TECTONICS OF THE RIO GRANDE DEPRESSION OF CENTRAL NEW MEXICO

by
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Introduction

The Rio Grande depression is the structurally or physiographically low area that constitutes the valley through which the Rio Grande flows. The depression extends southward for 450 miles from the head of the San Luis Valley in Colorado through the length of New Mexico to near El Paso, Texas. Only about one-half of the total length, or area, extending from a short distance north of Santa Fe, New Mexico, to the vicinity of Truth or Consequences, New Mexico, is considered here. This is the most intensely studied part of the depression, although within this area there are large parts which are only generally known either stratigraphically or structurally.

From a tectonic point of view it is impractical to consider the depression of a trough or trench without also a consideration of the rims. In fact, many of the conclusions regarding the actual depression are derived from data obtained in the bordering uplifts, tablelands, or platforms. Therefore, in the descriptions and discussions which follow, the borders will be considered as parts of the depression. In consequence, the width of the total structure, including the bordering uplifts, is often twice that of the intervening depression.

The Rio Grande depression is not a single graben or trough, but a series of north-trending grabens arranged in echelon north-northeasterly along the course of the Rio Grande. This series of linked basins is in turn a part of the New Mexico or Southern Rocky Mountain belt, which is somewhat greater in width and length than the depression. Thus, in northern New Mexico the Rio Grande depression is only the central part of a wider belt which includes several uplifts and smaller basins. In the Albuquerque basin, near the center of the Rio Grande depression, the belt is only 45 to 50 miles in width and comprises the entire Rocky Mountains. The fault belt, including the depression and the bordering uplifts, is bounded on the west by the essentially underformed Colorado Plateau and on the east by the broadly tilted Great Plains. In southern New Mexico, the Rio Grande depression lies in a belt of fault blocks about 150 miles in width between the plateau and plains provinces. From north to south the in echelon basins of the Rio Grande depression are as follows:

1. San Luis
2. Espanola
3. Santo Domingo
4. Albuquerque
5. San Marcial
6. Engle
7. Palomas

The San Luis basin will not be described here. The others are considered below with brief comments on the late Tertiary and early Quaternary geomorphic history.

Espanola Basin

The Espanola basin, which lies northwest of Santa Fe, is an irregular part of the Rio Grande depression 40 to 50 miles long and 18 to 40 miles wide as shown on the accompanying map. However, it is a generally north-trending basin which is bounded on the east by the Sangre de Cristo uplift, on the west by the Jemez uplift, on the north by the Embudo constriction, and the south by the La Bajada constriction.

The northern boundary is taken arbitrarily along the irregular Embudo constriction where pre-Cambrian fault blocks or buried hills rise above the Tertiary sediments of the Cerro Azul structural channel between the Espanola and San Luis basins. The principal structural channel and linkage of the Espanola and San Luis basin lies between the Ojo Caliente and Picuris prongs. At the north end of the Espanola basin, just south of the Embudo constriction, the depression widens greatly, and the Abiquiu and Penasco embayrnents are recognized as sub-basin. These embayments attest to the irregular nature of the bounding faults between the uplifts and the basin, although in part they are the result of overlap of Tertiary sediments in sectors of former great erosion and deposition. The La Bajada constriction, which bounds the basin on the south, is formed by the La Bajada fault zone which separates the Santo Domingo basin from the Cerrillos uplift and the White Rock channel. The Cerrillos uplift consists of Mesozoic and early Tertiary sediments and middle Tertiary volcanic rocks intruded by several porphyry masses. The connecting structure *between* the Espanola and the Santo Domingo basins is the White Rock channel. This linkage between the two basins lies between the buried northern end of the Cerrillos uplift and a small salient at the southeastern edge of the Jemez uplift.

The eastern margin of the Espanola basin is well marked by the resistant Sangre de Cristo escarpment which rises abruptly from the softer Tertiary strata of the basin.

The Sangre de Cristo uplift is the largest and longest in New Mexico. It is about 190 miles long and borders the Rio Grande depression on the east from near Santa Fe on the south to the northern termination of both structures at the Sawatch uplift some 90 miles north of the New Mexico-Colorado line. The rocks of the uplift are almost entirely either pre-Cambrian or Pennsylvanian. These have been complexly folded, overthrust eastward, and offset along large tear faults during intense Laramide deformation (C. 12.. Read, oral communication). The present western fault scarp is, however, caused by late Tertiary high-angle faults, that are in echelon or saw-tooth in their arrangement (Cabot, 1938, pp. 97-104). Unfaulted tilted erosional contacts appear to exist in many places along the eastern boundary of the basin and in the Picuris embayment (op. cit.).

The west escarpment is less well marked, and the faults between the basin and the Jemez uplift are not immediately obvious owing to the thick blanket of Pleistocene Bandelier rhyolite tuff along the western flanks of the Jemez Mountains. The fault zone responsible for the prominent Los Alamos fault scarp has brought early and middle Tertiary rocks of the uplift into juxtaposition with late Tertiary. Santa Fe rocks at many places along the eastern base of the Jemez uplift.

The rocks of the Espanola basin are predominantly those of the Santa Fe formation, and the exposures in this area are typical of the deposits which appear to be very characteristic of the entire Rio Grande depression. All along the eastern half of the Espanola basin the Santa Fe is tilted westward 5 to 10 degrees along the Sangre de Cristo fault scarp, and it appears that the entire western tilt of the Santa Fe on the east side of the Espanola basin is due to late and post-Santa Fe movement on the fault. Several large patches of Santa Fe sand and gravel occur on benches along the Sangre de Cristo escarpment several hundred feet above the general surface of the basin.

