EVOLUTION OF THE RIO GRANDE RIFT – A SUMMARY

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The purpose of this summary is to provide a concise overview of the Rio Grande rift. For details and other interpretations see the individual papers in this volume, regional syntheses by Chapin and Seager (1975) and Cordell (1978), and Guidebook to the Rio Grande Rift in New Mexico and Colorado compiled by Hawley (1978).

Rifting began between 32 and 27 m.y. ago when regional extension reactivated the southern Rocky Mountains, a major north-trending zone of weakness that had developed during late Paleozoic and late Cretaceous-early Tertiary orogenies. By 26 m.y. ago, the crust along the developing rift had sagged sufficiently to form broad, shallow basins in which mafic flows and volcanic ash beds were intercalated with alluvial fill. Preservation within rift basins of complete pre-rift volcanic sections and early-rift volcanic-alluvial sections eliminates regional doming as an early rift process. As the rift opened, it broke en echelon across a series of northeast- and west-northwest-trending flaws which appear as lineaments in the basement terrane of the southern Rocky Mountains. Basins forming on opposite sides of lineaments tended to develop opposing symmetries -- hinged on the west versus hinged on the east. Consequently, those portions of lineaments connecting the ends of staggered basins were subjected to a scissors-like torque in the brittle near-surface rocks and to a transverse shear at depth. Near-surface strain along these transverse structures has been relieved mainly by a complex intermeshing of normal faults of opposing sense rather than by strike-slip faulting. The deeply penetrating transverse structures have tended to leak magmas and to be zones of high heat flow and geothermal activity. See Chapin et al. (1978) for a map showing major lineaments transected by the Rio Grande rift and for geological and geophysical documentation of a transverse shear zone at Socorro.

The main portion of the Rio Grande rift can be divided into three segments, each with its own structural style and history but with a common thread of major events and timing. The northern segment, Leadville to Alamosa (Figure 1), began to open about 27 m.y. ago and is characterized by: a north-northwest trend paralleling the late Paleozoic and Laramide structural grain; a near absence of synrift volcanism in the axial basins; and a shift in extension away from the axial grabens into a broad belt along the east shoulder of the rift (Tweto, this volume). Extension continues northward to near the Wyoming border as a broad zone of block faulting (Tweto, this volume).

The central segment, Alamosa to Socorro (Figure 1), is characterized by a north-northeast-trending series of en echelon basins separated by complex transverse structures. This segment traverses an area of northeast-trending basement lineaments and crosses 1.4-1.8 b.y.-old Precambrian rocks (Hedge et al., 1968) in the north and 1.3-1.5 b.y.-old Precambrian rocks (White, 1978) in the south. Except near Taos,
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early-rift magmatism was relatively sparse within this segment, but late-rift bimodal volcanism was voluminous. The Jemez lineament and the Taos Plateau have been especially active during the past 5 m.y.

The southern segment, Socorro to El Paso (Figure 1), has undergone the most extension as evidenced by the widening of the rift near Socorro into a north-trending series of parallel basins and ranges with a total width about 2.5 times that of the large single basins to the north. The rift also bifurcates near Socorro with a weaker arm (the San Augustin rift) extending southwestward along the Morenci lineament into Arizona. Between the San Augustin arm and the southern segment of the main rift is a triangular area about 80 km on a side which has undergone moderate to extreme (> 50 percent) crustal attenuation and voluminous early-rift and late-rift magmatism. "Domino-style" normal faulting (Chamberlin, 1978) and 30 to 60° of rotation of early Miocene and older strata is common within this triangle, wherever intrarift horsts expose the floor of an early rift basin. A similar structural style is present in the Rincon-Radium Springs area north of Las Cruces. The Socorro triangle is bisected by a northeast-trending transverse shear zone across which the sense of rotation of strata and normal faulting changes 180°. A large, present-day, sill-like magma body at mid-crustal depths of 19 km (Rinehart et al., this volume) ends against this transverse structure and is apparently leaking magmas along it to form shallow reservoirs.

