# *What happed during Late Cretaceous time in the Raton and San Juan Basins--With some thoughts about the area in between*

James E. Fassett

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# WHAT HAPPENED DURING LATE CRETACEOUS TIME IN THE RATON AND SAN JUAN BASINS- WITH SOME THOUGHTS ABOUT THE AREA IN BETWEEN

JAMES E. FASSETT
U.S. Geological Survey
P.O. Box 959, Farmington, New Mexico 87401

## INTRODUCTION

The Raton and San Juan basins are in northern New Mexico and southern Colorado (Fig. 1); the Raton straddles the state line and the San Juan is mostly in northwest New Mexico. Both structural basins are asymmetric: the Raton has a steeper, east-dipping, west flank and the San Juan has a steeper, west-dipping, east flank. The structural axis of the Raton basin is arcuate and trends from northeast in New Mexico and northwest in Colorado; the axis of the San Juan basin trends northwest. In this paper the Raton basin is defined (Fig. 1) by the outcrop of the youngest marine sandstone (Trinidad Sandstone) and by the overlying Vermejo Formation. The San Juan basin is outlined by the outcrop of the marine Pictured Cliffs Sandstone. The distance between the basins from the westernmost outcrop of the Trinidad and Vermejo, to the easternmost outcrops of the Pictured Cliffs is about 90 miles (145 km).

The basins are presently separated by a structurally complex area—the Chile High—including fault-block mountains, grabens, platforms and embayments. Passing west from the Raton basin to the San Juan basin, the major structural elements traversed are the Sangre de Cristo Mountains (fault-block range), the San Luis-Espanola basin (part of the Rio Grande graben), the Chama basin and the San Pedro-Jemez uplift (Kelley, 1954). Most of these tectonic elements trend north. Physiographically, the area between the basins is the south part of the Southern Rocky Mountain Province (Fenneman, 1946).

Both the Raton and San Juan basins contain sedimentary rocks ranging in age from Paleozoic through Mesozoic to

