Mt Princeton Chapin (1971)

southern Rocky Mountains were beveled by an erosion surface of moderately low relief in the Late Eocene; thus the disappearance of great thicknesses of Oligocene volcanic rocks across the rift must be ascribed to Late Tertiary uplift and erosion rather than to nondeposition. Assuming an average elevation of 2,000 feet for the erosion surface in Late Eocene time, minimum uplift was approximately 5,000 to 12,000 feet during Late Tertiary time for ranges east of the rift and minimum subsidence was 4,000 to 24,000 feet within the rift. Numerous fault scarps cutting alluvial fans and Pleistocene surfaces indicate that differential movement is continuing.

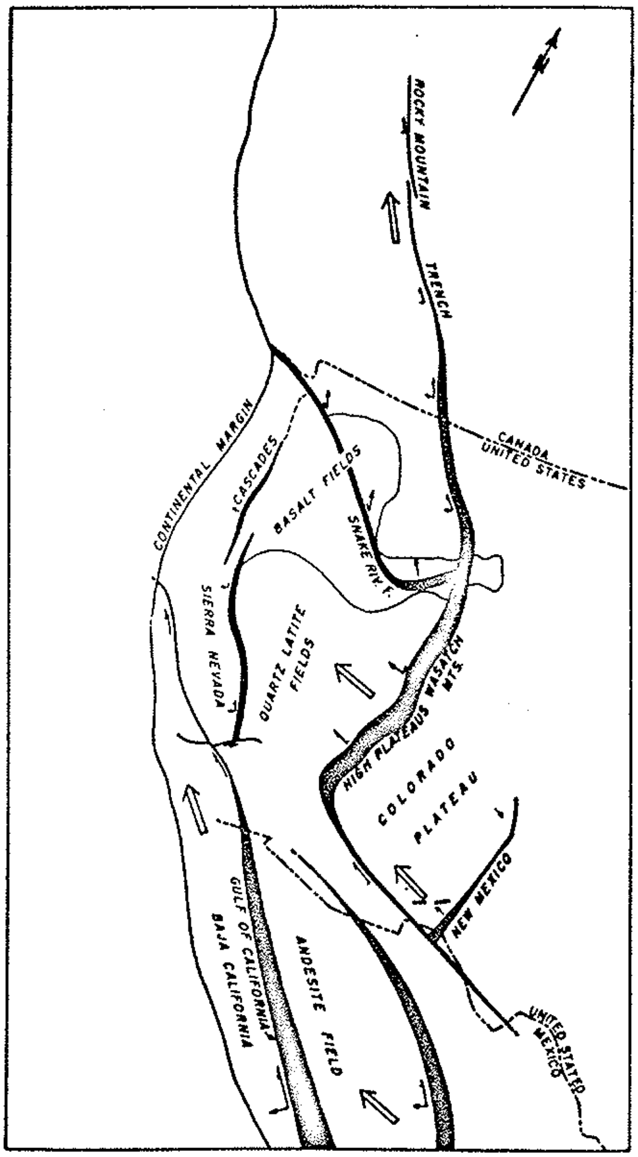


FIGURE 3.

Diagrammatic map exploring the concept of extension and drift affecting western North America. Black lines represent amount of expansion as if localized along a few separations. Small arrows represent apparent vectors of movement; large arrows the apparent resultant direction of the movement. From Eardley (1962, p. 510) with slight modifications along the Rio Grande rift.

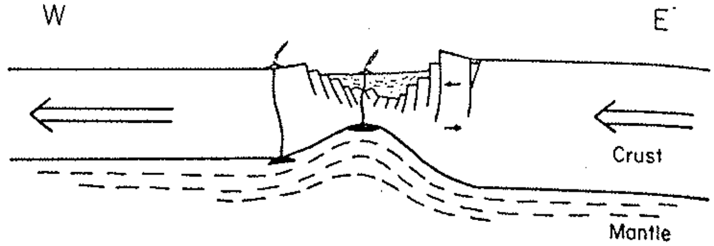


FIGURE 4.

