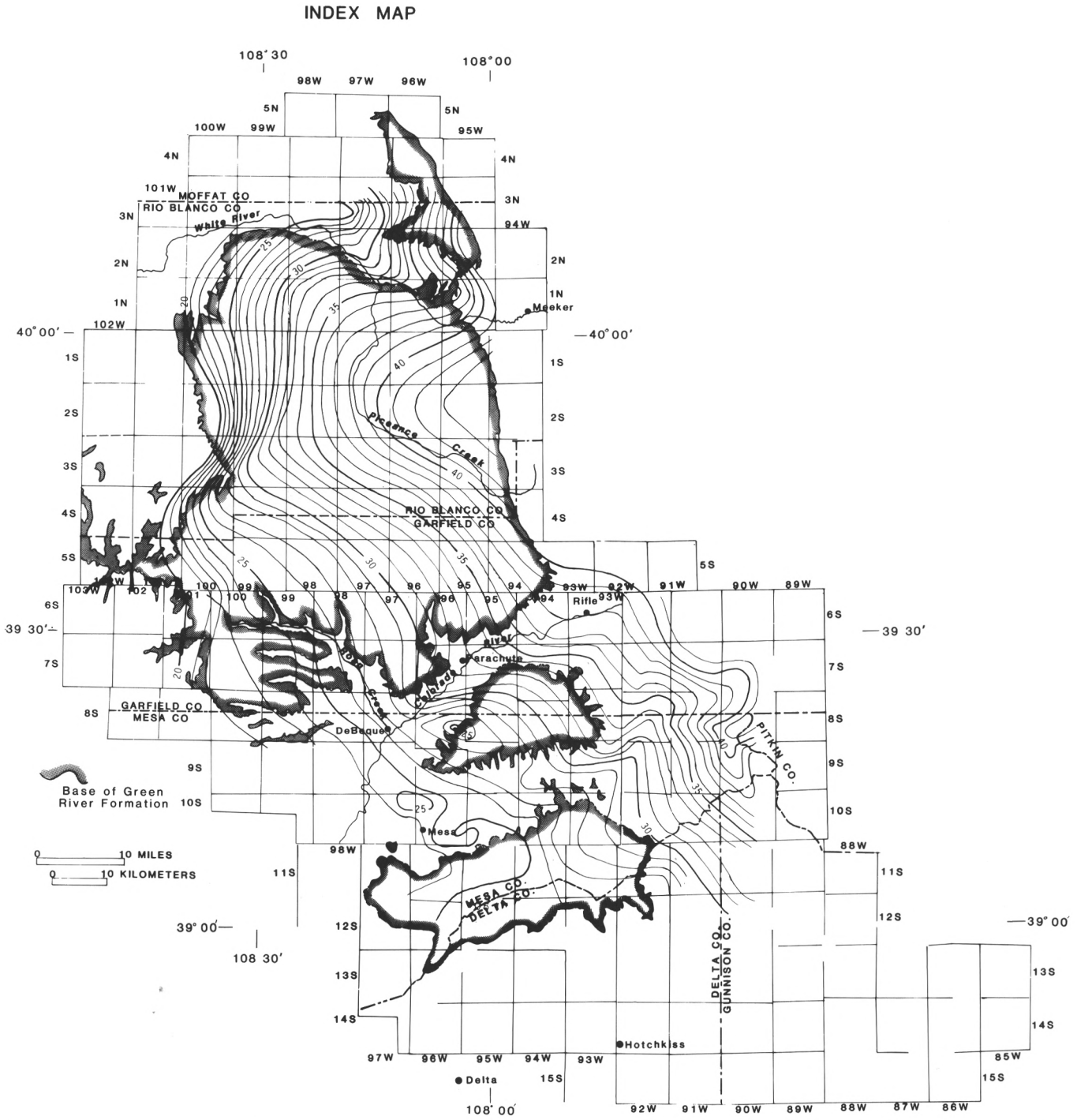


Figure 6. Isopach of the interval in the Mesaverde Group from the top of the Rollins (west) or Trout Creek Sandstone Member (east) to the Cretaceous-Tertiary unconformity. Modified from Granica and Johnson (1980). Contour interval, 100 ft (30.5 m).

the underlying Upper Cretaceous Hunter Canyon Formation or locally of the Mesaverde Formation (Johnson and May, 1980).

