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CRETACEOUS AND PALEOCENE ROCKS OF THE RATON BASIN, NEW MEXICO AND COLORADO—STRATIGRAPHIC-ENVIRONMENTAL FRAMEWORK

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Abstract—The Late Cretaceous in the Raton basin was a period of emergence of land and retreat of the Cretaceous epeiric sea. The coastline advanced eastward across New Mexico, as broad prograding deltaic and barrier coastal plains were formed seaward of aggrading fluvial systems. This report discusses the marine and marginal-marine formations and the rocks that were deposited by fluvial systems that drained the episodically emergent San Luis highland (Tweto, 1980) during the Late Cretaceous and Paleocene in the Raton basin. The uppermost Cretaceous and Paleocene rocks in the Raton basin are the marine Pierre Shale (Campanian to Maastrichtian), marginal-marine Trinidad Sandstone (Maastrichtian), nonmarine coal-bearing Vermejo Formation (Maastrichtian), nonmarine coal-bearing Raton Formation (Maastrichtian and Paleocene) and nonmarine non-coal-bearing Poison Canyon Formation (Maastrichtian and Paleocene).

INTRODUCTION

The Raton basin is a large asymmetric syncline (2500 mi^2 area) that extends from Huerfano Park, Colorado to Cimarron, New Mexico. As used here, the basin is defined by the limits of the outcrop of the Trinidad Sandstone. The Cretaceous and Tertiary rocks are sharply flexed to form hogbacks along the western margin of the basin on the east flank of the Sangre de Cristo Mountains. These rocks assume more gentle dips along the other margins of the Raton basin and are highly dissected. The sedimentary rocks of the Raton basin are shown in Figure 1. The marine Pierre Shale (Campanian to Maastrichtian) and overlying marginal-marine Trinidad Sandstone (Maastrichtian) underlie the nonmarine Upper Cretaceous and Tertiary rocks in the basin. Nonmarine sedimentary rocks in the Raton basin, from oldest to youngest, include the coal-bearing Vermejo Formation (Maastrichtian) and Raton Formation (Maastrichtian and Paleocene), and the non-coal-bearing Poison Canyon Formation (also Maastrichtian and Paleocene), which intertongues with the Raton Formation. The following discussion of the stratigraphy and environmental framework of these rocks is from Pillmore and Flores (1984, 1987).

STRATIGRAPHY

The Pierre Shale consists of dark, silty, noncalcareous shale about 1800 to 1900 ft thick deposited in prodeltaic and offshore marine environments in the Western Interior Cretaceous epeiric sea. Marine strata in the Raton basin range in age from Cenomanian to Maastrichtian based on ammonite fossils collected and identified by G. R. Scott and W. A. Cobban (Scott and Pillmore, 1989). The top of the Campanian is 100–150 ft below the top of the Pierre based on the occurrence near Raton of *Hoploscaphites nodosus* (*Owen*) (G. R. Scott, oral commun., 1986), which is approximately equivalent to *Baculites reesidei*. *Baculites reesidei* occurs near the base of the Maastrichtian (Obradovich and Cobban, 1976). The Pierre Shale grades upward into the Trinidad Sandstone through a tens-of-feet-thick Maastrichtian transition zone of interbedded shale and siltstone and sandstone that contains *Ophiomorpha* and other trace fossils. Other diagnostic fossils in the upper part of the Pierre below the transition zone are *Didymoceras cheyennense*, *Exiteloceras jenneyi*, *D. stevensoni* and *D. nebrascense* (Scott and Pillmore, 1989). Along the margins of the coal fields, the Pierre Shale forms slopes that are mantled by soil, talus and landslide debris resulting from oversteepening of slopes beneath cliffs of the Trinidad Sandstone. The Pierre locally intertongues with the overlying Trinidad (Harbour and Dixon, 1956; Billingsley, 1978; Wanek, 1963).

AGE	FORMATION NAME	GENERAL DESCRIPTION	SYMBOL	APPROXIMATE THICKNESS IN FEET
PALEOCENE	POISON CANYON FORMATION	SANDSTONE--Coarse to conglomeratic; beds 15-50 ft thick; interbeds of yellow-weathering, clayey sandstone. Thickens to west at expense of underlying Raton		500+
	RATON FORMATION	Formation intertongues with Poison Canyon Formation to the west UPPER COAL ZONE--Very fine grained sandstone, siltstone, and mudstone with carbonaceous shale and thick coal beds BARREN SERIES--Mostly very fine to fine grained sandstone with minor mudstone, siltstone, carbonaceous shale, and thin coal beds LOWER COAL ZONE--Same as upper coal zone; coal beds mostly thin and discontinuous. Conglomeratic sandstone at base; locally absent		0?–2100 K-T BOUNDARY
UPPER CRETACEOUS	VERMEJO FORMATION	SANDSTONE--Fine- to medium-grained; also mudstone, carbonaceous shale, and extensive, thick coal beds. Local sills		0–380
	TRINIDAD SANDSTONE	SANDSTONE--Fine- to medium-grained; contains casts of *Ophiomorpha*		0–300
	PIERRE SHALE	SHALE--Silty in upper 300 ft. Grades up to fine-grained sandstone. Contains limestone concretions		1800–1900