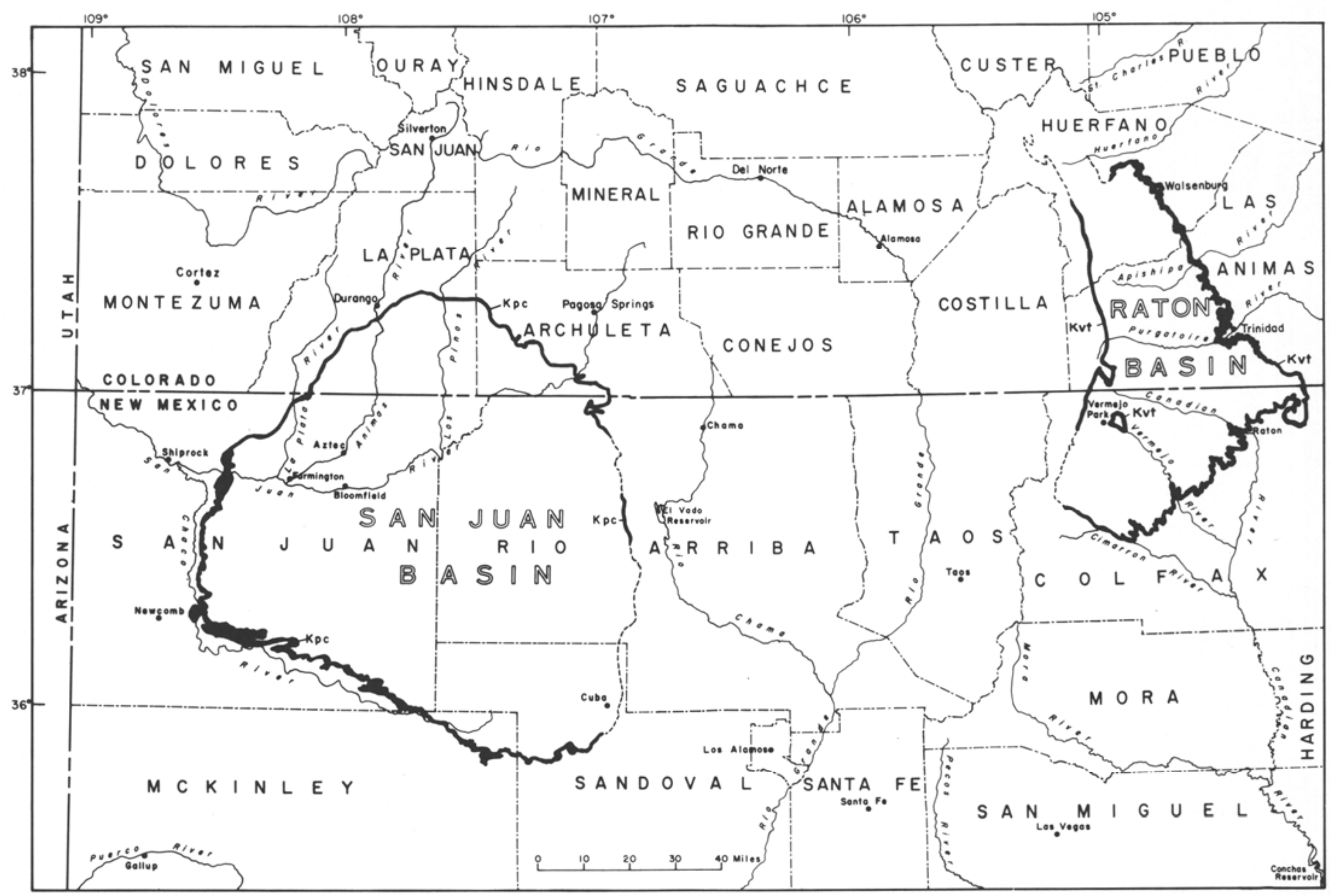


*Figure 1. Map showing locations of the Raton and San Juan basins. Kpc—Pictured Cliffs Sandstone; Kvt—Vermejo Formation and Trinidad Sandstone, undivided; all of Late Cretaceous age.*

Cenozoic. In the Raton basin the oldest known sedimentary rocks, as revealed by electric logs, are Pennsylvanian in age; in the San Juan basin the oldest sedimentary rocks are Cambrian. The total thickness of Cambrian and younger sedimentary rocks in the Raton basin is 8,000+ ft (2,440 m) and in the San Juan basin, 14,000+ ft (4,270 m) (Jensen, 1972).

## UPPER CRETACEOUS STRATIGRAPHY

Lower Cretaceous sedimentary rocks occur in both the Raton and San Juan basins; however, only the Upper Cretaceous sedimentary rocks of these basins will be discussed. During Late Cretaceous time the North American continent was bisected by an epeiric seaway about 1,000 miles (1,610 km) wide and about 3,000 miles (4,830 km) long (Fig. 2). The lithologic unit most commonly associated with the encroachment of this sea onto the continent is the Dakota Sandstone. The Dakota in the Raton basin is a "... complex suite of coastal plain fluvial, marginal marine dune-beach, and shallow marine beach-bar-deltaic environments" (Kauffman and others, 1969, p. 110). The Dakota of the San Juan basin, on the other hand, varies from almost entirely marine in the southeastern part to almost entirely nonmarine in the northwest (Owen, 1973). The Dakota Sandstone is of Early and Late Cretaceous age in the Raton basin and of Early (?) and Late Cretaceous age in the San Juan basin.

Once the shoreline of the Western Interior seaway transgressed beyond the Raton basin and reached its maximum