Paleocene

Sediments first began to accumulate on the unconformity in the eastern part of the basin in early or middle Paleocene, and spread westward, eventually burying the Douglas Creek arch on the western margin of the basin in early to middle Eocene time. Westward onlapping of Paleocene sediments on the unconformity has been noted in the southern part of the basin (Johnson and May, 1978), and also probably is responsible for the westward thinning of the lower member of the Fort Union Formation noted by Hail (1973, 1974) along the White River in the northern part of the basin.

Paleocene sediments represent the intensity of activity and the composition of surrounding Laramide uplifts. A thick sequence of coarse andesitic debris from the Sawatch uplift accumulated in the southeastern part of the basin. This unit, originally called the "Ruby beds" (Hills, 1890; Eldridge, 1894), and later included in the Wasatch Formation, is about 750 m thick at Ruby Peak in the southeasternmost part of the basin (Eldridge, 1894), but thins to

the north and is about 260 m thick at Rifle Gap. A sandstone section that ranges in thickness from 240 to 430 m, possibly derived from the Park Range to the northeast, is found at the base of the Fort Union Formation in the Meeker area in the northeastern corner of the basin. These sandstones pinch out to the west and southwest in the subsurface. Sandstones with sparse chert pebbles are found in the Fort Union at Fletcher Gulch in the northwestern corner of the basin. The Unita uplift to the northwest may have been the source area. The Paleocene section in the southwestern part of the basin is distinctly different. Onlapping of the Cretaceous-Tertiary unconformity occurred here in late Paleocene (Johnson and May 1978). However, with the exception of a thin basal chert and limestone-pebble conglomerate, the Paleocene section consists largely of gray to black shales with a few thin coals. The Uncompahgre uplift to the southwest was a positive feature during the Paleocene because sediments lap out on the Cretaceous-Tertiary unconformity to the southwest, but it was not a major source of coarse clastic sediments.

A paludal unit consisting mainly of dark-colored shales and thin coals with thin sandstones and siltstohes represents most of the Paleocene section in the central part of the basin (Johnson, 1979a, b, c) and the late Paleocene section around the margins of the basin (Hail, 1973, 1974; Pipiringos and Rosenlund, 1977; Johnson and May, 1978). Most of the early to middle Paleocene are coarse clastic units restricted to the margins of the basin and are overlain by upper Paleocene plaudal rocks.

Eocene

In early Eocene time, a permanent freshwater or near freshwater lake formed in the central and northwestern part of the Piceance Creek Basin. Deposits from this earliest stage of Lake Uinta are characterized by low-grade oil shale, ostracodal limestone, mollusk-bearing sandstone, and kerogen-rich shale interbedded with thin coals. One tongue of this deposit, as much as 60 m thick, extends as far south as the lower part of the Roan Creek drainage, just north of DeBeque (Johnson, 1975, 1977).

At about the same time that a permanent freshwater lake formed in the central part of the basin, a shift in deposition from paludal rocks to oxidized alluvial mudstone occurred around the basin's perimeter (fig. 3). Discontinuous sandstones are more common in these sequences than in the underlying paludal rocks of the late Paleocene, but sandstone still generally comprises less than 20 percent ot the section.

Clastic sediment entered the basin from at least two new directions during the Eocene, possibly indicating activity on uplifts that were not present, or were inactive, during the Paleocene. A thick pile of variegated mudstone and sandstone was deposited along the eastern margin of the basin (fig. 3), suggesting that the White River uplift began to rise during Eocene time. Farther basinward, a thick sandstone sequence was deposited along the eastern margin of Lake Uinta. More sandstone was deposited in this area of the lake than in any other.

A sand-dominated fluvial deposit as much as 150 m thick is found at approximately the base of the Eocene section in the southwestern part of the basin. This unit, named the Molina Member of the Wasatch Formation (Donnell, 1969), contains chert pebble lenses and is interpreted to be a braided-stream deposit (Johnson and May, 1978). The unit is in sharp contact with the underlying paludal rocks of late Paleocene age and grades upward into variegated mudstones. The Molina Member also grades laterally into variegated mudstones to the north, northeast, and east, and probably was deposited by streams flowing off the Uncompahgre uplift to the southwest. This is the only coarse clastic sequence in the Tertiary section that apparently had a southwestern source, despite the fact that several intervals in the Late Cretaceous and Tertiary thin toward the southwest (figs. 2,6,7).