FIGURE 1. Generalized stratigraphic section of Upper Cretaceous and Paleocene rocks of the Raton basin, New Mexico and Colorado.

Trinidad Sandstone

The Trinidad Sandstone, which is a tabular body 80–100 ft thick in the Cimarron area, was deposited contemporaneously in delta-front and barrier environments during the eastward progradation of the Cretaceous coastline. It ranges from 0 to 300 ft in thickness along the western margin of the basin. The Trinidad is locally truncated beneath conglomeratic sandstone at the base of the Raton Formation (Johnson and Wood, 1956) in the western portion of the basin. The Trinidad is composed mostly of fine- to very fine-grained sandstone that contains *Ophiomorpha*, *Diplocraterion* and other trace fossils (Pillmore and Maberry, 1976) and forms persistent, conspicuous, light-colored cliffs along the eastern and southern margins of the basin. *Ophiomorpha* is common to most sections, but *Diplocraterion* is limited to only a few localities. One of the best of these localities is at the mouth of Cerrososo Canyon where *Diplocraterion* "ladders" more than a meter long are visible at the top of the lower Trinidad Sandstone.

Vermejo Formation

The Vermejo Formation consists of interbedded sandstone, siltstone, shale, carbonaceous shale and coal that together form steep, generally debris-covered slopes above the cliffs of the Trinidad Sandstone. The Vermejo Formation varies in thickness from 370 to 390 ft at Vermejo Park and along the western border of the Raton basin to 0 ft in the eastern part of the basin, east of Raton, New Mexico. In the southern part of the basin in the vicinity of Cimarron, it ranges from 65 to about 188 ft thick (Haymes, 1989). Coal beds as much as 13 ft thick occur near the top and bottom of the formation in other parts of the basin. The Vermejo was deposited conformably on the Trinidad in contemporaneous fluvio-deltaic and back-barrier plains. It intertongues with the Trinidad along the southern margin of the basin northeast of Cimarron, New Mexico (Wanke, 1963; Haymes, 1989). This intertonguing relationship, along with the intertonguing of the Pierre Shale with the Trinidad Sandstone north of Aguilar, Colorado (Billingsley, 1978), probably represents either local minor transgressions or autocyclic shifts of depositional systems during the overall retreat of the Cretaceous sea.

Raton Formation

The Raton Formation contains the K/T boundary interval. The formation consists of sandstone, siltstone, mudstone, coal, carbonaceous shale and conglomerate. It ranges in thickness from more than 2100 ft in the west-central part of the basin to 1100 ft in the eastern part. A basal pebble-conglomerate bed in scour-based sandstones forms a persistent cliff throughout much of the Raton basin. An erosional unconformity is generally present at the base of this bed, but in the vicinity of Raton and Trinidad, the conglomerate is commonly absent, and no unconformity is evident. Lee (1917) originally divided the Raton into a basal conglomerate, a lower coal zone, a barren series and an upper coal zone. A more appropriate subdivision in the Raton and Trinidad areas, where the basal conglomerate is locally absent, includes the basal conglomerate in the lower coal zone.

The three subdivisions are persistent and recognizable throughout the Raton basin and thicken from east to west. The lower coal zone, which ranges from about 100 to more than 300 ft thick in the western part, consists of a ledge-forming basal conglomeratic sandstone that grades up into a fining-upward, slope-forming sequence of mudstone, siltstone, carbonaceous shale and coal beds interbedded with lenticular channel and tabular crevasse-splay sandstone beds. The lower zone contains most of the Cretaceous portion of the Raton Formation, inasmuch as the K/T boundary is at or near the top of the zone, beneath the cliff-forming barren series. The barren series (200–600 ft thick) is composed of a thick sequence of stacked channel sandstones with very few coal and carbonaceous shale beds. These sandstone beds form prominent persistent cliffs along the southern margin of the basin in the Cimarron area where Wanek (1963) mapped them as a tongue of the Poison Canyon Formation. The upper coal zone (600–1100 ft thick) consists of siltstone and mudstone beds also interbedded with channel and crevasse-splay sandstone, beds of coal up to 12 ft thick and carbonaceous shale. Along the eastern and southern margins of the basin, cliffs of the barren series commonly stand high above slopes of the lower coal zone and the Vermejo Formation. The upper coal zone of the Raton supports the hills and ridges above the barren zone in the interior part of the basin.