Near the course of the Rio Grande, which roughly coincides with the axis of the basin, the Santa Fe beds become nearly horizontal. The most westerly exposures of the Santa Fe are found in the bottoms of youthful canyons cut into the Pajarito Plateau along the west base of the Jemez uplift, and there the Santa Fe generally has a low easterly dip. Thus, the Santa Fe has a broad synclinal structure across the basin. Some of this structure is depositional but some of it, especially on the east side, is tectonic. Cabot (1938, p. 93) and Denny (1940, p. 689) have stated that Santa Fe materials were derived from the Sangre de Cristo uplift and Smith (1938, p. 956) has concluded that the Jemez uplift was not in existence or active during Santa Fe time. In this they were mistaken, for the Santa Fe around the Jemez uplift contains an abundance of rock fragments of Jemez provenance and little material from the Sangre de Cristo and northern areas. It is apparent that the central drainage line of the basin, which shifted intermittently during Santa Fe time in accordance with variations in the influx of materials and tilting of the subsiding floor, determined the separation as well as intertonguing of the east and west fades of the formation.

Some pyroclastic, as well as sedimentary volcanic materials, occur in the western facies of the Santa Fe, and these indicate volcanic activity in the Jemez uplift during Santa Fe time. Furthermore, the general coarseness of the western Santa Fe materials indicates the presence of an uplift in the Jemez area during much of Santa Fe time. In consequence, it appears that the Espanola basin recurrently subsided with reference to the adjoining uplifts throughout Santa Fe time; instead of being downthrown entirely by a single short tectonic event which came 7 the end of Santa Fe time. The end of Santa Fe time appears to be marked by a long period of quiescence, which allowed widespread bevelling of the deformed strata, especially along the eastern side.

The late Cenozoic structural and geomorphic history of the Espanola basin is unusually well revealed along the La Bajada constriction. Much of the physiographic expression of the Espanola basin is due to the numerous volcanic eruptions which began in late Santa Fe time in the Cerros del Rio just east of the Rio Grande. The tilting and bevelling of the Santa Fe beds along the margins of the basin began and were largely developed before these eruptions. Along the Rio Grande where many of these eruptions-occurred, channels in tilted Santa Fe strata are filled by basalt flows. Elsewhere, away from the main channel, the flows are interbedded with sediments of Santa Fe type. North of the lava flows lake clays termed the Culebra lake clay (Kelley, 1948, p. 6) accumulated in the impounded waters; and some of the lavas which poured into the lake form, with the clay, subaqueous puddingstone and pillow structure. In addition, at about the end of Santa Fe time and generally prior to the basaltic eruptions, renewed uplift of the Jemez block caused the spreading of alluvial fans (Puye gravel) over the slightly deformed earlier Santa Fe beds as far east as the Rio Grande. Volcanic activity also occurred in the Jemez uplift during Puye time, as is indicated by the lenses and thin beds of pyroclastic pumice within the Puye gravel.

Following the spreading of the Puye gravel and most of the basaltic eruptions of the Cerros del Rio, the La Bajada fault zone, which may have been initiated in Pliocene or earlier time, again became active and gave rise to the present La Bajada escarpment. Late basalt dikes were also injected along the fault in some places. The Rio Grande flowed out of the lake west of its present channel, and around the lobes of basalt, and over the rising La Bajada escarpment. After some dissection by the river of the elevated escarpment had occurred, great eruptions of rhyolite tuff from the Jemez uplift engulfed the river and filled its channels completely. The area of the great rhyolitic eruption then collapsed to form the Jemez caldera. Some slight rise of the escarpment appears to have continued after the eruptions of the Bandelier rhyolite tuff, as this formation is broadly downwarped over the western end of the escarpment near the Jemez uplift. The Rio Grande, forced eastward again to near its channel of late Santa Fe time, cut down during late Pleistocene and Recent time, and developed the present gorge of White Rock Canyon. The La Bajada escarpment is the most prominent structural feature that crosses the Rio Grande depression along its length. Its development had a profound effect upon the earlier formed geomorphic features in the area.

Bryan (1938), in accounts of the erosional surfaces of the Espanola and Santo Domingo area, described ..a high surface which he termed the Ortiz surface from its development around the Ortiz Mountains. This surface is widely developed around Santa Fe and northward in the Espanola basin. In the Santa Fe area and in the Cerros del Rio of the La Bajada constriction the Ortiz surface has cut across tilted Santa Fe beds and has been covered by later sand and gravel (Ancha formation) as well as lava flows of the Cerros del Rio centers. West of the Rio Grande along the Pajarito Plateau the Ortiz horizon lies beneath the Puye gravel, which is in places several hundred feet thick.

Santo Domingo Basin

The Santo Domingo basin is a small feature which can be considered separately as is done here, or could be discussed as an embayment of the Albuquerque basin. Its separation from the Espanola basin on the northeast is sharply defined by the La Bajada escarpment. Its separation from the Albuquerque basin on the southwest is more physiographic than structural. However, at the southern end a small prong of Mesozoic rocks clearly separates the. Albuquerque basin from the Hagan embayment. To the west of the Rio Grande, basalt flows in the vicinity of San Felipe and on Santa Ana Mesa are broken by a system of parallel small faults which extend southward from the Jemez uplift. These may be taken as the structural divide between the Santo Domingo and Albuquerque basins. The scarps of these faults are well preserved in basalt fields, but are obliterated in the weak Santa Fe or terrace gravels. It seems likely, however that similar late faults are widespread but with little or no surfac expression in several of the basins.

The surface upon which the basalt flows were erupted has been correlated by Bryan with the Ortiz surface. It is also traceable to the surface at the base of the La Bajada escarpment, which Bryan has called the La Bajada surface. However, the La Bajada surface is the Ortiz surface, which was dropped along La Bajada fault and then buried to some extent by material washed in from above the fault and by material brought in by Rio Galisteo. Northeast of the La Bajada escarpment the Ortiz surface has been greatly eroded but only slightly warped since its development. Southwest of La Bajada, however, the Rio Grande depression has been sharply lowered along La Bajada fault as well as along a syncline which is more or less parallel to the Rio Grande. These relationships are shown rather obscurely in the dissected surface east of the river but strikingly in the basalt-capped surface of Santa Ana Mesa where lavas which originally flowed westward from their cones are now tilted eastward toward the axis of downwarp. It is possible that these downwarping movements which were initiated in post-Ortiz time may be still continuing along the Rio Grande. Although the Rio Grande may have deposited material for a time along the post-Ortiz sag in the Santo Domingo basin, in Recent time it has breached the sag to a depth of about 300 feet. In the process low stream terraces • have been formed and these have been termed Pena Blanca or Cochiti by Bryan and his co-workers.