Hypothetical cross-section of the Rio Grande rift. The large arrows indicate direction and relative rate of drift of continental plates. The small arrows indicate a force couple acting on the east shoulder of the rift. Freund (1965, p. 340) has experimentally produced a similar, but symmetric, model of the rifting and "necking" of sand above a convection current in a heavy fluid substratum.

Synthesis of the above observations suggests the following model (see figs. 3 and 4): (1) the continental plate west of the rift is drifting faster than the continental interior (mantle convection may be pulling it over the East Pacific Rise in a "conveyor belt" manner similar to that suggested by Cook, 1962); resultant crustal attenuation formed the Basin and Range province and is splitting the Colorado Plateau block away from the interior; (2) the east side of the rift developed greater structural relief due to riding up of thicker crust onto an upward bulge of mantle material beneath the rift; (3) the west side of the rift is relatively subdued due to crustal stretching accompanied by abundant normal faulting and a tendency to pull the crust away from the mantle bulge beneath the rift; (4) stretching and normal faulting along the west side relieves subcrustal pressure and provides avenues for ascent of magmas and hydrothermal solutions; (5) longitudinal faults along the east side are relatively tight and unconducive to magmatism; westward drift of the interior block against the mantle bulge tends to rotate the fault planes to a near vertical position and may change the sense of movement from normal to reverse; (6) northwestward drift of the Colorado Plateau as suggested by Eardley (1962) causes a slight clockwise rotation against the north end of the rift which tends to keep it tight and relatively free of volcanism; this may also explain the unusually high upthrusting of the Sangre de Cristo horst along the east side of the San Luis Valley; (7) continued widening of the Rio Grande rift in New Mexico appears to be accelerating volcanism and may cause the rift to evolve into a lava-filled trough similar to the Snake River rift.

## THE UPPER ARKANSAS GRABEN AND PROBLEMS OF THE NORTH END

North of the San Luis Basin of Colorado, a narrow, north-tapering, sharply defined trough extends for at least 60 miles to the continental divide north of Leadville (fig. 2). That this basin is a graben with a tectonic style similar the Basin and Range province has been recognized by workers in the Leadville area for many years. Emmons, Irving, and Loughlin (1927, p. 97) recognized that Lower Paleozoic strata in the Mosquito Range had undergone at least 8,000 feet of post-ore uplift relative to the same strata in the upper Arkansas Valley at Leadville. They discussed the relative merits of subsidence versus uplift and spoke of the similarity of this faulting to that in the Great Basin. Their cross-sections (pl. 12) show the same progressive stepping down of strata towards the valley axis by numerous longitudinal faults as is characteristic all along the rift. Tweto (1948, pl. 7) showed this structure very well on a cross-section of the upper Arkansas Valley at Leadville and labeled the valley a graben. Both sets of cross-sections show a progressive steepening of the fault planes towards the east boundary of the graben, which culminates in upthrusting of the crest of the Mosquito Range along reverse faults.

Gableman (1952, p. 1608-1609), in a very perceptive discussion based largely on geomorphology, projected the graben structure of the San Luis Valley northward up the Arkansas Valley to Leadville. In 1960, Van Alstine and Lewis (p. B245) described Early Pliocene fossils from a 500-foot section of alluvial fill exposed near Salida. The following year, Tweto (1961, p. B133) named the alluvial fill of the upper Arkansas Valley the Dry Union Formation for exposures near Leadville and showed their continuous distribution along the valley. He also presented evidence for recurrent faulting of unconsolidated sediments continuing into Holocene time; this phenomenon is a nearly universal characteristic of the Rio Grande rift. Chapin and Epis (1964, p. 158) presented evidence for downfaulting of Oligocene ash-flows by as much as 2,100 feet in the Browns Canyon area north of Salida. But the real breakthrough came in 1968 when R. E. Van Alstine (p. C158) demonstrated that the Arkansas and San Luis Valleys are connected by a structural trough containing Late Tertiary sediments. The trough crosses Poncha Pass west of U.S. Highway 285 and is not obvious from that route. In a later paper Van Alstine (1970, p. B46) extended the age of the Dry Union Formation to Late Miocene on the basis of vertebrate fossils identified by G. E. Lewis. On the basis of similarities in structural style, age of alluvial fill, alignment, and physical continuity, the upper Arkansas graben is clearly part of the Rio Grande rift.