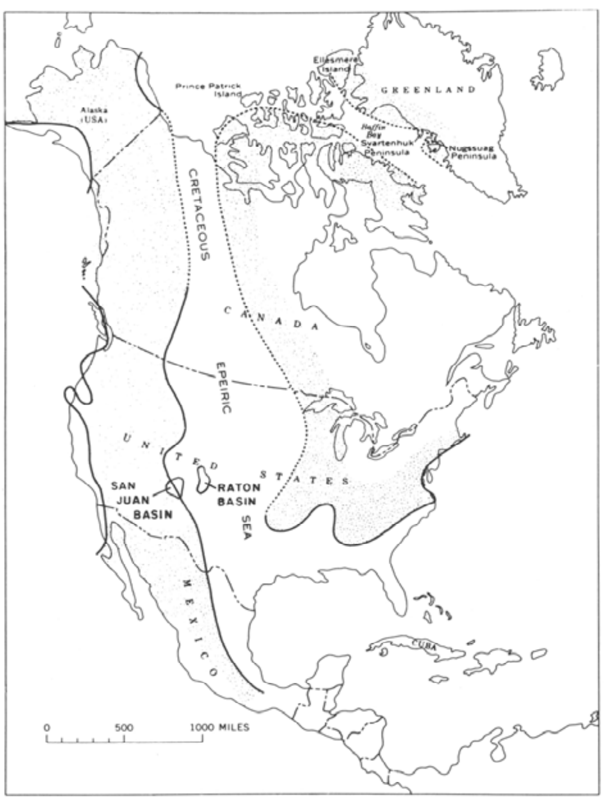


*Figure 2. Western Interior seaway during Late Cretaceous time showing the locations of the Raton and San Juan basins. (After Gill and Cobban, 1966, fig. 15).*

western limit, it did not return again to the Raton basin until perhaps 22 m.y. later, the time interval between the early Cenomanian and late Campanian-early Maastrictian (Obradovich and Cobban, 1975, table 1). At the time of maximum extent of the seaway, deposition of siliceous sand-size sediment in the Raton and San Juan basins was, with the exception of one brief period, almost nonexistent. During this time, the shale and carbonates of the Graneros, Greenhorn and Carlile formations of the Raton basin and of the Graneros, Greenhorn and (lower) Mancos formations of the San Juan basin were deposited. The Raton basin was then located in (Fig. 1) the "outer shelf," where pure carbonate muds and clayey carbonate muds were deposited (Kauffman and others, 1969). The San Juan basin was then located in the "midshelf" where dark clay muds were laid down.

## CODELL AND SEMILLA SANDSTONES

In both basins a break in the deposition of clay-size clastics and carbonate rocks occurred with deposition of the Codell Sandstone Member of the Carlile Shale in the Raton basin and the Semilla Sandstone Member of the Mancos Shale in the San Juan basin. Codell lithologies (Kauffman and others, 1969, p. 106) range from thin-bedded sandy shale to more massive fine-to medium-grained siliceous sandstone to "carbonaceous sandy shale and shaly sandstone." It thickens from 0 to 70 ft (0 to 21 m) and becomes coarser westward across the Raton basin. The Semilla (Dane and others, 1968) is composed of siltstone and fine-grained sandstone at the base and medium-grained, massive sandstone ledges at the top. The sandstone is arkosic, containing 20 to 30 percent of subangular to angular grains of feldspar. The Semilla ranges from 0 to 70 ft (0 to 21 m) in thickness and has northwest dipping crossbeds.

During deposition of the Codell and Semilla Members, the shoreline of the Western Interior seaway was located from 100 to 300 miles (160 to 480 km) to the west or southwest (McGookey and others, 1972). Dane and others (1968, p. F13) stated for the Semilla that "... there must have been a local source not far to the southeast." Kauffman and others (1969) stated that the Codell grades "... upward into flat bedded units probably representing beach and forebeach cross-bed sets, and finally to highly carbonaceous, locally coaly, densely burrowed sandy shale and shaly sandstone of probably mud flat and coastal marsh-lagoon margin" and that "Association of coaly layers in and above the marine Codell sands at various localities suggests emergence...." Though Kauffman and others (1969) never quite suggest a nearby western source area for the Codell, they imply this. If the Codell had a western source and the Semilla a southeastern source, presence of middle Carlile island highlands between the present Raton and San Juan basins is implied.

Molenaar (1973) suggested that the Semilla Sandstone Member is equivalent in age to the Atarque Member (lower part) of the Gallup Sandstone. This indicates that during the lower Gallup regression the shoreline was just east of the Arizona-New Mexico state line near Gallup, New Mexico, at about the time that the Codell and Semilla source-highlands had emerged in north-central New Mexico. The easternmost pinchout edge of the regressive marine sandstone of the lower Gallup (Molenaar, 1973) is about 90 miles (145 km) from the westernmost pinchout edge of the Semilla; however, Molenaar (oral commun., 1976) prefers a wave-current origin for the quartz sandstone of the Codell and Semilla Members which would require carrying these sediments across the flat shallow shelf from their shoreline source many tens of miles to the west.