The surface rocks of the Santo Domingo basin are entirely Cenozoic and are chiefly the Pliocene Santa Fe formation. As in the Espanola basin the beds west of the Rio Grande are rich in alluvial and pyroclastic volcanic materials. In the Hagan embayment the Santa Fe beds are tilted 5 to 25 degrees east-northeasterly. Along the Jemez uplift the beds are tilted 5 to 15 degrees south-southwesterly, and in the center of the basin they are slightly deformed beneath the Quaternary erosion surfaces.

Albuquerque Basin

The Albuquerque basin is the largest of the series that make up the Rio Grande depression. It extends for 90 miles from La Bajada escarpment and the Jemez uplift on the north to the San Acacia constriction on the south. The basin is bounded by the Sandia-Manzano uplift on the east and the Puerco platform, Lucero uplift, and Ladron uplift on the west. In consequence, it has a length of about 90 miles and a width of 30 miles. As with the Espanola basin, the western bounding structures of the Albuquerque basin are generally low as compared to the eastern uplifts. At the northwestern corner of the basin a small part of the Nacimiento uplift forms the boundary between the Jemez uplift and Puerco platform. The Puerco platform is a low and much faulted section some 40 miles in length and 4 to 15 miles in width. The numerous faults are of north-northeasterly trend and terminate in echelon on a remarkably even line against the undeformed margin of the Colorado Plateau. The principal faults on which the basin was depressed adjacent to the Puerco platform are along the eastern side of the belt. The faults to the west are mostly downthrown to the west even though the beds involved dip generally east.

Along the structurally highest part of the Puerco platform the pre-Cambrian surface generally lies at about sea level; whereas in the Lucero uplift to the south, it is as much as 5,500 feet above sea level. In the Nacimiento uplift to the north it is roughly 7,000 feet above sea level. However, at many places in the basin the pre-Cambrian surface may be 10,000 to 15,000 feet below sea level.

The Lucero uplift bounds the southwestern side of the Albuquerque basin between U. S. Highway 66 on the north to the Ladron uplift on the south for a distance of about 35 miles. It is a strongly asymmetrical domical uplift, the long western limb of which descends gradually to the Colorado Plateau. The crest is sharply flexed into a short and steep eastern limb which is terminated by a westward-dipping thrust of early Tertiary age and by high-angle faults of late Tertiary age.

The Ladron uplift at the southwestern margin of the Albuquerque basin consists largely of a pre-Cambrian prong which juts conspicuously eastward into an area of Tertiary, sediments. Although it is only about 10 miles from north to south and 6 miles east to west, its structural elevation is comparable to that of the great Sandia and Manzano uplifts which bound the east side of the basin. In fact the structural relief of this feature is indeed singular in comparison with other features along the west side of the Rio Grande depression.

The east side of the Albuquerque basin is bounded by a series of mountains some 80 miles in length which_ essentially constitute one great uplift. From north to south the uplift includes the Sandia, Manzanita, Manzano, and Los Pinos Mountains. Generally speaking, it is a single eastward-tilted fault block, but it is divided or broken into its several mountainous divisions by cross faults and other structural deviations from the dominantly simple structure.

The Sandia uplift, about 18 miles in length, is capped by the essentially unbroken rim of Pennsylvanian Magdalena limestone strata which dip 10 to 15 degrees eastward. On the north the uplift terminates in a maze of complicated high-angle faults of several trends. The eastern dip-slope of the mountains is broken by several longitudinal high-angle faults of small throw. The southern end of the mountains is marked by the diagonal Tijeras fault along Tijeras Canyon. At the eastern base of the mountains a small wedge-shaped block known as the Tijeras coal basin has been considerably folded and dropped along the Tijeras fault. The pre-Cambrian rocks lie as much as 2,000 feet below sea level in the Tijeras basin; whereas on the Sandia rim only 4 miles to the west, they are nearly 10,000 feet above sea level. The throw on the great fault at the western base of the Sandia Mountains ranges from 4,000 to 10,000 feet.

South of Tijeras Canyon there is a low section in the uplift known as the Manzanita Mountains. In these mountains the top of the pre-Cambrian is generally only 6,000 to 6,500 feet above sea level, and the uplift and tilting is relatively slight. The uplift is only 8 to 10 miles in length; and is bounded on the south by cross faults which separate it from the more elevated Manzano Mountains.

The Manzano Mountains are nearly 30 miles in length, and have been uplifted at least 4,000 to 10,000 feet. The Manzano Mountains are marked by a prominent moderate to high-angle fault, upthrust on the west, and lying generally a short distance to the east of the crest of the range. The Manzano Mountains are terminated physiographically, rather than structurally, by a low pass along Abo Canyon at the south end.

The Los Pinos Mountains are a southern structural extension of the Manzano Mountains and the high-angle thrusting of the latter continues along the length of the Los Pinos uplift. The buried fault along which the range was uplifted extends southward from the Manzano frontal fault and probably lies very near the west base of the Los Pinos escarpment. The uplift terminates gradually to the south in low dips which descend into the northern end of the Jornada del Muerto depression.

Joyita Hills Structures

The Joyita Hills are a north-trending uplift which lies at the southern end of the Albuquerque basin along the margin of the Socorro constriction. The structure is a low fold or anticlinal bend which intervenes between the Jornada del Muerto and Rio Grande depressions. This low fold is intricately broken by a network of small high-angle faults. The thrust faults of the Los Pinos uplift die out or pass into younger normal faults in the north end of the Joyita Hills. Although the Santa Fe formation is downthrown against the Joyita structure in most places, the upper beds overlap upon the older structures in others. At several localities along the western edge of the hills the structure rises abruptly and pre-Cambrian rocks are exposed along the bounding fault of the Rio Grande depression.

