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1984, pp. 123-128. https://doi.org/10.56577/FFC-35.123

in:

Rio Grande Rift (Northern New Mexico), Baldridge, W. S.; Dickerson, P. W.; Riecker, R. E.; Zidek, J.; [eds.], New Mexico Geological Society 35th Annual Fall Field Conference Guidebook, 379 p. https://doi.org/10.56577/FFC-35

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CORRELATION OF EOCENE ROCKS OF THE NORTHERN RIO GRANDE RIFT AND ADJACENT AREAS: IMPLICATIONS FOR LARAMIDE TECTONICS

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INTRODUCTION

The oldest Tertiary rocks in the northern Rio Grande rift are of Eocene age. These rocks—the Galisteo, El Rito, and Blanco Basin Formations—represent continental sediments that were shed from complex uplifts and deposited by rivers in adjoining basins as the result of an essentially amagmatic basement deformation, the Laramide orogeny (Chapin and Cather, 1981; Lucas and Ingersoll, 1981). For many years, the age of the basal Tertiary rocks in the northern Rio Grande rift was imprecisely known. However, recent stratigraphic, vertebrate paleontological, and sedimentological studies now permit a more refined correlation of these units, a correlation that suggests that there was a middle Eocene pulse of Laramide deformation in northern New Mexico. This paper reviews these recent studies, presents a revised correlation of the Eocene rocks of the northern Rio Grande rift, and briefly discusses the implications of this new correlation for the Laramide tectonic history of northern New Mexico.

GALISTEO FORMATION

The Galisteo Formation (Hayden, 1869) consists of as much as 1,300 m of fluvial sandstone, mudstone, and conglomerate exposed in north-central New Mexico between Albuquerque and Santa Fe (Fig. 1) (Stearns.

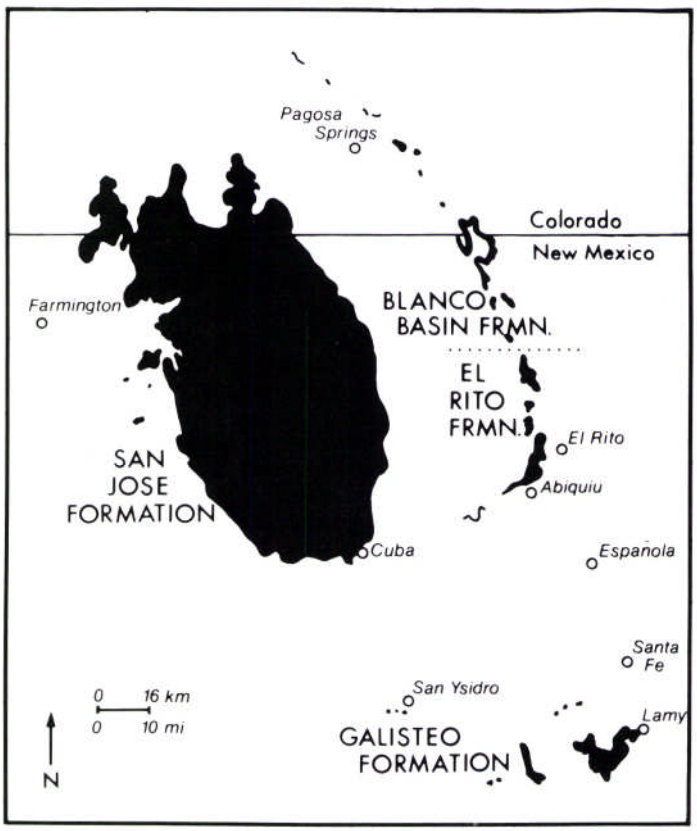


FIGURE 1. Distribution of the Galisteo, El Rito, San Jose, and Blanco Basin Formations in northern New Mexico and southern Colorado. From Dane and Bachman (1965) and Tweto (1979).