Poison Canyon Formation

The Poison Canyon Formation (Hills, 1888) overlies the Raton Formation throughout most of the Raton basin; but to the west and southwest, the Poison Canyon intertongues with the Raton. This coarsening and intertonguing relationship can be seen in Cimarron Canyon. The Poison Canyon consists of thick to massive, lenticular, ledge-forming beds of coarse-grained to conglomeratic arkosic sandstone intercalated with beds of nonresistant, yellow-weathering, sandy, micaceous mudstone and siltstone. This sequence is about 500–650 ft thick in the central Raton coal field near York Canyon. The contact with the underlying Raton generally is indefinite and gradational through a transition zone as much as 150 ft thick. The contact is picked above the highest coal bed where the soil changes from the grays of the Raton Formation to yellow and orange colors of the Poison Canyon and beds of arkosic granule sandstone may occur.

DEPOSITIONAL AND TECTONIC HISTORY

The depositional and tectonic history of the Raton basin during deposition of the Pierre Shale through the Poison Canyon Formation is shown in Figure 2. The Cretaceous epeiric sea covered the area of the Raton basin during most of Late Cretaceous time. The epeiric sea was filled by a thick sequence of calcareous, marine or basinal shales, overlain by the Pierre Shale, which consists of shallow marine or shelf shales and siltstones. Most of the Pierre consists of gray noncalcareous shale that coarsens upward into silty shale and siltstone, reflecting the influx of coarser material as the paleoshoreline of the sea retreated eastward across what is now Colorado and New Mexico during late Campanian and early Maastrichtian time. The upper part of the Pierre grades into the overlying Trinidad Sandstone. This transition zone contains increasing amounts of siltstone and sandstone beds that were deposited in the lower shoreface of coastal barriers, which locally merged with prodeltaic deposits. These transition beds represent time-equivalent deposits of the delta-front and barrier-bar environments of the overlying Trinidad.

The Trinidad was deposited in contemporaneous delta-front and interdeltaic barrier environments as the sea continued to regress eastward across the area. The delta-front deposits include distributary mouth-bar and distributary channel sandstones (Flores and Tur, 1982). In the vicinity of Starkville, Colorado, syndepositional faults (growth faults?) are developed in delta-front deposits. At this locality, distributary channel sandstones were formed on the downthrown sides of the growth faults. This relationship, in addition to diapiric structure, graded bedding, sole marks and submarine channel sandstones in the underlying Pierre Shale, is characteristic of deltaic progradation. Growth faults and associated deposits are principal areas of hydrocarbon accumulation in ancient deltaic sequences. The deltaic systems of the Trinidad prograded seaward and supplied sediments that were reworked and redeposited along flanking coastal barriers. The barrier-bar deposits consist of middle shoreface, river-estuarine-inlet, and beach sandstones (Leighton, 1980). The delta front-strandplain deposits grade upward into the fluvial-deltaic and back-barrier deposits of the Vermejo Formation.

The Vermejo Formation was deposited as fluvio-deltaic sediments landward of delta-front and barrier deposits of the Trinidad Sandstone (Flores and Tur, 1982). Coal beds in the lower part of the formation formed in poorly drained back-barrier coastal swamps and in swamps adjacent to distributary channels of delta plains. The depositional environment of the upper part of the Vermejo was characterized by a lower alluvial plain dissected by meandering streams separated by flood basins. Sandstones were deposited in stream channels and fine-grained sequences of siltstone and mudstone were deposited in floodplains associated with crevasse-splay and minor crevasse-channel sandstones. Coal and carbonaceous shale accumulated in poorly drained backswamps or floodplains. These alluvial deposits grade upward into the more landward deposits of the Raton Formation.