The sediments'exposed within the Albuquerque basin are predominantly sand, silt, gravel, and clay of the Santa Fe formation. Locally along the northwest border of the basin near the Puerco platform alluvial volcanic rocks of Miocene age are found at the surface while the east side of the base of the Sandia-Los Pinos uplift there are outcrops of rocks that range in age from Pennsylvanian to early Tertiary. A few basalt flows are intercalated in the Santa Fe at various horizons, and several post-Santa Fe extrusive bodies occur as isolated cones, clusters, or fissure alinements on the floor of the basin. The Santa Fe formation is variously tilted throughout the basin, but is more deformed along the borders than in the center. Large folds or tilted fault blocks of Santa Fe beds in which the beds are tilted nearly to the vertical and strike from parallel to normal to the borders are present. Along the western side near the Lucero uplift, the axis of a large fold trends northwesterly. The fold has been termed the Gabaldon anticline by Wright (1946, p. 4-5), and has nearly 5,000 feet of Santa Fe strata exposed in its western limb (Wright, 1946).

In some parts of the Albuquerque basin several thousand feet of middle and early Tertiary strata may lie beneath the Santa Fe, and the depth to late Cretaceous petroliferous strata may be as much as 10,000 to 15,000 feet. Elsewhere in the basin Santa Fe strata may lie directly on rocks as old as pre-Cambrian.

Toward the end of Santa Fe time a widespread erosion surface appears to have developed across the Albuquerque basin and into the adjoining uplifts. Remnants of this surface occur widely on both sides of the Rio Grande and even on the east side of the Sandia uplift where it can be traced more or less continuously around the north end. This surface may be correlated for the most part with the Ortiz surface as described in the Espanola and Santo Domingo basins. These and other surfaces, which are probably roughly time equivalents, are at markedly different altitudes owing to original differences in rate of erosion, to differences in gradients, and to subsequent tilting and faulting. Still other and generally lower surfaces are undoubtedly younger, but the correlation of these lower surfaces outside of the basin or even within the basin is very uncertain.

The inner valley of the Rio Grande is commonly considered to be a Quaternary feature, and the dissected slopes are usually believed to be underlain by Santa Fe beds. However, the picture may not be quite so simple, as occasional vertebrate remains are found in Pleistocene or even Recent beds in the lower slopes of the inner valley. It appears that the Rio Grande may have repeatedly cut and filled its channel during Quaternary time in a manner not wholly unlike that depicted by Lee (1907, p. 20). Beds of rather contrasting age may lie in obscure juxtaposition along the central part of the basin. As a result of this process it is often difficult to distinguish between basalt flows intercalated with Santa Fe beds and Quaternary basalt flows in the course of the inner valley which have been subsequently covered by Quaternary deposits and then re-exposed.'

Socorro Constriction

The Socorro constriction as defined here extends about 40 miles from the San Acacia channel on the north to the San Marcia! basin on the south. South of the Albuquerque basin there is, in addition to a pronounced narrowing of the Rio Grande depression, a marked change in the structural alinement of the bordering uplifts. Furthermore, volcanic rocks are prominent especially along the west side of the depression. The Socorro channel is the main linkage of the Albuquerque basin with the San Marcial basin through this constriction. The channel lies between the Joyita uplift on the east and the Socorro uplift on the west. The Rio Grande depression along this channel is only 5 to 10 miles wide. Pre-Cambrian rocks are at the surface locally in the bordering uplifts.

The Socorro uplift is a low southward structural extension of a part of the Ladron uplift, and bounds the La Jencia-Snake Hills basins on the east. The snake Hills graben lies' between the low Socorro uplift to the east and high Magdalena uplift to the west. Deposits of Santa Fe type occur in the La Jencia-Snake Hills basins and Denny (1940, pp. 84-97) has shown that the Socorro uplift probably was initiated in Miocene time. In consequence, the La Jencia and Socorro basins were probably separated during part of Santa Fe time. However post-Santa Fe faulting along the eastern base of the Socorro uplift appears to have completed the isolation of the east and west grabens.

A very curious reversal of tilt in the Socorro and Magdalena uplifts occurs near their mid points. In the Socorro uplift, north of Socorro Canyon and about the latitude of Socorro, the tilt of the block is moderately to the west. However, south of this point the Socorro uplift which consists largely of middle Tertiary volcanic rocks, is rather uniformly tilted east. 15 to 30 degrees. The same reversal is noted in the Magdalena uplift where pre-Cambrian rocks at the north end form a bold eastern escarpment and the overlying Paleozoic and volcanic rocks often are tilted moderately west. In the southern part of the uplift a thick series of middle Tertiary rocks is tilted eastward, and the latitude of the pivot is almost the same as in the Socorro uplift. Oblique or transverse faults appear to be responsible for the change of structure. The significance of the pivot in the north-trending uplifts is difficult to evaluate. However, the regional nature and trend of this cross structure is evidenced by the same sort of pivotal cross structure at the Mockingbird Gap fault-wedge between the Oscura and San Andres uplifts along the east side of the Jornada del Muerto depression. The northwesterly alinement of these pivotal "twists" coincides with a belt of northwesterly-trending folds, faults, and outcrops which extend across the State from the Zuni uplift on the northwest to the Guadalupe uplift on the southeast. Activity along this Zuni-Guadalupe trend appears to have occurred chiefly after middle Tertiary time, but stratigraphic and structural considerations give some suggestion of a Laramide or earlier inception along this feature which may be a major regional tectonic axis.