1943; Lucas, 1982). During the Wasatchian (early Eocene), most of the lower part of the Galisteo Formation was deposited in a rapidly subsiding basin centered near Cerrillos by primarily high-sinuosity meandering streams that flowed south and southwestward from the Brazos–Sangre de Cristo uplift (Gorham, 1979; Gorham and Ingersoll, 1979). However, by Duchesnean (late Eocene) time, sediments of the Galisteo Formation were being deposited in a broader basin by streams of generally lower sinuosity that flowed south and southwestward from the Brazos–Sangre de Cristo uplift and eastward from the Nacimiento uplift (Gorham, 1979; Gorham and Ingersoll, 1979). The Wasatchian interval of the Galisteo Formation contains fossils of palms and ferns (Lee and Knowlton, 1917), and of gars, soft-shelled turtles, and mammals that were amphibious browsers *(Coryphodon)*, rooters *(Ectoganus)*, and small herbivores or omnivores *(Hyopsodus, Hyracotherium, Microsyops)* (Lucas, 1982). These fossils suggest the presence of a warm, wet, heavily vegetated environment in north-central New Mexico during the Wasatchian (Lucas and Schoch, 1981). However, by Duchesnean time, a subtropical, seasonally arid climate, and the presence of parkland in north-central New Mexico is suggested by palynomorphs (Leopold and MacGintie, 1972) and fossils of ruminant artiodactyls, hyracodontid rhinoceroses, hyaenodontid creodonts, and tortoises from the upper part of the Galisteo Formation (Lucas, 1982; Lucas and Schoch, 1981).

The fossil mammals from the Galisteo Formation provide a firm basis for age assignment. The Cerrillos local fauna (Lucas and Kues, 1979), from an interval 369-424 m above the base of the Galisteo Formation near Cerrillos, is of middle Wasatchian (Lysitean) age (Lucas, 1982; Lucas and others, 1981). The Tongue local fauna, from the upper part of the Galisteo Formation in the Cerrillos area, Hagan Basin, and Rio Puerco fault zone, is of Duchesnean age (Lucas 1982; Lucas and others, 1981). Thus, the fossil mammals of the Cerrillos local fauna support correlation of most of the lower part of the Galisteo Formation with the Almagre local fauna of the Regina Member of the San Jose Formation in the San Juan Basin (Fig. 2) (Lucas, 1982; Lucas and others, 1981). The Tongue local fauna is equivalent to most (or all) of the mammal-bearing interval of the Baca Formation in west-central New Mexico (Fig. 2) (Lucas, 1982, 1983). Assignment of a Duchesnean age to the Tongue local fauna is also consistent with radiometric dates from the predominantly volcaniclastic Espinaso Formation, which overlies the Galisteo Formation in the Cerrillos–Hagan Basin area. The oldest K–Ar dates reported from clasts within the Espinaso are 34.3 ± 0.8 m.y. (10 m above the base: Kautz and others, 1981, table 1), 34.6 0.7 m.y. (200 m above the base: Kautz and others, 1981, table 1) and 37.8 ± 1.2 m.y. (lower part of the type section: Weber, 1971). These dates indicate that the contact between the Galisteo and Espinaso Formations in north-central New Mexico is at, or very close to, the Eocene–Oligocene boundary (Fig. 2).

Despite the paleontological and radiometric data that bear on the age of the Galisteo Formation, the precise age of Galisteo strata below the Wasatchian mammal-bearing interval and between the Wasatchian and Duchesnean mammal-bearing intervals is somewhat unclear. The 369 m of Galisteo Formation below the Wasatchian mammal-bearing interval in the Cerrillos area are mostly medium- to coarse-grained conglomeratic sandstone (Lucas, 1982) that unconformably overlies the Upper Cretaceous Mesaverde Group. Elsewhere, the basal Galisteo Formation unconformably overlies either the Mesaverde Group or the Upper Cretaceous Mancos Shale (Beaumont, 1979; Lucas, 1982). On