## JUANA LOPEZ MEMBER

The Upper Cretaceous Juana Lopez Member is one of the most laterally persistent and lithologically distinctive divisions of the Mancos Shale in northwestern New Mexico and southwestern Colorado and of the upper part of the Carlile Shale in central and southeastern Colorado and northeastern New Mexico" (Dane and others, 1966, p. 111). The Juana Lopez throughout the Raton and San Juan basins consists of thin beds of calcarenite interlayered with thicker beds of gray to black marine shale. The calcarenite grains consist largely of broken and worn fragments of shell material, primarily fragmented *Inoceramus* prisms. The fossil hash also contains minor amounts of broken oyster shells, worn fish teeth and bone fragments, and fragments of other invertebrates.

The basal contact of the Juana Lopez in the Raton basin represents "... a major erosional disconformity of probably marine origin" (Kauffman and others, 1969, p. 106), whereas in the San Juan, "The contact between the Juana Lopez and the underlying Mancos Shale is gradational and conformable" (Dane and others, 1966, p. H10). According to Kauffman and others (1969), the thickness of the Juana Lopez ranges from 3 to 5 ft (1.0 to 1.5 m) in the Raton basin; however, Pillmore and Eicher (this Guidebook) found the Juana Lopez to be 26 ft (8 m) thick in a measured section at Gold Creek, Colfax County, New Mexico. In the San Juan basin the Juana Lopez ranges from 90 to 135 ft (27 to 41 m) in thickness (Dane and others, 1966). The Juana Lopez is primarily shale where it reaches its maximum thickness.

During deposition of the Juana Lopez in the Raton basin, practically no clastic material was being deposited, and "Faunal zones indicate as much as two million years of time were involved in deposition of the three- to five-foot unit" (Kauffman and others, 1969, p. 116). In the San Juan basin, where this unit averages 100 ft (30 m) thick and consists of two or three thin-bedded calcarenite zones separated by shale, clay-size material apparently was swept onto the shelf area in one or two pulses. The Juana Lopez of the San Juan basin area correlates directly with the nonmarine portion of the Atarque Member of the Gallup Sandstone in the Acoma basin (Molenaar, 1974).

Following the maximum regression of the lower Gallup (Atarque Member), which moved the Western Interior shoreline just east of the Arizona-New Mexico state line near Gallup, New Mexico, there was a long period during which the shelf area of the Raton and San Juan basins was flat and extremely stable; the sea was relatively shallow; and very little clastic sediment was deposited. At that time there was a "... landward gradation of this environment to a mud flat shoreline where wave energy was minimal due to the shallow sea, and hence, the lack of coastal barrier sand development" (Molenaar, 1973, p. 94). Apparently little or no tectonic uplift occurred to the southwest in the source area, with little clastic material being furnished to the Juana Lopez sea.

## TRINIDAD AND PICTURED CLIFFS FORMATIONS

Following deposition of the Juana Lopez Member, the similarities in the depositional history of the Raton and San Juan basins ended for the next 20 m.y. (Obradovich and Cobban, 1975). In the Raton basin, deposition of offshore marine limestone and shale, represented by the upper shale member of the Carlile Shale, the Niobrara Formation and the Pierre Shale, resulted in the accumulation of about 3,000 ft (914 m) of sediment. At the same time, in the San Juan basin, the Western Interior shoreline retreated and advanced repeatedly, resulting in deposition of a complex series of interbedded marine and continental sediments up to 5,000 ft (1,524 m) thick. These sediments extend from the top of the Juana Lopez to the base of the Trinidad Sandstone and Pictured Cliffs Sandstone, as determined from electric logs in the Raton and San Juan basins. Obviously, the subsidence of the San Juan basin must have been faster than that of the Raton basin area during this 20 m.y. period.

Many workers have studied the classic transgressive and regressive deposits of the San Juan basin. Sears, Hunt and Hendricks (1941) proposed that shoreline fluctuations in early Mancos time, represented by the Gallup Sandstone, Dalton Sandstone Member of the Crevasse Canyon Formation and Hosta Tongue of the Point Lookout Sandstone between Gallup and Albuquerque, New Mexico, resulted from a variation in the amount of sediment supplied to the western edge of a subsiding seaway. An increase in sediment influx filled and pushed the shoreline seaward; whereas, a decrease in sediment supply allowed the shoreline to advance landward. Subsequent work on the stratigraphy of the rocks of the Upper Cretaceous San Juan basin has substantiated this hypothesis.