Of further tectonic significance in this area is the fairly normal pre-Tertiary section that lies beneath the middle Tertiary volcanic series along the east side of the depression. To the east of the depression in a great area that extends from the Ladron and Lucero uplifts or about the Rio Salado on the north, southward to about the latitude of the southern end of the Cabello Mountains; all the Mesozoic rocks and often much of the Permian and Pennsylvanian rocks are missing, and great thicknesses of the middle Tertiary volcanic and sedimentary materials rest upon rocks as old as the pre-Cambrian. A great uplift accompanied by wide stripping of the pre-Tertiary beds must have occurred in early Tertiary time. The stripping appears to have occurred throughout much of western Socorro and eastern Catron Counties, and the relations are suggestive of a broad warp or plateau-like epeirogenic uplift.

Extensive late Tertiary to Quaternary erosion surfaces are developed on both sides of the Rio Grande in the area of the Socorro constriction. Denny (1941, pp. 228-229) has mapped and described these and concluded that the most widespread of these, the Tio Bartolo and Valle de Parida, were younger and lower than the Ortiz surface of more northerly areas such as the Ceja del Rio Puerco. He found only minor remnants of a surface equivalent to the Ortiz. The present author can not agree with Denny's conclusions, and believes that the widespread uppermost (Tio Bartolo) surface and part of the Valle de Parida surface may be equivalent to the Ortiz surface. Faulting, tilting, and dissection make the geomorphic problems complex.

San Marcial Basin

South of the Socorro constriction the Rio Grande depression again widens into an irregular basin about 30 miles long and 10 to 15 miles wide. It is terminated on the south by the Pankey channel which connects it with the Engle basin to the southwest. The main axis of the San Marcia! basin trends essentially south-southwest and coincides with the Rio Grande. It is bounded on the east by a low edge of the Jornada del Muerto which lies to the east. This border is here termed the San Pasqual platform, and may be a sort of sub-alluvial bench surmounted by local basalt flows. The sub-alluvial bench of Santa Fe sediments probably does not connect with deep Pliocene basins in the Jornada del Muerto. The western border is more complicated and marked by the in echelon Socorro, Magdalena, and San Mateo uplifts. The intervening troughs or downthrown parts of the fault blocks merge with the San Marcial basin and appear to be embayments from the latter.

Although little is known of the stratigraphy and structure of the southern Magdalena Mountains or the San Mateo Mountains, they appear to be largely fault-block uplifts involving at the surface predominantly acidic to intermediate Tertiary volcanic beds and alluvial beds that are intruded locally by porphyry stocks. Along the San Pascual platform east of the basin small patches of late Paleozoic or Mesozoic rocks rise above the Santa Fe or Quaternary sediments.

The extensive, although much dissected, erosion surface which exists on both sides of the Rio Grande in the San Marcial basin is largely cut upon slightly deformed Santa Fe beds. Tight (1905), Lee (1907), and Bryan (1938) believed that the Rio Grande during late Pliocene or early Quaternary time flowed across the San Pasqual platform, through the Jornada del Muerto, and thence southward to El Paso along its present course. According to these writers the diversion of the Rio Grande to its present course west of the Fra Cristobal and Cabal lo Mountains and then to El Paso was caused by eruptions of basalt along the river at San Marcial. This postulated history of the Rio Grande is not supported by direct evidence. The basalt flows are not located in positions on the old surface so that damming.and diversion could have been effected. Furthermore, the Jornada del Muerto contains only a small thickness of Santa Fe sediments as compared to that present in the Rio Grande basins. The late Tertiary and Quaternary evidence of continued depression of the basins along the Rio Grande depression favors the permanent existence of through-flowing drainage.

Engle Basin

The Engle basin is similar in its physiographic and structural setting to the San Marcial basin. However, it is but 15 miles long, and 20 miles wide. It is bounded on the north chiefly by the San Mateo uplift. It has a northwesterly embayment into the Monticello trough and a northern linkage with the San Marcial basin through the Pankey channel. On the west the basin is bounded by the Cuchillo Negro uplift which is a northwestward-trending fault block that is tilted northeast. On the east the basin is prominently bounded by the strong Fra Cristobal uplift, a north-trending east-tilted fault block. At the southeast corner the Cutter platform occupies a position with reference to the Engle basin that is similar to the relationships of the San Pascual platform and the San Marcia! basin. On the south the northwest-trending Mud Springs prong and the Caballo uplift constrict and terminate the Engle basin.

Pre-Cambrian rocks are brought to the surface in the surrounding Cuchillo Negro, Mud Springs, and Fro Cristobal uplifts, and overturned fold belts in echelon to the fault blocks are present in the Mud Springs and Fra Cristobal uplifts.

Palomas Basin

The Palomas basin is a rather regular north-trending depression 30 to 35 miles long and about 12 miles wide. It is terminated at the north by Mud Springs prong and connected with the Engle basin to the north through the Cuchillo channel west of the Mud Springs uplift. On the south the feature opens into the wide irregular basins and sub-alluvial benches which surround the bedrock islands of the older physiographic and structural area of the Arizona-New Mexico Basin and Range Province. At the south end the Rio Grande swings sharply east and follows the west-northwesterly axis of the Hatch basin. On the east the Palomas basin is sharply delineated by the bold Caballo uplift and on the west by the low Animas uplift.

The dominating structural element of the Palomas basin is the Caballo uplift which is a fault block that is gently tilted to the east. Santa Fe beds and pediment gravels are downfaulted against pre-Cambrian granite, gneiss, and schist along a well marked fault at the western base. The upper part of the fault scarp consists of a typical southern New Mexico section of lower Paleozoic rocks overlain by the Pennsylvanian Magdalena group along the crest of the uplift. Several separate and in echelon overturned fold belts cross the tilted block. The southern end of the uplift, north of the Hatch basin, consists of numerous small high-angle faults and short folds whose dominant trends are northwest.