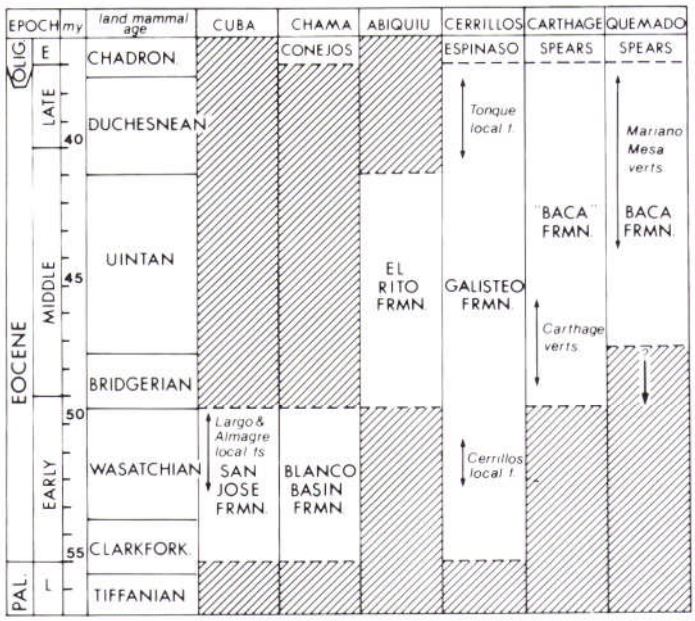


FIGURE 2. Correlation of the Eocene formations of northern New Mexico with the Baca Formation in the Baca Basin and the "Baca Formation" in the Carthage–La Joya Basin. Baca correlations based on Lucas (1983, 1984) and Lucas and others (1982, 1983). Eocene time scale from Berggren and others (1978), Hardenbol and Berggren (1978), Lowrie and Alvarez (1981), and Prothero and others (1982).

the basis of lithologic similarity, and because Wasatchian mammals from Galisteo mudstones above the basal sandstones are temporally equivalent to Wasatchian mammals from the Regina Member of the San Jose Formation, a tentative correlation of the basal sandstones of the Cuba Mesa Member of the San Jose and the Galisteo Formation sandstones below the Wasatchian mammal-bearing interval seems reasonable (Fig. 2).

Numerous unconformities are present within the Galisteo Formation between the Wasatchian mammal-bearing interval and the Duchesnean mammal-bearing interval (Gorham, 1979; Gorham and Ingersoll, 1979). Clearly, this interval spans much of the Eocene (medial Wasatchian to Duchesnean, about 10 m.y.), but it seems unlikely that Galisteo strata within this interval represent a continuous record of this period (Lucas, 1982; Lucas and Ingersoll, 1981).

BLANCO BASIN FORMATION

The Blanco Basin Formation (Cross and Larsen, 1935) consists of as much as 175 m of arkosic sandstone, conglomerate, and silty mudstone exposed as isolated erosional remnants south of the San Juan Mountains in Colorado and west of the Tusas Mountains in New Mexico (Fig. 1) (Larsen and Cross, 1956; Muehlberger and others, 1960; Dunn, 1964a; Muehlberger, 1967, 1968). The work of Dunn (1964a) indicates that the Blanco Basin Formation represents a "complex of alluvial fan, mudflow and pediment gravel deposits" (p. 38) derived from a complex metamorphic terrane intruded by silicic and alkalic rocks to the north and east of the present San Juan and Tusas Mountains. Red mudstones of the Blanco Basin Formation appear to be multicyclic red beds derived from Mesozoic and Paleozoic red beds of the source terrane (Dunn, 1964a).

No fossils are known from the Blanco Basin Formation, but on the basis of lithology, stratigraphic position, and inferred depositional history most workers (e.g., Van Houten, 1957; Baltz, 1965, 1967, 1978; Muehlberger, 1967) have considered it to be a correlative of the San Jose Formation of the San Juan Basin and, therefore, of early Eocene age. Dunn (1964a, 1964b, 1965) provided the most explicit documentation of this correlation based on the following observations and conclusions:

(1) The mineralogy of basal sandstones (Cuba Mesa Member) of **the** San Jose Formation is virtually identical to that of the Blanco Basin Formation (also see Muehlberger, 1967).

(2) In Colorado, the Blanco Basin unconformably overlies the Paleocene upper member of the Animas Formation. [In New Mexico, there is an angular unconformity between the Blanco Basin and rocks of Triassic (Chinle) to Late Cretaceous (Lewis) age: Muehlberger and others, 1960.] In the San Juan Basin of northwestern New Mexico, the San Jose Formation unconformably overlies the Paleocene Nacimiento Formation (Baltz, 1967). The Nacimiento Formation grades into, and intertongues with, the upper member of the Animas Formation in the northern San Juan Basin, and it is clear that the upper Animas is a piedmont facies proximal to the basinal facies of the Nacimiento Formation (Baltz, 1967). Therefore, the Blanco Basin and San Jose Formations occupy the same stratigraphic position above rock units of equivalent age.

(3) Crossbedding in the Blanco Basin Formation indicates transport from northeast to the southwest, towards the San Juan Basin. The work of Baltz (1967), who built upon earlier work by Dane (1946), and preliminary paleocurrent data gathered by Larry Smith of the University of New Mexico (oral comm. 1984) indicate a north to northeasterly source area for at least the basal Cuba Mesa Member of the San Jose Formation. The Blanco Basin and San Jose Formations are texturally similar, although the Blanco Basin is generally coarser-grained than the San Jose. Therefore, the Blanco Basin is readily interpreted as an upslope, piedmont facies that gave way basinward to the basinal San Jose.