The Raton Formation was deposited on an upper alluvial plain (Flores, 1984) characterized by various modes of aggradation and erosion. The alluvial plain was interrupted by several styles of fluvial sedimentation. Following the deposition of fluvio-deltaic plain and back-barrier sediments of the Vermejo Formation, rapid uplift of the source area to the west (San Luis highland) caused widespread erosion and concurrent deposition of the basal conglomerate of the Raton. The basal conglomerate, which consists of medium- to coarse-grained channel sandstones with lenses and stringers of conglomerate, was probably deposited in basin-margin braided streams merging basinward into meandering streams. These channel sandstones also contain as much as 98% quartz west of Trinidad, Colorado, indicating recycling of older quartzose sedimentary rocks such as the quartzitic Dakota Sandstone. The introduction of the quartzose sediments into the fluvial system probably marks the initial rise of the San Luis highland, which promoted erosion of Lower Cretaceous rocks. The uplift of the highland during Laramide time may have occurred along thrust faults that bordered the western margin of the basin (Woodward and Snyder, 1976). After deposition of the basal conglomerate, more stable tectonic conditions returned, and sandstones were deposited mainly in meandering streams at the same time that interbedded thin coal, carbonaceous shale, mudstone and sandstone beds accumulated in floodplains and backswamps. Crevasse splays periodically interrupted and infilled low-lying floodplains during high discharge. Though some thick coal beds were deposited locally in the lower coal zone (particularly, the 6-ft-thick Sugarite coal bed), most coal swamps that formed in the flood basins were well-drained, small and shallow, thus limiting peat accumulation. The result was thin coal beds, mostly less than 8–12 in. thick. At the close of the Cretaceous, the extensive alluvial plain was an ideal environment for deposition