The Mud Springs uplift at the north end of Palomas basin has a northwesterly trend, and consists of a tilted fault block whose strata are inclined 20 to 30 degrees northeast. The southeastern end of this block is characterized by an overturned fold of the type found in the Cabal lo uplift, but the strong north-trending frontal faults of the Caballo uplift sharply terminate the northwesterly structure of the Mud Springs uplift. The uplifting frontal fault of the Mud Springs block is buried by late Santa Fe beds or pediment gravel, but it may continue northwest beneath the near-surface beds of the Cuchillo channel into the frontal fault which bounds the Cuchillo Negro uplift on the southwest.

The Animas uplift along the west side of the Palomas basin consists mostly of middle Tertiary volcanic and intrusive rocks, but locally some Paleozoic rocks are exposed. The uplift is relatively low and probably older than the Caballo fault block. Its structure is incompletely known but appears to be complicated by numerous cross faults. Probably it is also generally tilted eastward. Regionally it may be considered a southerly branch of the Cuchillo Negro uplift.

The small Hatch basin at the south end of the Caballo uplift has little or no separation from the Palomas basin, and it may be considered an east embayment from the Palomas structure. From the point of view of regional tectonics the southern end of the Caballo uplift as well as Hatch basin may be considered a part of the older Arizona-New Mexico Basin and Range Province which is dominated by northwesterly trends near its junction with the Colorado Plateau and Rio Grande structures to the north. There appears to be a wide, irregular, and deep-seated zone of regional magnitude along which the northerly structures of the Rio Grande inter-penetrate with the northwesterly structures of the southern province. This great tectonic division or line probably terminates the Rio Grande depression, at least locally, at the south end of the Palomas and Hatch basins.

The Palomas basin is underlain chiefly by Santa Fe beds. It is asymmetrical with its axis of downwarp near the CabeFlo uplift and essentially along the present course of the Rio Grande. Near the Caballo uplift the Santa Fe beds are often considerably deformed, and the beds dip moderately into or away from the uplift. The western limb of the fold in which the Santa Fe beds are depressed in the basin is long and only slightly more inclined than the great Palomas erosion surface that truncates it.

Jornada del Muerto Depression

The Jornada depression is a great downwarp lying to the east of the Rio Grande depression. It lies between the uplifts and platforms to the east of the Rio Grande depression and the San Andres uplift. It is from 100 to 120 miles long, and joins the Rio Grande depression on the south where the separation of the two features is obscure and problematical. At the north end where it is bounded on the east and west by the Oscura uplift and the San Pascual platform, it appears to be a faulted synclinal depression and this condition may obtain to the latitude of the north end of the Fra Cristobal uplift. In the southern part, on the other hand, in the latitude of the San Andres and Caballo uplifts, the Jornada depression is generally a broad syncline between the two flanking uplifts (Keyes, 1905, p. 67). The buried structure of the depression may be a synclinorium complicated by some faults and cross folds.

The Jornada depression lacks the considerable thickness of Santa Fe beds which is characteristic of the Rio Grande depression. The floor of the depression appears to be underlain in many places by a considerable section of the early Tertiary Baca and McRae non volcanic suite of sediments, and these may be overlain in some places by middle Tertiary volcanic rocks. In most places there is probably a thick section of Cretaceous and Paleozoic strata beneath the Tertiary sediments. Along the center of the depression all of these rocks are covered by a relatively thin layer of late Tertiary and Quaternary rocks; and although there are probably beds equivalent to the Santa Fe, they are not likely to exceed 1,000 feet in thickness.

From the above stratigraphic data and the very wide pediment surfaces in the Jornada del Muerto, it appears that the depression was for the most part formed in pre-Santa Fe time and that the strong downfaulting that was imposed on the Rio Grande depression during late Tertiary time was not active in the Jornada depression. Much of the width of the present depression is due to the very wide pediments cut across tilted pre-Tertiary rocks (Keyes, 1903, pp. 207-210). This feature in itself distinguishes the Jornada depression from the Rio Grande depression, and is further evidence of the greater age of the former.

Summary

In the analysis of the tectonics of the Rio Grande depression stratigraphy, structure, and physiography become so interrelated as to be nearly inseparable. The stratigraphic sequence and litho logy reflect the contemporaneous structure and physiography. In the geomorphology of the region the recognition and understanding of deformational features that are both younger and older than the physiographic features are of utmost importance. Also many of the largest and most significant structural elements are inferred from the geomorphology. Above all else, the geologic history is important, and the securing of a correct sequence of structural and geomorphic events, as well as the stratigraphy sequences, requires careful and often painstaking detailed work. The salient regional aspects of the stratigraphy, structure, and geomorphology are summarized below.

In late Cretaceous time the last great seaways to invade the continental interior gradually gave way to expanding floodplains. Toward the end of Cretaceous time the great floodplains began to be disturbed by linear upwarps, which often developed a pronounced asymmetry that culminated in overturned folds and great overthrusts. These early, Laramide tectonic features were developed along the entire length of the New Mexico Rocky Mountains, and although most of the thrusts dip westward, some dip eastward. The uplifts resultant from these compressional structures appear to have been paralleled by flanking downwarps which became filled with the products of erosion from the uplifts. The Laramide sediments, represented by such formations as the Raton, El Rita, Gal isteo, San Jose, Baca, and McRae, formed in basins of much greater expanse than the later trough-filling deposits of the Rio Grande depression. Although the early Laramide suite of sediments was largely non volcanic in lithology, in certain areas, especially toward the south and in the San Juan Mountain sector to the northwest, earlier and contemporaneous volcanic sources are evident.