(4) Cobbles of the Blanco Basin Formation present on top of Archuleta Mesa suggest earlier continuity of the Blanco Basin across the Gallinas—Archuleta arch, the structural feature that presently divides the San Juan Basin (and San Jose Formation) to the west from the northern Chama Basin (and Blanco Basin Formation) to the east.

Therefore, it seems most reasonable to consider the Blanco Basin Formation to be of early Eocene age, a correlative of the San Jose Formation. However, more work will be needed to determine whether or not the Blanco Basin Formation is equivalent to the entire San Jose Formation, or only part of the San Jose.

The Conejos Formation, of Oligocene age (Lipman and others, 1970; Butler, 1971), disconformably overlies the Blanco Basin Formation (Dunn, 1964a; Muehlberger, I967). Cross and Larsen (1935) and Larsen and Cross (1956) described this contact as an "apparent conformity" and, because they assigned a Miocene age to the Conejos, tentatively assigned an Oligocene age to the Blanco Basin Formation. However, Epis and Chapin (1975) attributed the near concordance between the Blanco Basin and Conejos to the development of a prevolcanic, late Eocene erosional surface of low relief that developed on the upper surface of the Blanco Basin Formation prior to Conejos deposition.

EL RITO FORMATION

The El Rito Formation (Smith, 1938) consists of as much as 120 m of predominantly brick-red quartzite conglomerate, quartzose sandstone, and breccia (Fig. 3A) exposed as isolated erosional remnants in northern New Mexico from Cerro Pedernal eastward to the western flank of the Tusas Mountains (Smith, 1938; Budding and others, 1960; Smith and others, 1961; Bingler, 1968a, 1968b, I 968c; Logsdon, 1981). Analysis by Logsdon (1981) indicates that the El Rito is an alluvial-fan deposit derived from debris flows and braided streams which had their headwaters on the Precambrian crystalline terrane of the Brazos—Sangre de Cristo uplift and on the Gallina—Archuleta arch and Nacimiento uplift. Logsdon's (1981) work thus supports earlier suggestions by Baltz (1978), Gorham (1979), and Gorham and Ingersoll (1979) that the El Rito and Galisteo depositional basins were at some time continuous, and thus that the El Rito is an upslope, piedmont facies of at

least part of the Galisteo Formation. Logsdon (1981) also noted extensive diagenetic effects in the El Rito that are typical of Cenozoic desert alluvium, including pore fillings of calcite, zeolite, and hematite, replacement of grains, feldspar alterations, and the removal of heavy minerals. These features suggest that diagenesis of the El Rito Formation may have taken place under arid to semiarid conditions (Logsdon, 1981).