Lake Uinta expanded rapidly to cover most of the basin in the late early to early middle Eocene. This transgression is marked throughout much of the basin by a distinctive gastropod-rich marker bed called the marker bed at Long Point (Johnson and May, 1978). Salinity began to increase after the transgression and eventually led to the precipitation of great quantities of nahcolite, dawsonite, and halite. These saline minerals were precipitated both on the lake floor and in the unlithified lake sediments (Dyni, 1974; Beard and others, 1974). Kerogen content of the sediments is much greater than in the earlier freshwater stage, and all the economically important oil shale is found in rocks of this age.

In the middle to late Eocene, a delta consisting largely of volcaniclastic debris prograded southward across the basin (Surdam and Stanley, 1980; Johnson, 1981), filling in the Piceance Creek Basin part of Lake Uinta. This deltaic complex, named the Uinta Formation, is the youngest stratigraphic unit preserved in the Piceance Creek Basin.

RESOURCES

Oil Shale

The shale-oil resource potential of the Green River Formation has been of interest for many years and has been discussed in several publications (Donnell, 1961; Donnell and Austin, 1971; Donnell and Blair, 1970; Keighin, 1975; Pitman, 1979; Pitman and Donnell, 1973; Pitman and Johnson, 1978). In general, Green River oil shale is a very fine-grained, carbonate-rich rock containing high but variable quantities of kerogen, which yields oil when subjected to destructive distillation. The center for oil-shale deposition is the north-central part of the basin, where there is as much as 550 m of nearly continuous oil shale (figs. 7,8). Rich oil shale is in two members of the Green River Formation, the older Garden Gulch member, which contains abundant clay, and the younger Parachute Creek member, which contains abundant saline minerals and more carbonate and authigenic feldspars than the Garden Gulch Member (Robb and Smith, 1974). In the center of the basin, the Garden Gulch Member extends from the marker bed at Long Point to the base of the R-2 oil-shale zone (fig. 3), and the overlying Parachute Creek Member extends up to the base of the Uinta Formation. Both members grade toward the basin margins into marginal lacustrine sandstone, mudstone, and limestone of the Anvil Points and Douglas Creek Members of the Green River. Both the Garden Gulch and the Parachute Creek contain significant oil-shale deposits; however, the Parachute Creek member has attracted the most attention, primarily because it is thicker and the overburden is less. Both members have been subdivided into persistent rich and lean oil-shale zones (fig. 8). Many of these time-stratigraphic zones can be traced into the Uinta Basin to the west (Cashion and Donnell, 1972). The richest and most widespread of these zones is the Mahogany zone (or Mahogany ledge in surface exposures). This is one of the few oil-shale zones that is rich enough to be mined on outcrop (fig. 9).

The mineralogy of the Green River oil shale is moderately complex and is variable throughout the oil-shale interval (Brobst and Tucker, 1973; Desborough and Pitman, 1974; Robb and Smith, 1974). The nonorganic fraction consists of variable quantities of dolomite, calcite, quartz, potassium and plagioclase feldspars, analcime, nahcolite, dawsonite, pyrite, and clay minerals, primarily illite. Study of oil shales by X-ray diffraction and scanning electron