In about middle Tertiary time volcanic activity that extruded rhyolitic to andesitic rocks developed on an enormous scale. These eruptions, together with their great outwash of alluvial material, accumulated to thicknesses of several thousand feet. The volcanic suites occur mostly in the western half of the Rocky Mountain belt and in the adjacent Colorado Plateau; but locally, as in the Raton, Cerrillos-South Mountain, and Sierra Blanca areas, the eruptions developed along the Great Plains border. Nevertheless, the uplifts bordering the east side of the depression are notably lacking in this suite of rocks. Little or no sharp folding or overthrusting accompanied the volcanic episode. High-angle faulting, however, appears to have accompanied and followed the great igneous activity. In several places there appears to have been two or three distinct volcanic stages separated by intervals of tectonic disturbance and erosion. Although local basins of accumulation appear to have developed during this epoch of Tertiary deposition and deformation, the areas of accumulation appear to have been rather wide, and the trough-like aspects of the later Rio Grande depression were not yet developed. In wide areas, the middle Tertiary flows and pyroclastic and volcanic alluvial beds lie with only slight unconformity or discordance upon the earlier non volcanic sediments. The intense fracture belt and prominent tilted blocks which are so characteristic of the Rio Grande depression and adjoining uplifts are later features,

The development of the Rio Grande structural belt probably began in late Miocene time and culminated in what may be termed the Cascadian orogeny toward the end of Pliocene time. With the development of the linked in echelon basins the Santa Fe sediments, which are the characterizing feature of the Rio Grande depression, began to form. The Santa Fe has been assigned to ages that range from late Miocene to Pleistocene. In its typical development it is an alluvial-fan deposit of a characteristic pinkish or light-tan color. Although it is locally grayish it generally stands in fairly marked contrast to the somber brown, purplish-brown, or grayish-white of the middle Tertiary sediments upon which it often rests. The Santa Fe is typically a relatively non volcanic sediment, but in many places, especially along the west side of the depression, its coarse fragments may be almost exclusively volcanic, but even in these places the characteristic pinkish color is evident in the clay and sand beds. The Santa Fe in large part reflects the rocks which were at the surface in the adjoining uplifts, and the superposition of its local members often roughly reflects, in reverse order, the stratigraphic superposition of the adjoining areas. In many places where the adjoining uplift consisted of carbonate rocks such as the Magdalena, San Andres, or lower Paleozoic formations, the adjacent Santa Fe is largely a calcirudite fanglomerate. Elsewhere playa and lake deposits form a large part of the Santa Fe. Pyroclastic breccia and tuff may be abundant in the Santa Fe, and this is especially true around the Jemez uplift. Basaltic flows are almost a characteristic of the Santa Fe, and are intercalated sparingly throughout the section.

In the upper part of the Santa Fe beds of well rounded gravel are common, and these have been taken to indicate the presence of a through-flowing river. Although these beds indicate a considerable distance of transportation, they do not prove, however, that a river such as the Rio Grande flowed to the ocean. Even the late Santa Fe gravel cannot be continuously traced along the depression.

The birth of the present Rio Grande still remains a problem. It appears to be at least as old as the late stages of development of the Ortiz pediment surfaces. Whether the Rio Grande existed during all or part of Pliocene time or during the bulk of Santa Fe deposition cannot be demonstrated. A factor often overlooked in connection with the possible existence of the ancient Rio Grande is the conclusion by Atwood and Mather (1932, p. 21) that the San Juan Mountains, the principal source for most of the present river, was a peneplain at the end of Pliocene time. It has been accepted for a long time that the Rio Grande once flowed through the Jornada del Muerto depression. The writer does not agree with this hypothesis, but recognizes that many parts of the Rio Grande drainage system have been considerably changed during Quaternary time. Bryan and McCann (1938, pp. 12-14) have postulated that during Ortiz time the upper Rio Puerco flowed into the Rio Grande near Los Lunas many miles north of its present junction. It seems also that several other tributaries of the Rio Grande have been captured in Quaternary time. In the Tijeras basin, to the east of the Sandia Mountains, a number of erratic vesicular basalt cobbles have been found which could have come only from the north in the vicinity of Santa Fe Canyon or the Cerros del Rio. Thus, it appears that the Galisteo or some other tributary must have flowed east of the Sandia Mountains into either Estancia valley or into Tijeras Canyon, and thence to the Rio Grande.

The Ortiz surface along the Rio Grande is roughly assigned to a Pleistocene age, but parts of it may be late Pliocene in age. It has also been noted that the Ortiz surface may be correlated through a series of outlying remnants with the general level of the High Plains, which is an extensive cut-surface overlain by the Pliocene Ogallala formation. Thus, the Ortiz surface, which is probably the most expansive in the Rio Grande area at present, and its many correlatives may be of widely varying ages. There are places where the Ortiz surface is being extended by pedimentation into the mountain fronts at the present time.

Viewed broadly, the Ortiz surface, its overlying deposits, and all later surfaces and deposits are a part of the Santa Fe group. Santa Fe time is a time characterized by filling of the basins flanked by the uplifts. The filling process is going on today. The cutting of the pediments and the inner canyons during Pleistocene and Recent times is a process which has been repeated many times. Unconformities, old erosion surfaces, and caliche (marl) beds are found in many places within the Santa Fe especially along the margins of the depression. There are also beds younger than- Santa Fe obscurely laid - against and in the Santa Fe beds along the inner canyon, indicating that the Rio Grande has cut and filled at earlier times. Finally, along the center of the depression there are places where little or no break in deposition occurred until the Recent canyon cutting cycle. The bajadas from the mountainward pediments are in continuous unbroken sequence with the underlying Santa Fe deposits along many parts of the depression.

The dominant structures of the Rio Grande depression are of the so-called Basin and Range type. However, these features are so far removed from the. Basin and Range structures of the Great Basin and so different from the Arizona Basin and Range structures that it is better to consider the Rio Grande structural belt as a separate and distinct type included with the Rocky Mountain structural belt. The depression is a great rift belt, and there is much evidence of horizontal shifting which may aggregate many miles. The vertical displacements may be only incidental to the horizontal shifting across the entire rift belt. The late Tertiary tectonic pattern is specialized and distinct enough to warrant the application of the term Rio Grande Rift Belt of the Rocky Mountains. The pattern is dominated by faults of northerly to northeasterly trends. Faults of westerly or northwesterly trend are uncommon and usually not large. Most of the faults were initiated in late Tertiary time, but a few such as the Tijeras fault, may have had beginnings in pre-Cambrian time. Numerous others, as described above, had beginnings in early or middle Tertiary time. The fracture pattern is markedly in echelon, and the so-called bounding faults of the major uplifts are often curved or saw-toothed in plan.