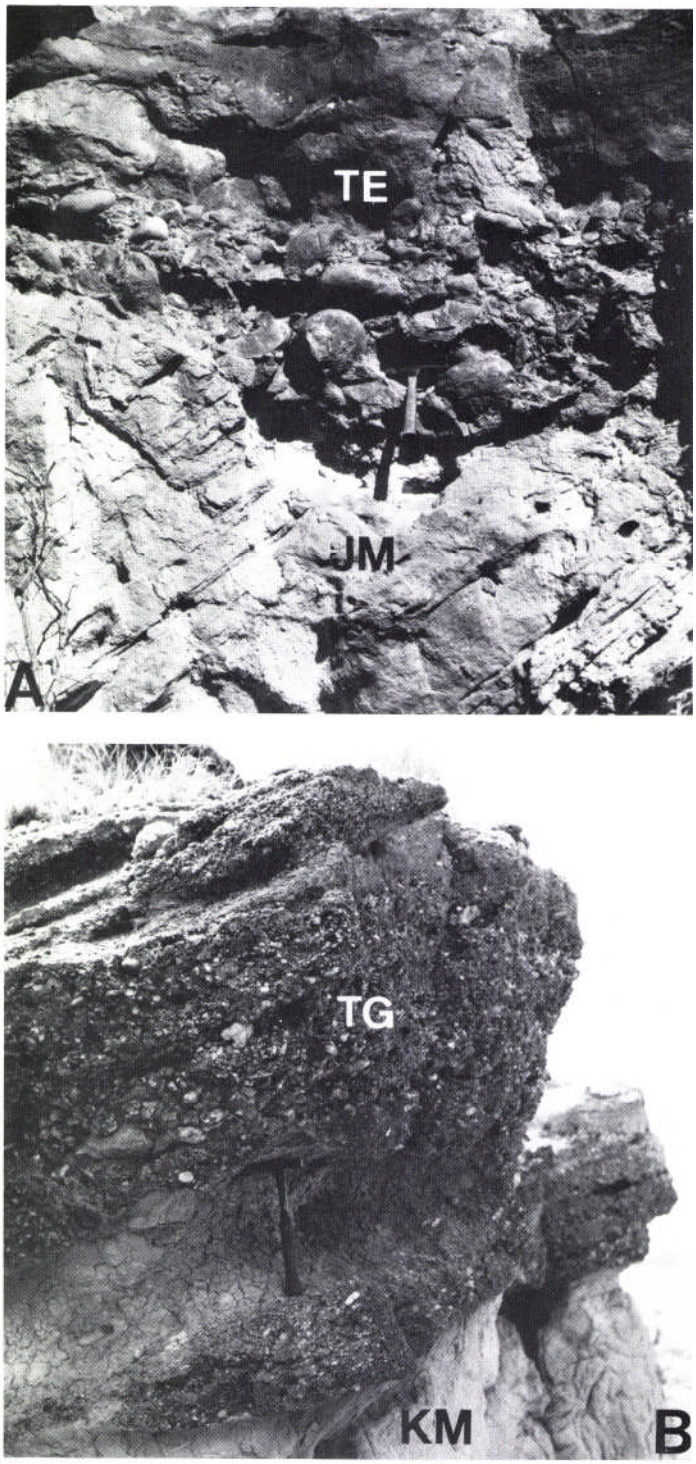


FIGURE 3. Basal conglomerates of the El Rito and Galisteo Formations. **A,** Brick-red conglomerate and sandstone of the El Rito Formation (TE) unconformably overlying buff sandstone of the Upper Jurassic Morrison Formation (JM) near Abiquiu, New Mexico. **B,** Brown conglomerate of the Galisteo Formation (TG) unconformably overlying buff sandstone of the Upper Cretaceous Menefee Formation (KM) near Windmill Hill in the Rio Puerco fault zone, New Mexico.

As with the Blanco Basin Formation, no fossils are known from the El Rito Formation. Nevertheless, based on its lithology, stratigraphic position, and inferred depositional history, the consensus (e.g., Baltz, 1978; Logsdon 1981; Lucas and Ingersoll, 1981) is that it is a correlative of the Galisteo Formation. This correlation, however, is not very precise because it indicates a Wasatchian—Duchesnean time span of more than 15 m.y. for the El Rito Formation. The El Rito Formation unconformably overlies rocks that range in age from Precambrian to Late Cretaceous (Mancos) (Budding and others, 1960; Smith and others, 1961; Bingler, 1968c), and is unconformably overlain by rocks as old as Oligocene (Conejos) (Manley, 1981). Therefore, precise age limits are not placed on the El Rito Formation by its stratigraphic position. Muehlberger (1968) asserted that near Brazos Peak in the northern Tusas Mountains the El Rito and Blanco Basin Formations "interfinger," which might indicate that they are time equivalent (Lucas and Ingersoll, 1982). However, Muehlberger's assertion actually reflected his uncertainty as to whether or not an outcrop north of Canones Box, interpreted as Blanco Basin Formation, might actually pertain to the El Rito Formation; no actual interfingering of the two units was ever documented (Muehlberger, 1967).

Despite its lack of fossils, the El Rito Formation may be correlated more precisely by the use of "event stratigraphy" (Alter, 1973, p. 63). Event stratigraphy is the correlation of depositional (or tectonic) events when neither biostratigraphic nor strictly lithological correlations are possible. An event-stratigraphic correlation of the El Rito Formation necessitates the identification of sediments in the Galisteo Formation that were produced by the tectonic event responsible for El Rito deposition. I identify the basal Galisteo conglomerate in the Rio Puerco fault zone (near San Ysidro, Fig. 1) and medial Galisteo conglomerates in the Hagan Basin—Cerrillos area as the Galisteo sediments that correspond to the El Rito depositional event. This identification is based on the following observations:

(1) The basal unit of the Galisteo Formation in the Rio Puerco fault zone is a polymodal, mostly clast-supported conglomerate with a generally unordered fabric (Fig. 3B). Cobbles of this conglomerate are predominantly quartzite. This conglomerate is overlain by predominantly red mudstone of the Galisteo Formation that contains Duchesnean mammals (Lucas, 1982). Imbrication of pebbles in locally ordered fabric of this conglomerate and crossbedding in Galisteo sandstones above the red, mammal-bearing mudstones indicate a northwestern source for these sediments, the Nacimiento uplift (Gorham, 1979; Gorham and Ingersoll, 1979). It should be noted that Slack (1973, 1975) and Slack and Campbell (1976) erroneously identified these Galisteo strata in the Rio Puerco fault zone as San Jose Formation, and therefore concluded that the Nacimiento uplift acted as a source area for these sediments during the latest Paleocene—early Eocene (Lucas, 1980, 1982).

(2) Medial conglomerates and conglomeratic sandstones of the Galisteo Formation in the Hagan Basin (lower white-conglomeratic sandstone member, lower buff-conglomerate and sandstone member, and middle white-conglomeratic sandstone member of Gorham, 1979, and Gorham and Ingersoll, 1979) and Cerrillos area (units 50-52, 62, and 66-67 of Lucas, 1982, fig. 4) have conglomeratic portions that are generally polymodal, mostly clast-supported conglomerates that usually have unordered fabric and significant amounts of quartzite cobbles. These conglomerates are stratigraphically below Duchesnean mammal-bearing mudstones and sandstones. Crossbedding and pebble imbrications indicate that the conglomerates were derived from a source to the northwest, the Nacimiento uplift (Gorham, 1979; Gorham and Ingersoll, 1979). Each of these conglomerates has an erosional base, and correlation within the Hagan Basin indicates that these bases are intraformational unconformities with locally significant stratigraphic relief (Gorham, 1979; Gorham and Ingersoll, 1979).

(3) Paleocurrents from the lower part of the Galisteo Formation below these conglomerates indicate a northern source area (Brazos—Sangre de Cristo geanticline), not a source area to the northwest (Nacimiento uplift) during this primarily (or entirely?) Wasatchian phase

of Galisteo deposition (Gorham, 1979; Gorham and Ingersoll, 1979).

(4) As noted above, Dunn's (1964a) work suggests continuity of the Blanco Basin and San Jose Formations across the Gallina—Archuleta arch during at least part of the Wasatchian. Thus, this uplift could not have been a source for El Rito sediments until after the Wasatchian, or during the late Wasatchian (Logsdon, 1981).

(5) Preliminary paleocurrent analysis of the Cuba Mesa Member of the San Jose Formation (L. Smith, oral comm. 1984) does not indicate a southeastern or eastern source area (Nacimiento uplift) for these early Eocene sediments; a northern source area is indicated.

(6) "The red-bed phase of the Galisteo Formation that crops out along the escarpments southwest of Lamy, New Mexico, and along U.S. Highway 85 at La Bajada Hill suggests a close similarity between the El Rito Formation and the upper part of the Galisteo Formation" (Galusha and Blick, 1971. p. 34).

(7) Baltz (1967) noted that the medial sandstone member of the San Jose Formation, the Llaves Member, thins and fines westward, and contains cobbles and pebbles of bluish and gray metaquartzite similar to the metaquartzites of the Brazos uplift. He thus suggested derivation of the Llaves Member from the Brazos—Sangre de Cristo uplift. This would mean that there were probably no highlands (Nacimiento uplift, Gallina—Archuleta arch) between the San Juan Basin and the Brazos—Sangre de Cristo uplift during the Wasatchian.

(8) The paleontological evidence cited above suggests that the Duchesnean upper part of the Galisteo Formation was deposited under seasonally arid climatic conditions. If Logsdon's (1981) suggestion that El Rito diagenesis took place under an arid or semiarid climate is correct, this diagenesis may have taken place during the Duchesnean, after the termination of El Rito deposition.

The above observations support the idea that during at least most of the Wasatchian. the Nacimiento uplift and Gallinas—Archuleta arch did not supply sediment to the San Juan or Galisteo Basins. It is during the post-Wasatchian interval of Galisteo deposition that sandstones and conglomerates derived from source areas to the west and northwest appear. The El Rito Formation, which received some sediment from the west and northwest, thus is probably equivalent to these post-Wasatchian Galisteo sandstones and conglomerates. The appearance of seasonally dry climates during the Duchesnean in the Galisteo Basin suggests that El Rito deposition may have been essentially over by this time. Thus, a Bridgerian—Uintan age assignment for the El Rito Formation seems most reasonable (Fig. 2).