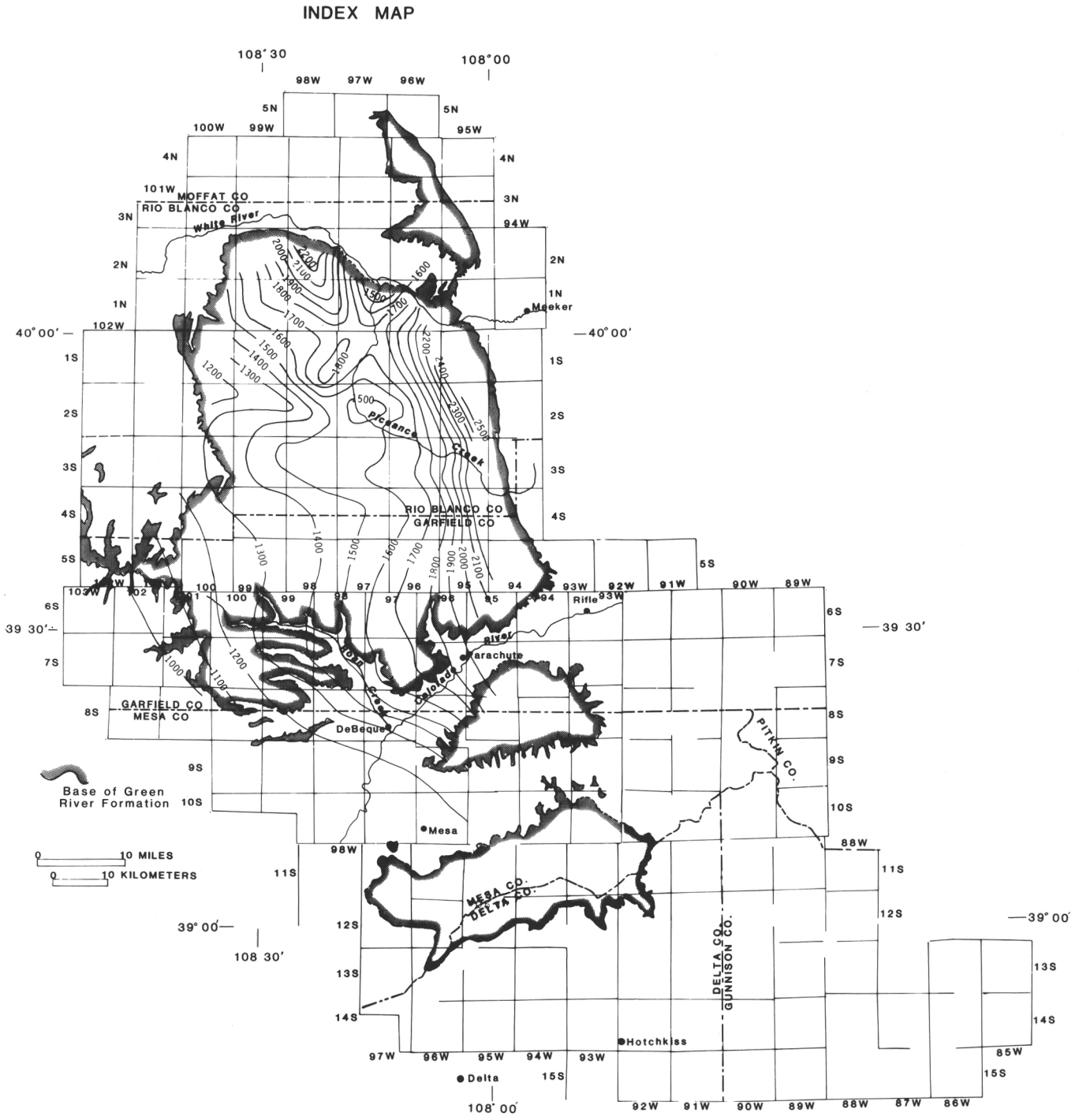


Figure 7. Isopach of the interval in the Green River Formation from the base of the bed at Long Point in the Douglas Creek Member, to the top of the Mahogany zone. Note general east-northeast thickening trend. Rapid thickening in the northern and eastern parts of the basin are due to clastic influxes. Contour interval, 100 ft (30.5 m).