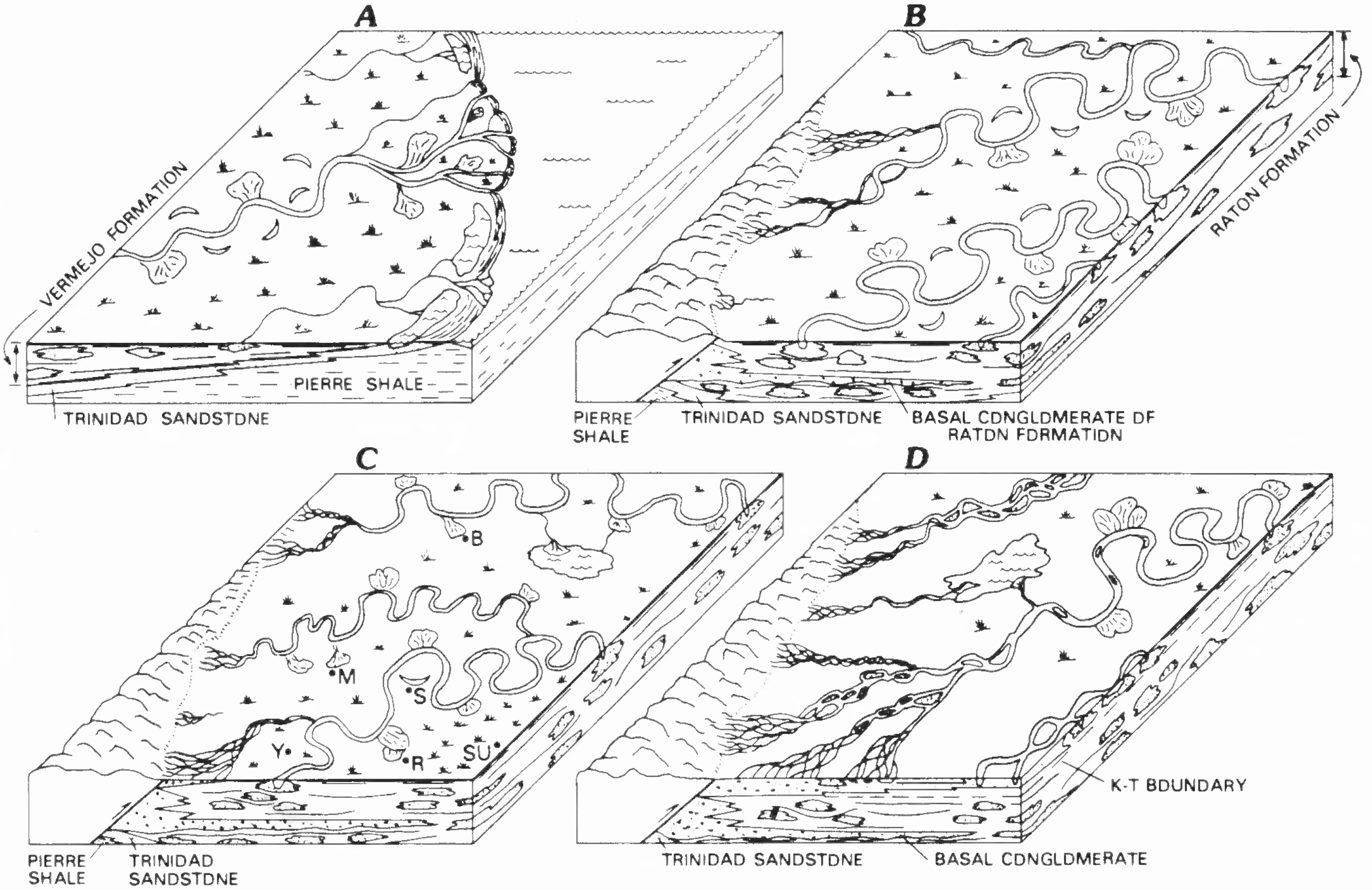

FIGURE 2. Diagrammatic block diagrams depicting paleoenvironments of Late Cretaceous and Paleocene rocks of the Raton basin. A, Offshore environments of Pierre Shale; the contemporaneous delta front and barrier environments of the Trinidad Sandstone; and the fluvio-deltaic plain of the Vermejo Formation. Diagram shows oxbow lakes, crevasse splays and swamps related to meandering streams of the lower delta plain. B, Floodplain and fine-grained meanderbelt environments on the alluvial plain that developed during the Late Cretaceous after deposition of the basal conglomerate of the lower coal zone of the Raton Formation. The floodplain was characterized by swamps and oxbow lakes. C, Depositional environments on the alluvial plain of the lower coal zone of the Raton Formation at the end of the Cretaceous Period. The K/T boundary fallout material was deposited on a surface such as that shown here. The letters show representative depositional sites: B, Berwind site (floodplain sequence, dominated by crevasse splays from nearby stream channel); M, Madrid site (channel-floodplain-crevasse splay sequence); S, Starkville sites (floodplain sequence developed on abandoned channel sequence); Y, York Canyon (floodplain-crevasse splay sequence); R, Raton site (floodplain, marginal to major backswamp); SU, Sugarite site (dominated by large swamp). See Pillmore and Fleming, this volume, for map location of the K/T boundary sites. D, Braided stream and coarse meanderbelt environments of the Paleocene barren series of the Raton Formation.

and preservation of the ash or dust fallout resulting from the K/T boundary event (Alvarez et al., 1982).

Shortly after the close of the Cretaceous, tectonic conditions in the Raton basin changed as uplift of the source area was reinitiated in the west (Fig. 2). It is proposed that episodic upthrusting along the fault belt to the west (Flores and Pillmore, 1987), possibly accompanied by a change in climate and an increase in rainfall, as suggested by results of studies of fossil plant remains by Wolfe and Upchurch (1986), created extensive erosion and sediment input into the basin. Sediment load increased and a fluvial system characterized by braided streams merging basinward into meandering streams and well-drained flood basins once again characterized the depositional basin. Streams aggraded broad belts across the alluvial plain, resulting in sheetlike to vertically stacked channel sandstones that form the prominent, persistent cliffs and ledges of the barren series from west to east of the basin. These deposits are locally interbedded with and laterally grade into floodplain mudstone and siltstone deposits. Associated carbonaceous shale and coal beds formed in well-drained backswamps; these beds are mostly thin and limited in areal extent.

The barren series was succeeded by deposits of a low-gradient alluvial plain, resulting from a decrease or cessation of tectonism in the source area. This tectonic pause, perhaps combined with basin subsidence, led to aggradation of the alluvial plain by a meandering fluvial system. The system was accompanied by floodplains in which poorly drained backswamps developed. Peat accumulation in these backswamps gave rise to coal beds as thick as 12 ft (York Canyon bed). The floodplains were locally filled by overbank and crevasse splay detritus during episodes of floods. These deposits extended into the backswamps and caused splits of coal beds where the peat swamps reestablished after detrital influx. Deposits of this setting grade upward into deposits of more landward environments of the Poison Canyon Formation.

The Poison Canyon Formation was deposited in a high-gradient alluvial plain environment (Strum, 1984), characterized by non-coal-bearing floodplain and braided to meandering stream-alluvial fan deposits. The high sediment input into the alluvial plain indicated by these high-bedload streams and fans probably reflects intensive erosion of a rapidly rising source area. These tectonic and depositional conditions probably correspond to a pulse of upthrusting to the west. The abundance of potash feldspars in the channel sandstones indicates that this renewed upthrusting exposed granitic core rocks. The granitic core probably was flanked by Mesozoic and Paleozoic rocks of the borderland. The Poison Canyon deposits coarsen to the west, forming conglomeratic sandstones of alluvial fans of the piedmont environment marginal to the San Luis highland of Tweto (1980).

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