Rifting began about 5 m.y. earlier (32 m.y.) in the southern segment of the Rio Grande rift. The change to bimodal volcanism occurred near the beginning of ash-flow magmatism in the Datil-Mogollon field (Elston and Bornhorst, this volume) instead of at the end as in the San Juan field (Lipman et al., 1978). Large volumes of basaltic-andesite lavas with high initial Sr/$^{87}$Sr/$^{86}$ ratios (0.7055-0.7090, Stinnett and Stueber, 1976) are interbedded with high-silica ash-flow sheets dated at 32 to 26 m.y. in age. Basaltic andesite volcanism continued to about 20 m.y. and was followed by a lull in magmatism between about 20 and 13 m.y. ago. A similar hiatus occurred throughout the Intermountain West but was shorter in the Basin and Range province(s) (20-17 m.y., McKee et al., 1970). Following the middle Miocene lull, bimodal magmatism changed to a basalt-rhyolite suite with low initial Sr$/^{87}$/Sr$/^{86}$ ratios (basalt, 0.7034-0.7051; rhyolite, 0.7048-0.7070). Everson and Silver (this volume) report highly radiogenic rock leads similar to those of oceanic islands in Pliocene and Pleistocene basalts of the southern segment and suggest a deep mantle upwelling. The structural characteristics of the southern segment and its magmatic evolution support their conclusion. In contrast, magma source regions in the central and northern segments remained in the lithosphere throughout rifting as evidenced by the lack of systematic chemical changes between early-rift and late-rift rocks (Lipman et al., 1978; Baldridge, this volume; Williams and Murthy, 1978; Dungan et al., 1978). The more silicic pre-rift and early-rift rocks of the southern

segment and their higher initial Sr$^{87}$/Sr$^{86}$ ratios probably reflect
differences in age and composition of the Precambrian lithosphere
between the two areas.

Volcanism along the Rio Grande rift increased slowly after the
middle Miocene lull (20-13 m.y.) with activity concentrated ini-
tially in the Socorro triangle and the Jemez Mountains where the
rift transects major northeast-trending lineaments. The southern
Rocky Mountains and adjacent areas were strongly uplifted between
about 7 and 4 m.y. ago. Total uplift since middle Miocene has been
about 1100 m (Axelrod and Bailey, 1976), much of which probably
occurred during this brief interval. The uplift is probably due
to mantle upwelling like that documented for the Great Basin and
adjacent areas by Eaton et al. (in press). Block faulting accom-
panying epeirogenic uplift disrupted the early broad basins of the
Rio Grande rift and formed the modern topography, with narrower,
more sharply defined basins. Preliminary calculations based on
deflection of lineaments indicate a total extension across the Rio
Grande rift of 100-150%. These figures are an order of magnitude
larger than previous estimates, but they are consistent with the
quantities of basaltic magma that must be injected into the crust
to maintain the heat flow anomaly (A. Lachenbruch, 1978, oral
commun.) and to explain the residual positive gravity anomaly along
the rift axis (Decker and Smithson, 1975; Cordell, 1978).

Increased runoff from newly elevated alpine regions integrated
the drainage to form the ancestral Rio Grande prior to 4 m.y. ago.
Widespread geomorphic surfaces, graded to the ancestral Rio Grande
and its tributaries, became mantled with basalt flows following
sharp acceleration of basaltic volcanism about 5 m.y. ago. Lowering
of base levels following capture of the Rio Grande at El Paso during
middle Pleistocene time (Kottlowski, 1958) resulted in dissection of
basins along the Rio Grande drainage and isolation of basalt-capped
mesas. Epeirogenic uplift has continued since 4 m.y. ago but at a
reduced rate. Rifting continues today as evidenced by abundant
fault scarps cutting Pleistocene deposits, high heat flow, modern
elevation changes, modern magma bodies, and geophysical evidence for
anomalous crust and upper mantle beneath the rift.

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