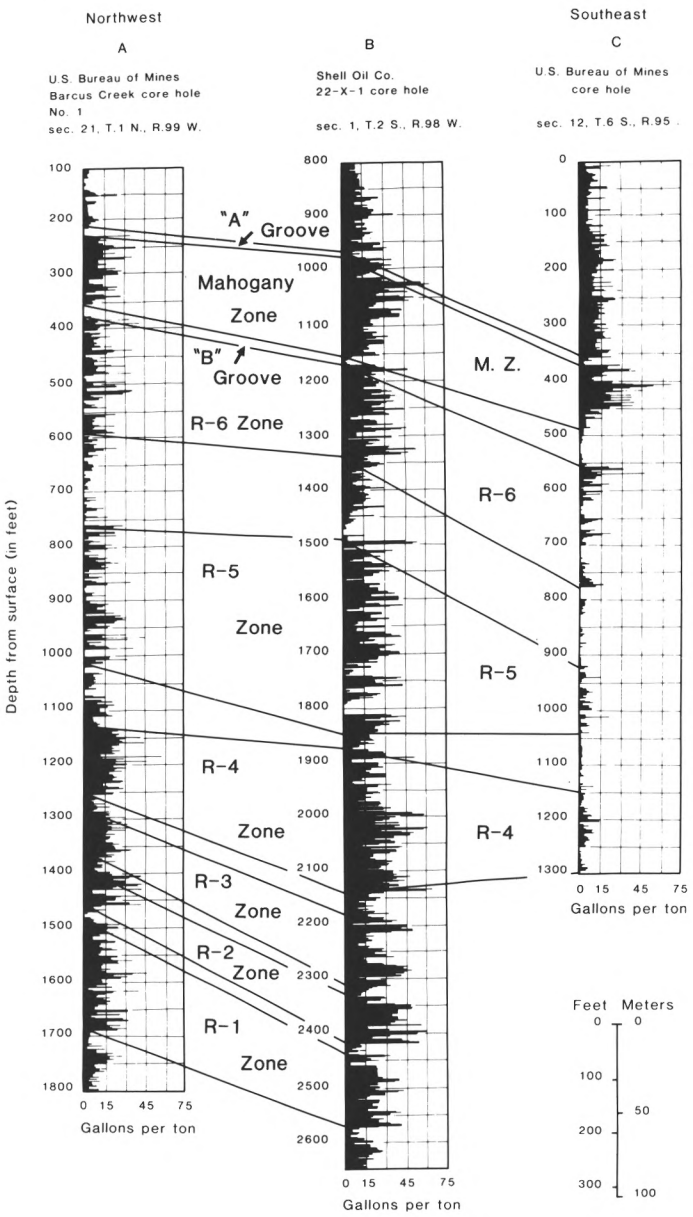


Figure 8. Northwest-southeast cross section showing oil-yield histograms of lower part of the Parachute Creek Member of the Green River Formation, and correlation of rich oil-shale zones labeled R-1 to R-6 and Mahogany zone. Location of core holes is shown in Figure 2 as B-B'.

microscopy demonstrates that most of the feldspars, and many of the other minerals, are authigenic. The nature and distribution of some of these minerals within a sample of oil shale are illustrated in Figure 10. Knowledge of the mineralogy and mineral distribution in the oil shale is important for planning the economic potential of the resources. For example, Ca-Mg-Fe carbonates, when associated with sodium bicarbonates, act as a flux during retorting, and have a significant effect on the thermal requirements for retorting (Desborough and Pitman, 1974). Some minor and trace elements may be deleterious if leached from spent shale; knowing the residence(s) of these elements is desirable.

In beds greater than 3.1 m thick and yielding 25 gallons (100 l) or more of oil per ton, there are an estimated 471 billion barrels of oil in place (Keighin, 1975). Work is in progress on evaluating, on a zone by zone basis, oil-shale resources (Pitman and Johnson, 1978; Pitman, 1979).

Saline Minerals

A saline facies of the Green River Formation is present in the central part of the Piceance Creek Basin (fig. 9) that contains nahcolite ($NaHCO_3$), dawsonite ($NaAl(OH)_2CO_3$), and halite associated with oil shale. The saline facies is found in the lower part of the Parachute Creek Member of the Green River Formation (fig. 3). It is overlain by a leached zone as much as 200 m thick (Hite and Dyni, 1967; Dyni, 1974; Beard and others, 1974) in which most of the nahcolite and halite have been leached by ground water. At the saline depocenter of the basin (eastern part of T. 1 S., R. 98 W.), the thickness of nahcolite-bearing oil shale reaches a maximum of approximately 345 m and is overlain by 430 to 600 m of overburden (Dyni, 1974, p. 112). Nahcolite occurrence is variable, and ranges between nonbedded crystalline aggregates and coarse-grained beds.

Nahcolite could serve as a raw material for a number of basic industrial chemicals, although this market is now dominated by the trona industry of Wyoming. Of more immediate potential value is the use of nahcolite to remove SO_2 from powerplant stack gases. Beard and others (1974, p. 108) estimated that approximately 29 billion tons of nahcolite are within the Piceance Creek Basin.

Dawsonite, a potential source of alumina, is associated with nahcolite. It is not easily leached by ground water and therefore has a somewhat greater lateral and vertical distribution than nahcolite or halite. Dawsonite is disseminated throughout an oil-shale matrix as fine crystals (Beard and others, 1974), where it may account for as much as 25 percent of the rock. Approximately 19 billion tons of dawsonite are estimated to be present in the Piceance Creek Basin (Beard and others, 1974, p. 108).