IMPLICATIONS FOR LARAMIDE TECTONIC HISTORY

The idea that Laramide deformation in northern New Mexico was the result of primarily northeastward movement of the Colorado Plateau so that it impinged upon the basement buttresses of the Rocky Mountain foreland, finally resulting in significant wrench tectonism, is widely accepted (e.g., Kelley, 1955; Sales, 1968; Baltz, 1967, 1978; Woodward and Callender, 1977; Chapin and Cather, 1981; Lucas and Ingersoll. 1981). Although some earlier workers suggested an Eocene culmination of Laramide deformation in northern New Mexico (e.g., Baltz, 1967, 1978), it was Chapin and Cather (1981) who more specifically stated that the sharpest pulse of Laramide deformation began about 55 m.y. ago in latest Paleocene—earliest Eocene time. According to Chapin and Cather (1981), it was at this time that the majority of the Laramide Echo Park basins (including the Galisteo—El Rito and Carthage—La Joya Basins in New Mexico) formed as en-echelon, asymmetric downwarps and tilted and subsided blocks between strands of the wrench-fault system. However, the correlations presented here and the recently published paleontological evidence on the age of the "Baca Formation" in the Carthage—La Joya Basin (Lucas and others, 1982, 1983) suggest that the Laramide Echo Park basins of north- and south-central New Mexico did not form until the middle Eocene, at, or just after, 50 m.y. They thus suggest that there was a major pulse of Laramide deformation of the Rocky Mountain foreland during the middle Eocene.

By Paleocene time, crowding of the Colorado Plateau against the foreland produced the basement-cored Brazos—Sangre de Cristo uplift