A brief summary of the major geologic events which resulted in deposition of Upper Cretaceous transgressive-regressive complex of the San Juan basin is given in Figure 3. Following the lower Gallup regression, the main Gallup regression occurred, moving the Western Interior shoreline northeast to a line running between Albuquerque and Shiprock. Following this regression, there was uplift and erosion (probably subsea) in the northeast San Juan basin followed by a transgression to the southwest (the Mulatto transgression). Scattered, discontinuous sandbar deposits variously referred to as the Tocito Sandstone Lentil of the Mancos Shale, basal Niobrara Formation and transgressive Gallup Sandstone were deposited. Following this transgression, a short cycle of regression-transgression occurred, during which the Dalton Sandstone Member and the Hosta Tongue Sandstone were deposited. Following these events, the most extensive regression prior to the final regression occurred and the Point Lookout Sandstone was deposited. At that time, the shoreline shifted northeastward, with a northwest orientation, nearly to Pagosa Springs, Colorado. The final transgression then occurred, depositing the Cliff House Sandstone with its associated La Ventana Tongue. This shift carried the shoreline back to near Newcomb, New Mexico, about midway between Gallup and Shiprock. The final regression of the sea laid down the Pictured Cliffs Sandstone.

During this time, the Raton basin was continuously accumulating a thick, unbroken sequence of limestone and shale far to the northeast. Throughout the Juana Lopez, Pictured Cliffs and Trinidad intervals, there is little evidence of activity between the two areas. Perhaps this lack of evidence is the result of insufficient detailed studies of the rocks adjacent to this area. With the beginning of the Pictured Cliffs-Trinidad regression, the two basins were about to be connected stratigraphically for the last time.