Other Commodities

Other major resources found in the Piceance Creek Basin include gas and oil from both the Cretaceous and Tertiary and coal from the Cretaceous. These resources are discussed by others in this guidebook and will be discussed here only briefly. Most sandstones in the Late Cretaceous appear to be capable of producing some gas over large areas of the basin. Major factors that have restricted development are, (1) limited size of individual reservoirs, (2) low permeability, (3) drilling depth, and (4) local water-bearing reservoirs. Structure does not appear to have a major influence on gas accumulation (fig. 11); however, reservoir permeability is generally better on structural highs and closures. The nonmarine part of the Mesaverde Group probably contains the greatest in-place gas reserves, but sandstones are discontinuous and reservoir quality is low. Sandstones in the marginal marine part of the Mesaverde are more persistent and generally have slightly better permeability. These reservoirs have been extensively developed in the southern part of the basin, in areas where the drilling depth is not too great.

Occurrence of gas at shallow drill depths has also contributed to the development of the "Mancos B," a silty and sandy zone in the Mancos Shale (Kellogg, 1977). The unit has been extensively developed in the western part of the basin on and adjacent to the Douglas Creek arch, where drilling depths are generally less than 1,500 m. The Dakota Sandstone is too deep throughout most of the basin to have attracted much attention thus far; however, production has been established in isolated areas throughout much of the southwestern and western parts of the basin, and areas of production are actively being extended. Drilling depth to the Dakota in this area ranges from about 2,000 to 3,000 m.