The forces which have given rise to the present system of fractures are difficult to conceive from the pattern alone. The geologic history indicates repeated deformation from Laramide to Recent. Many earthquakes in the depression suggest that the deformation is presently in progress. It may be observed that in the total deformation, fracturing prevailed over folding. The controlling external or deep-seated forces have undoubtedly changed throughout the Cenozoic, and with each shift of major forces there was set up a complicated set of secondary and tertiary forces among highly diverse blocks; prisms, and irregular rock masses of the region. Although the belt has probably always been subjected to compression of one sort or another, there were at times local areas of tension.

It does not appear, however, that the grabens or basins were formed by an east-west release of compression that would allow the simple depression of blocks by gravity alone. Rather it appears that the basins were forced down under compression just as the uplifts were forced up. A deep-seated shear zone acted upon by tangentially directed forces of a couple would cause lateral shift, and this in turn would set up in the outer crust the observed in echelon structures.

During the creation of the surface welts and furrows of the Rio Grande Rift belt it has been postulated (Dorton, 1928a, p. 99) that anticlines were formed early and that the present fault blocks are merely faulted anti' dines. Exception to this idea has been expressed frequently, and the other school of thought prefers the idea that the faults developed early and that the folding is only incidental and in the nature of drag—There is much I to support the concept of "broken anticlines", especially at the ends of such uplifts as the Sandia, Cabello, Ladron, and Oscura. Some of the uplifts may have been asymmetrical anticlines in the early stages and others-may have been fault blocks.

The faults which bound the uplifts are mostly covered by pediment and alluvial fan deposits, but where observed, generally appear steep to vertical. The steep faults generally dip toward the depression, but whether these faults are dominantly and over-all, high-angle thrusts or ramps or high-angle gravity faults is not known. Under the hypothesis of rifting both types are compatible.

In conclusion it should be emphasized that the early Cenozoic structural elements and sedimentary prisms exerted an influence upon the resolution of the later secondary and tertiary forces and the consequent structures. The structural pattern is complicated and cannot be interpreted by a single simple set of regional forces. Deep-seated rifting in late Tertiary time probably is the underlying cause of the in echelon basins and uplifts which constitute the Rio Grande depression.

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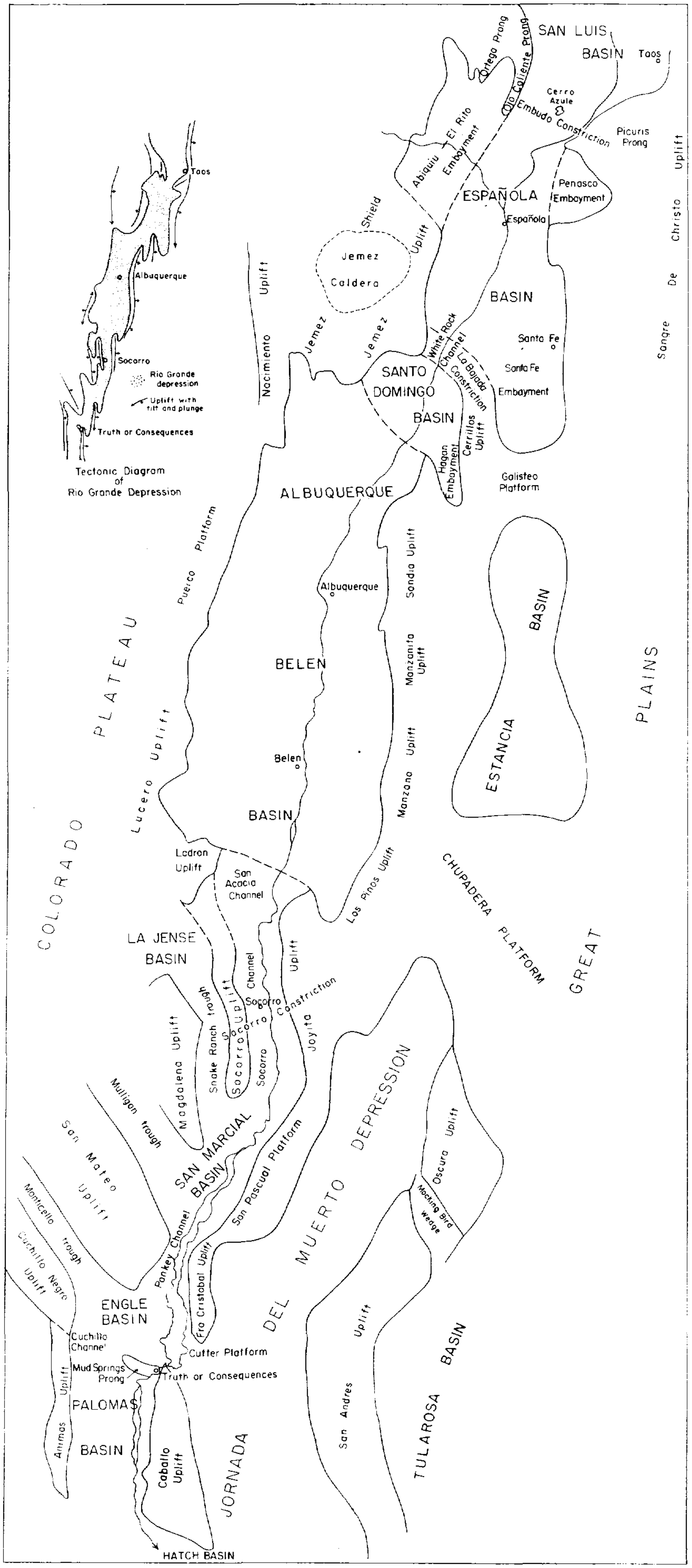

MAP OF A PART OF THE RIO GRANDE DEPRESSION
SHOWING MAJOR TECTONIC FEATURES