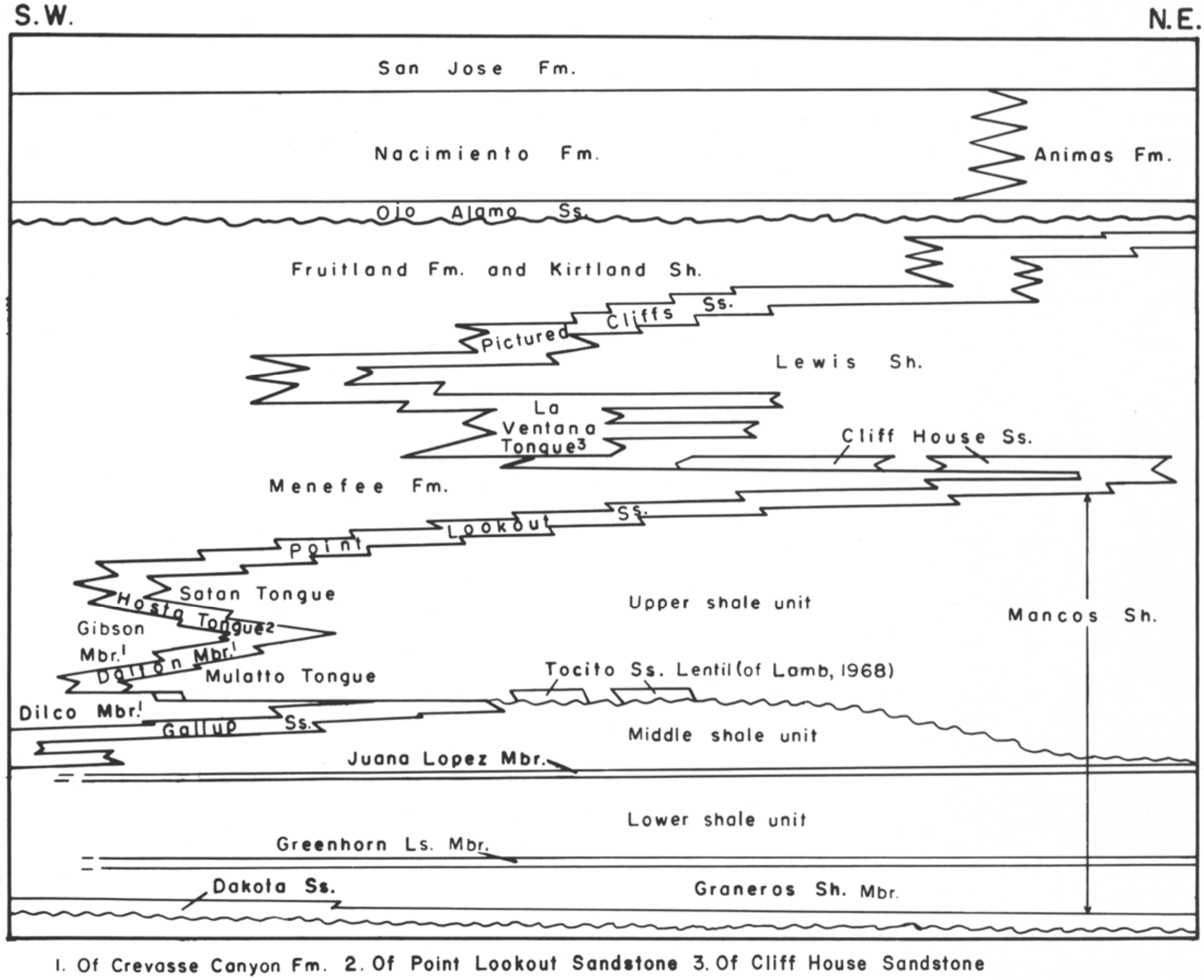


*Figure 3. Diagrammatic stratigraphic cross section of Cretaceous and Tertiary rocks of the San Juan basin. Cretaceous-Tertiary boundary generally at top of Kirtland Shale. Vertical exaggeration about X 150 (Fassett, 1974).*

## PICTURED CLIFFS AND TRINIDAD FORMATIONS

Following the Cliff House-La Ventana Sandstone transgression, the shoreline retreated a few tens of miles west of the southwesternmost outcrop of the Pictured Cliffs Sandstone (Fig. 1) (Fassett and Hinds, 1971). As the shoreline moved northeastward, it rose stratigraphically about 1,100 ft (335 m). This regression was not continuous and even, but was interrupted by pauses or even minor transgressions of the shoreline. In the north-central part of the basin the Pictured Cliffs attained a thickness of 300 ft (91 m). The shoreline transgressed to the southwest more than 17 miles (27 km) before it finally retreated out of the present basin.

During regression of the Pictured Cliffs sea, the shoreline orientation was generally northwest, but it varied considerably from nearly east to about N. 45° W. The shoreline, with minor exceptions, appeared to be relatively straight and showed little evidence of deltaic sedimentation, indicating that long-shore currents kept sand evenly distributed along the shoreline.

Uplift may have occurred southeast of the present San Juan basin; here the Pictured Cliffs is absent and the Fruitland Formation, which normally overlies the Pictured Cliffs (Fassett and Hinds, 1971), rests directly on the Lewis Shale (Fig. 1). This could be due to uplift rather than sediment infilling, causing the sea to retreat. Other evidence of uplift along the eastern San Juan basin is the absence of coal in the normally coal-bearing Fruitland Formation in a narrow band paralleling the eastern rim of the basin. Uplift of this area would have restricted the accumulation of vegetal matter. The extent of the uplift is unknown, but was probably slight because it apparently did not serve as a source area during the time of Pictured Cliffs time.

The area now separating the San Juan and Raton basins was possibly emergent at the time of Pictured Cliffs regression from the San Juan basin area (Baltz, 1965, 1967). Fassett and Hinds (1971) did not agree with this interpretation and suggested that because all available evidence indicated "... that the Pictured Cliffs shoreline was regressing to the northeast as the sea left the present basin area ... there was no landmass immediately northeast of the area at the time." If an emergent landmass did exist between the present San Juan and Raton basins, and if the Pictured Cliffs-Trinidad shorelines were receiving sediment from this positive area at that time, "... the Pictured Cliffs Sandstone should be equivalent in age in parts of the northern and southern San Juan basin and also it should be equivalent in age to part of the Trinidad Sandstone in the Raton basin. Unfortunately, the age of the Trinidad in the Raton basin relative to the Pictured Cliffs is not known."

Fortunately, the age of the Trinidad Sandstone is now known, at least in part of the Raton basin. Cobban (written commun., 1976) states, "I failed to find anything datable in the upper part of the Pierre Shale at Raton. About 3 miles (5 km) north of Trinidad, *Baculites jenseni* was collected 67 ft (20 m) below the base of the sandy transition beds separating typical massive Trinidad Sandstone from typical Pierre Shale. I would guess the type Trinidad lies in the *B. eliasi* or *B. bacu/us* zone." Of the San Juan basin, Cobban wrote (1973, p. 150), "The uppermost part of the Lewis Shale and the lowermost part of the Pictured Cliffs Sandstone probably lie in the zone of *Didymoceras cheyennense* (Meek and Hayden). This ammonite occurs in orange weathering limestone concretions in the upper part of the Lewis Shale near Chimney Rock about 30 miles (48 km) east of Durango in the NW' SEA sec. 17, T. 34 N., R. 4 W., Archuleta County (D 4806)."