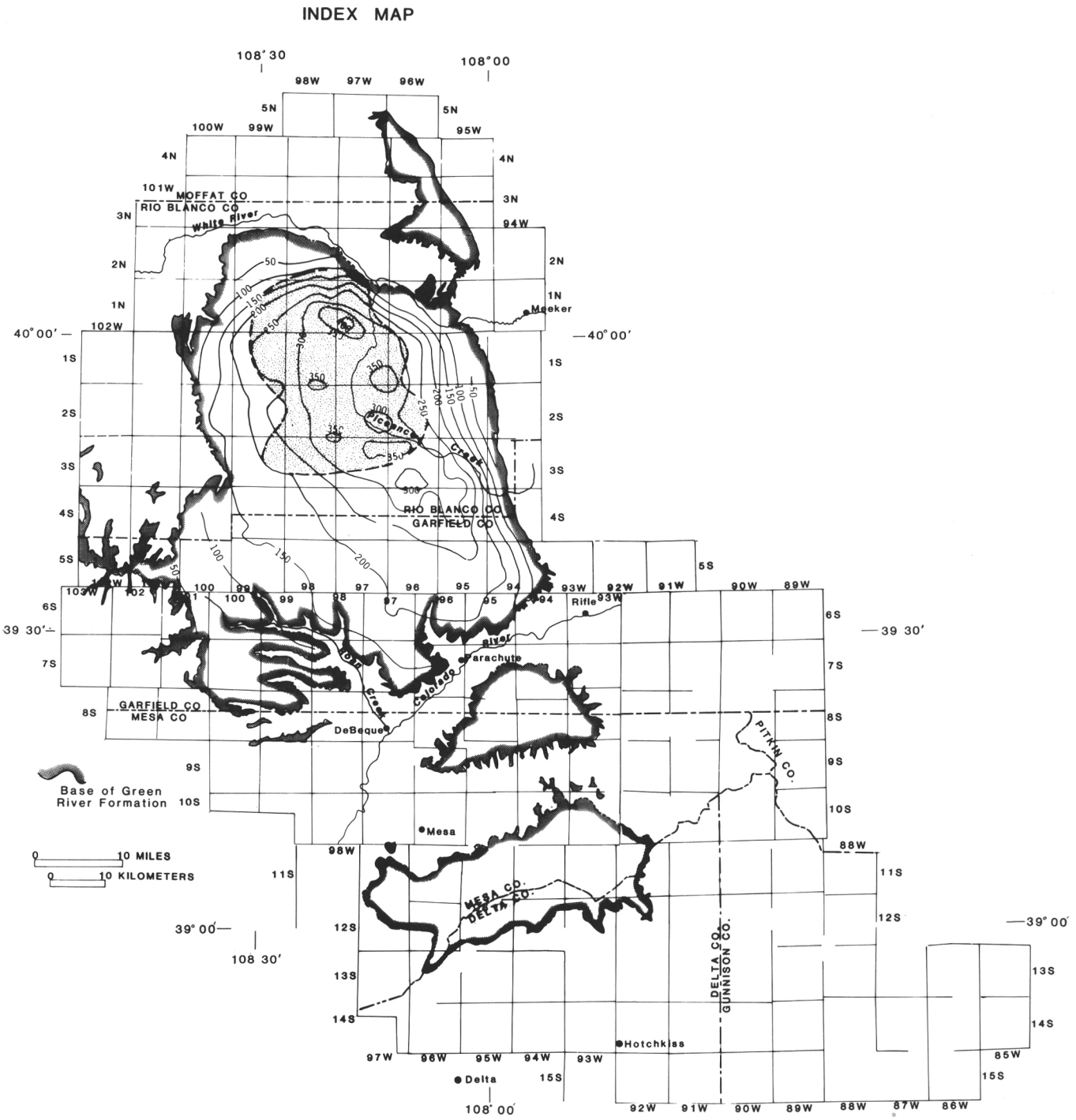


Figure 9. In-place oil resources for the Mahogany zone in barrels per acre. Contour interval, 50,000 barrels per acre. From Pitman and Johnson (1978). Stippled area is approximate limit of nahcolite occurrence (from Beard and others, 1974).

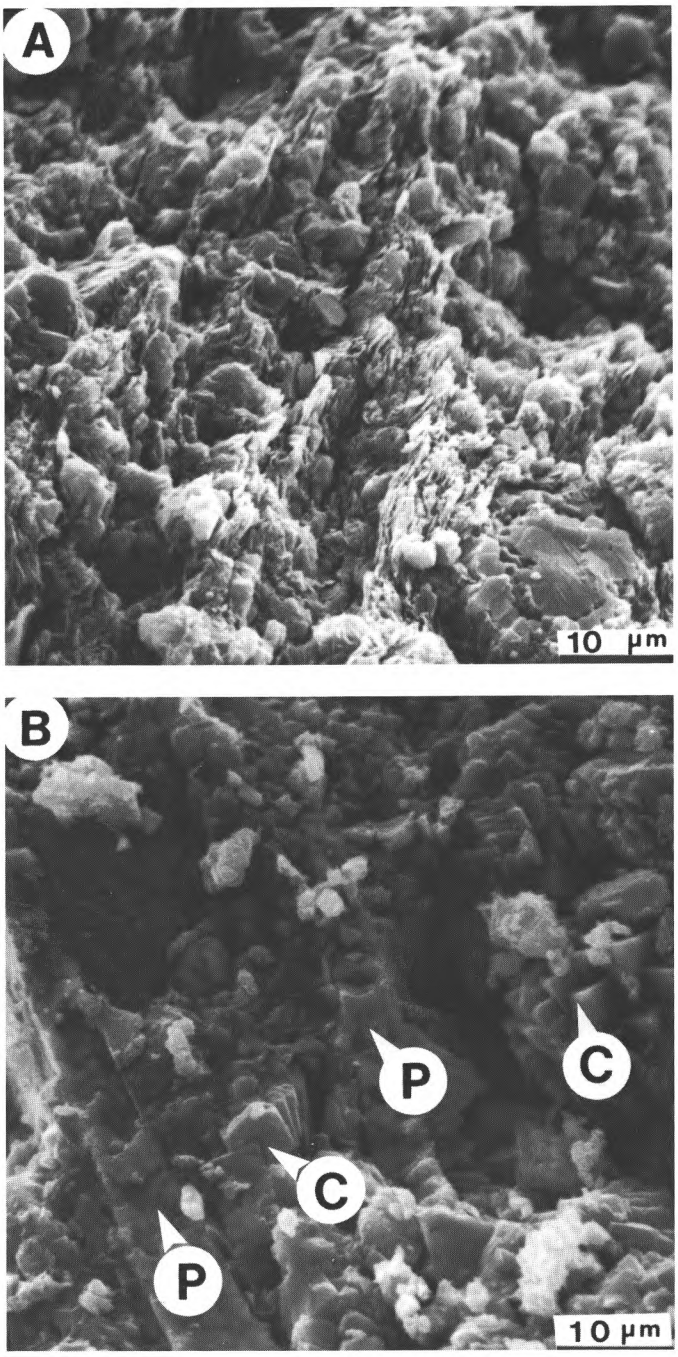


Figure 10. Scanning electron micrograph of oil shale that yields 25 gallons of oil per ton. **A,** *Intimate mixture of very fine grained detrital, platey kerogen and clays, and euhedral to subhedral authigenic minerals;* **B,** *high concentration of authigenic minerals: P, iron sulfide (pyrite?) and C, calcite.*

Tertiary gas and oil production has been established in the central part of the basin from the marginal lacustrine sandstone of the Douglas Creek Member of the Green River Formation, and in the Wasatch Formation, with most production coming from fluvial sandstones between the F and the I marker (fig. 3). Farther to the south, along the Colorado River, production recently has been established in the Molina Member of the Wasatch Formation.