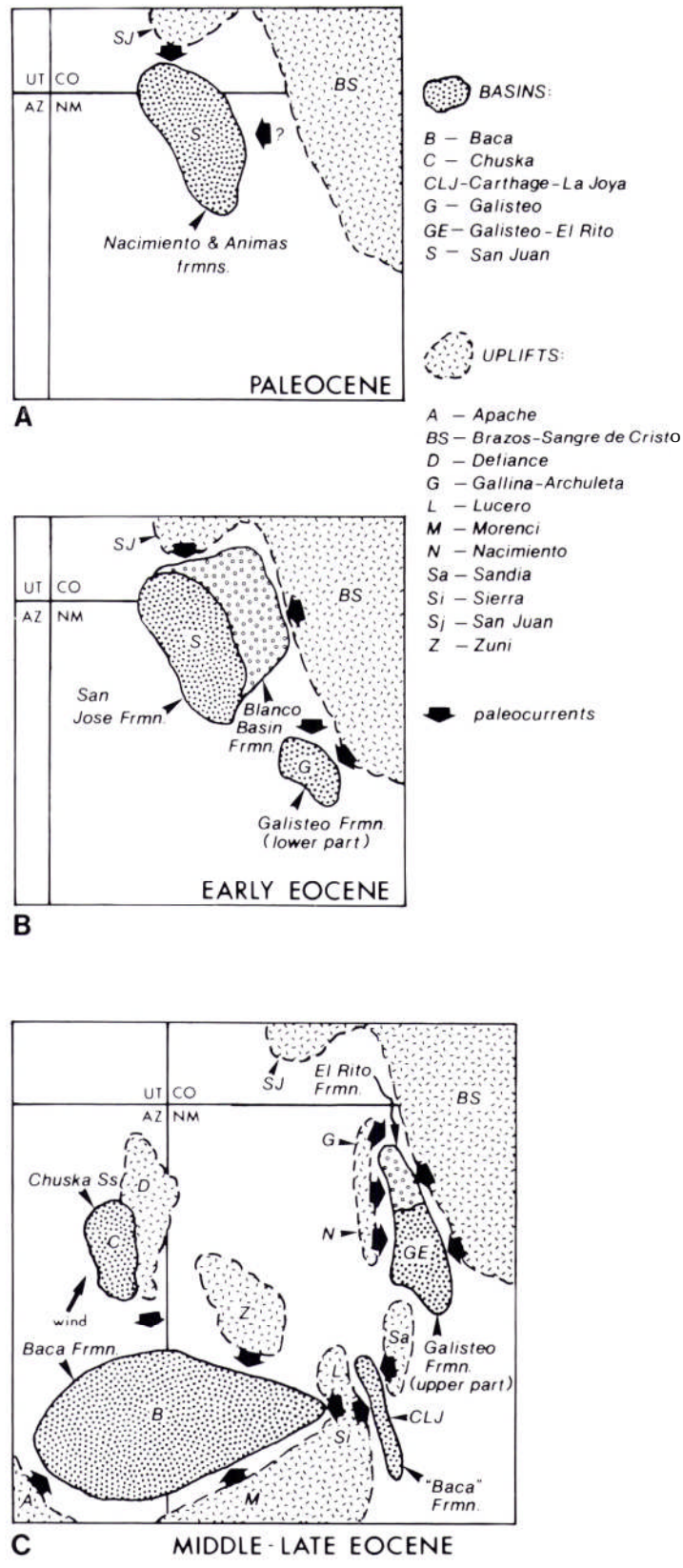


FIGURE 4. Three stages of Laramide deformation and sedimentation of the Rocky Mountain foreland of northern New Mexico. **A,** Paleocene; **B,** early Eocene; **C,** middle–late Eocene. Presence of Sandia uplift during the middle–late Eocene is conjectural. Based on the arguments in the text and on Baltz (1978), Chapin and Cather (1981), Lucas and Ingersoll (1981), and Cather (1983a, 1983b).

and, on the Colorado Plateau, the monoclinal San Juan uplift (Kelley, 1955; Tweto, 1975; Chapin and Cather, 1981). Paleocene sediments shed from these uplifts were deposited in the San Juan Basin (Fig. 4A): Ojo Alamo, Nacimiento, and Animas Formations (Baltz, 1967; Powell, 1973; Sikkink, 1983). Movement of the Nacimiento uplift began just before the Eocene (Baltz, 1967), but no sediments were shed from the Nacimiento uplift at this time. The beginning of the Eocene saw major upthrusting of the San Juan and Brazos—Sangre de Cristo uplifts and the consequent enlargement of source terranes. These larger terranes were the sources of thick, generally coarse-grained sediments deposited in the rapidly subsiding San Juan (Blanco Basin and San Jose Formations) and Galisteo (lower part of Galisteo Formation) Basins (Fig. 4B). Red beds of Mesozoic and late Paleozoic age contributed significant amounts of sediment to these basinal deposits and account for the multicyclic red beds that characterize their finer-grained intervals (Dunn, 1964a; Baltz, 1967). However, it was not until middle Eocene time that new, en-echelon, Echo Park basins formed in the foreland (Fig. 4C). The Galisteo—El Rito Basin was superimposed in part on the older Galisteo Basin, and the Carthage—La Joya Basin formed between the Sierra and Sandia uplifts. At, or slightly after, this time, deposition began in the Baca Basin along the southern margin of the Colorado Plateau, and the San Juan Basin was elevated to form an area of nondeposition (Fig. 4C). The eolian Chuska Sandstone, definitely older than middle Oligocene (Naeser, 1971; Hackman and Olson, 1977) and possibly of late Eocene age, was deposited just west of the San Juan Basin by winds from the south (Fig. 4C) (Wright, 1956; Trevena and Nash, 1978).

Identification of a middle Eocene pulse of Laramide deformation in the Rocky Mountain foreland of northern New Mexico is at slight variance with the conclusions of Chapin and Cather (1981). Nevertheless, it should be pointed out that basinal sedimentation may have lagged behind the initiation of compression. If this lag had a duration of as much as 5 m.y., then Chapin and Cather's (1981) identification of a sharp pulse of Laramide deformation beginning about 55 m.y. is upheld. However, the timing of this pulse of Laramide deformation is only as precise as the correlation of the synorogenic sediments it produced. The new correlation of Eocene rocks of the northern Rio Grande rift and adjacent areas presented here needs additional, especially paleontological, corroboration. If it is accepted, it does suggest that a major pulse of Laramide deformation that produced the wrench-faulted, Echo Park-type basins of the Rocky Mountain foreland of New Mexico occurred in the middle Eocene rather than at the beginning of the Eocene.

ACKNOWLEDGMENTS

I am especially grateful to the following people for information related to this paper: S. M. Cather, T. W. Gorham, R. V. Ingersoll, L. D. McFadden, and L. N. Smith. I also thank M. B. Lucas and A. Lucas, without whom this paper could not have been completed. Finally, comments on an earlier version of this paper by C. E. Chapin and R. V. Ingersoll improved its content and clarity.

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