The *Baculites eliasi* zone (Obradovich and Cobban, 1975) is around three million years younger than the *Didymoceras cheyennense* zone; thus, the Trinidad Sandstone of the Raton basin is considerably younger than the Pictured Cliffs Sandstone of the San Juan basin. Because the Trinidad of the Raton basin is much younger than the Pictured Cliffs of the San Juan basin, these units were not deposited contemporaneously and there was no landmass between the basins during the final regression of the Western Interior seaway. Other evidence that negates the presence of a landmass between the basins is the presence of Pictured Cliffs Sandstone in the Cerro Summit quadrangle (Dickinson, 1965) near Montrose, Colorado. Cobban noted (1971, p. 152) that "The top of the Mancos Shale (base of the Pictured Cliffs) in the Montrose area probably lies in the zone of *Didymoceras cheyennense."* Thus, the Pictured Cliffs shoreline was probably continuous north, from the northern San Juan basin to the Montrose area, as the Western Interior seaway withdrew eastward from the San Juan basin area for the last time.

After departing from the San Juan basin area, the sea continued to regress, withdrawing eastward until it finally crossed the Raton basin, never returning. There is a hint that as the shoreline withdrew from the northeastern San Juan basin its orientation was changing (Fassett and Hinds, 1971) from northwest to north. The trend of the shoreline, as the sea withdrew across the Raton basin, is somewhat controversial. Matuszczak (1969), on the basis of an isopach map of the Trinidad, ripple-mark orientation and the long-axis strike of heavy-mineral lenses, concluded that the Trinidad shoreline trend in the Raton basin was northwest. On a paleogeographic map representing middle Bearpaw time, McGookey and others (1972) showed the Trinidad shoreline trending northwest, although they admitted there was little evidence for this trend in the Raton basin. Pillmore (1969a) stated that as the Cretaceous sea retreated from the Raton basin the shoreline was north to northeast-trending. He based this conclusion on the fact that thick coal beds of the lower Vermejo Formation (near the top of the Trinidad Sandstone) are elongate in a northeast direction, reasoning that back-shore coal swamps would tend to parallel the shoreline of the sea.

The environment of deposition of the Trinidad Sandstone in the Raton appears to be very similar to that of the Pictured Cliffs Sandstone in the San Juan basin; that is, beach and littoral environments migrating and rising stratigraphically to the east as the sea regressed. Unfortunately, the subsurface control needed to document and quantify the amount of stratigraphic rise of the Trinidad is not yet available in the Raton basin. Also, the apparent scarcity of guide fossils in or near the base of the Trinidad throughout the Raton basin has prevented a faunal determination of the Trinidad's stratigraphic rise. It is hoped that future studies may shed more light on this problem. At any rate, the sea did finally pass eastward, out of the Raton basin, and out of this story.

The last or youngest Upper Cretaceous rocks deposited (and still present) in the two basins consist of back-shore swamp, flood-plain, and fluvial deposits represented by the Fruitland Formation, Kirtland Shale and McDermott Member of the Animas Formation of the San Juan basin (Fassett and Hinds, 1971), and the Vermejo and lowermost Raton Formations of the Raton basin (Pillmore, 1969b). As the sea retreated, back-shore swamps became the sites of large accumulation of vegetal matter destined to become the valuable coal resources of the Fruitland Formation and the Vermejo Formation of today.

The similarities in the sediments of the two basins again ended with deposition of the back-shore swamp deposits of the lowermost Fruitland Formation and the lowermost Vermejo Formation. In the San Juan, the Fruitland Formation is overlain by the Upper Cretaceous Kirtland Shale and the McDermott Member of the Animas Formation. The lower Kirtland is lithologically similar to the Fruitland, whereas the upper Kirtland contains a series of closely spaced, relatively narrow-channel sandstones and interbedded shale known as the Farmington Sandstone Member. Overlying the Kirtland in the northwestern part of the San Juan basin is the McDermott Member of the Animas Formation, composed largely of fluvially deposited volcanic debris.