Cretaceous coals have been mined in many parts of the basin where the marginal marine-fluvial transitional part of the Mesaverde Group crops out.

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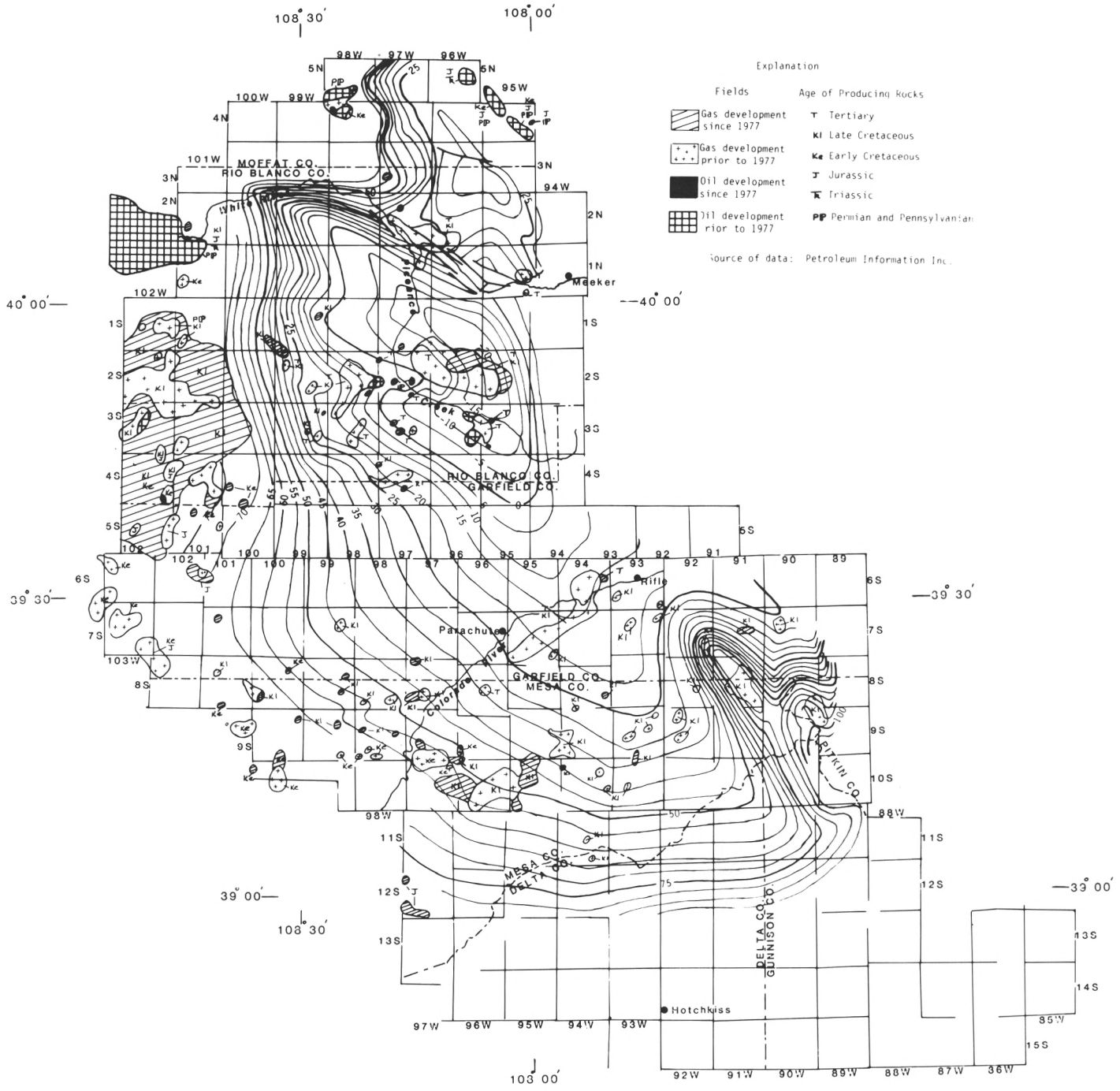


Figure 11. Oil and gas fields in the Piceance Creek Basin. Structure contours are on the Cretaceous-Tertiary unconformity, and are modified from Granica and Johnson (1980). Contour interval, 500 ft (152 m).

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