How far the Rio Grande rift extends beyond Leadville is uncertain. Geomorphically, it appears to end at about the Continental Divide; however, as Tweto (1968, p. 566) has recently pointed out, scattered *en echelon* north-trending faults extend northward to near the Wyoming line and may be related to the rift. Kelley (1956, 1970) has postulated that the Rio Grande depression, the Colorado Parks, and the Laramie Basin are linked in a right-lateral *en echelon* system of intermontane troughs. However, the intermontane parks of Colorado are Laramide basins distinct in structural style and age of sedimentary deposits from the post-Laramide grabens of the rift (see summary by Tweto, 1968, p. 563, 566, 567). The contrast is especially sharp between South Park and the adjacent upper Arkansas Valley. South Park is a Laramide basin which received at least 1,000 feet of andesitic extrusives of Paleocene age (57 m.y.) and 8,000 feet of arkosic conglomerates prior to folding and thrusting in the Late Paleocene or Early Eocene (Sawatzky, 1964, 1968). During the Late Eocene, South Park was beveled by a surface of low relief onto which Oligocene eruptive rocks and volcanic detritus from the adjacent Thirtynine Mile field (Epis and Chapin, 1968, p. 56) were emplaced. The only Late Tertiary sediments of appreciable thickness occur in the Antero syncline in the extreme southwest corner of the park. This small basin developed synchronously with the Rio Grande rift as a small subsidiary downwarp along the inflection line of its uplifted eastern shoulder and will be discussed in the following section. In contrast, the area now occupied by the upper Arkansas Basin was situated high on the flanks of the Sawatch anticline until the Miocene when subsidence accompanying regional uplift split the anticline to form a narrow, highly-elongate graben. Streams flowed eastward off the Sawatch anticline in the Late Eocene and were filled with ash-flow tuffs in the Oligocene; these paleovalleys and their volcanic rocks have been tilted to the west and downfaulted over 2,000 feet into the upper Arkansas graben (Chapin, Epis, and Lowell, 1970; Lowell, 1969, and this guidebook). The upper Arkansas Valley then received 500 to 2,000 feet of Late Tertiary sediments which are very similar to those of the Santa Fe Group in New Mexico. Thus, the upper Arkansas graben is the northward extension of the Rio Grande rift, not the Colorado Parks.

## INFLECTION BASINS

The sharply uplifted and outward-tilted shoulders of the rift are generally 10 to 30 miles in width beyond which the structural slope is more gentle. The change in slope is rather sharp and marked by an inflection line along which numerous faults, small folds, and local downwarps occur. These smaller structures parallel the rift and were formed contemporaneously with it. They appear to be more abundant east of the rift, probably because of the greater uplift and tilting on that side. Four local downwarps, whose development can be demonstrated to be synchronous with the rift, are the Antero, Pleasant Valley, Moreno, and Estancia basins; others probably exist.

### *The Antero Basin*

The Antero Basin of southwestern South Park is a north-to-northwest-trending syncline, which parallels the upper Arkansas graben about 10 miles east of its rim. Oligocene ash-flow tuffs and volcaniclastic sedimentary rocks of the Thirtynine Mile field have been folded as much as 28 degrees about the synclinal axis (De Voto, 1964, p. 124). Alluvial fan deposits of the Late Tertiary Trump and Wagontongue formations are as much as 700 feet thick in the southern part of the syncline; these beds dip 5 degrees or less (op. cit.). Vertebrate fossils from the Wagontongue Formation have been identified by C. L. Gazin (in Stark and others, 1949, p. 69) and by G. E. Lewis (in De Voto, 1961, p. 168) as species of Late Miocene or Early Pliocene age. Thus, formation of the Antero Basin was approxi-