In the Raton basin, the Vermejo is succeeded by the Raton Formation, of which only the lowermost part is Cretaceous in age. The basal Raton is a conglomeratic sandstone. The continental Upper Cretaceous section of the San Juan basin reaches a thickness of 2,100 ft (640 m) (Fassett and Hinds, 1971), whereas this interval in the Raton basin does not exceed 800 ft (244 m) (Pillmore, 1969a). The significance of these thicknesses may not be too meaningful due to unconformities in the section.

In the San Juan basin, the appearance of the conglomeratic McDermott Member of the Animas Formation containing pebbles and cobbles of andesite, apparently derived from a nearby source area to the north (Fassett and Hinds, 1971), clearly signaled the beginning of Laramide orogeny. The entire basin was tilted westward with the east side uplifted; the first basinwide cycle of erosion then ensued, resulting in removal of as much as 2,100 ft (640 m) of Upper Cretaceous rock from the east side of the San Juan basin (Fassett and Hinds, 1971). This erosion cycle was followed by deposition of the Paleocene Ojo Alamo Sandstone.

The definition, age and particularly the nature of the basal contact of the Ojo Alamo have been and still are controversial problems in the San Juan basin. For a review of the various interpretations of this formation, the interested reader is directed to Fassett (1973). This uplift of the eastern San Juan signaled the start of a time, continuing to the present, when the San Juan and Raton basins were separated by an orogenic complex.

Evidence of the beginning of this orogenic cycle in the Raton basin is the unconformity at the base of the Raton Formation, indicating uplift in Late Cretaceous time. An interesting comparison of the Cretaceous-Tertiary boundary of the two basins shows that in the Raton basin the basal Raton unconformity is below this boundary, whereas in the San Juan basin the basal Ojo Alamo unconformity is at the boundary. In at least one area (Fassett and Hinds, 1971), the Cretaceous-Tertiary boundary is below the basal Ojo Alamo unconformity.

## COAL, OIL AND GAS

The San Juan basin is the second largest gas field in North America, after the Hugoton field, and gas has been produced from almost every marine sandstone in the basin. Some oil has also been discovered, primarily in the discontinuous transgressive Gallup offshore bar sandstones. Coal deposits are present in the back-shore facies of every one of the transgressive and regressive marine sandstones of the basin from the Dakota Sandstone through the Crevasse Canyon Formation, the Mesaverde Group and the Fruitland Formation. Coal has been commercially mined from all of these units.

The Raton basin has produced only minor amounts of oil and gas; however, to date it has not been thoroughly explored (Speer, this Guidebook). The Raton basin has been a major coal producer for many years, with high-quality coking coal being mined from the Cretaceous Vermejo Formation and the Cretaceous and Tertiary Raton Formation. The major differences between the coal of the San Juan and Raton basins are: (1) San Juan basin coal is noncoking, whereas Raton basin coal is coking; and (2) San Juan basin coal is Cretaceous in age and closely related to transgressive and regressive shoreline cycles, whereas in the Raton basin there are not only Cretaceous regressive shoreline coal deposits but also Tertiary coal beds of a strictly continental origin (Pillmore, this Guidebook).

## CONCLUSIONS

The Upper Cretaceous geologic history of the two basins and the intervening highland can be divided into two different cycles. Cycle one, represented by deposition of the Dakota Sandstone through the Juana Lopez Member of the Carlile Shale, represents a time when there was little differential tectonic activity in the area and various rock units were being deposited in essentially parallel layers continuously in both basins and, presumably, in the area in between. This kind of deposition may reflect a general transgressive cycle resulting from a eustatic sea-level rise across a broad, very flat shelf with occasionally minor eustatic sea-level fluctuations. Local small uplifts in the central highland may be reflected by the Codell and Semilla Sandstone Members. Cycle two, represented by the classic transgressions and regressions of the San Juan basin, was probably the result of an overall subsidence of the land surface near the Western Interior seaway, with concomitant rising of a western source area. Subsidence rates must have been different in both basins because a much greater thickness of rock was laid down in the San Juan than in the Raton basin. Eustatic sea-level changes may have accompanied this cycle but this would be difficult, if not impossible, to demonstrate because changes in the rate of subsidence would leave a similar record in the resulting sedimentary rocks.

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