Tectonics of the San Juan Basin

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In the "Guidebook of the San Juan Basin" which accompanied the First Field Conference of the New Mexico Geological Society the major structural elements of the basin were described and its tectonic evolution was outlined (Kelley 1950, p. 101-108). The long geologic history and early controls upon the deformation of the area were pointed out. A brief comparison of the San Juan Basin with other basins in the Rocky Mountain region was made and the general theory of intermontane basin deformation was discussed. Most of the original paper, which was written as background material for the field trip along the east and north sides of the basin, is appropos to the present trip along the south and west side of the basin. This paper differs, however, from the earlier one in placing more emphasis upon the southern part of the basin and in pointing up certain structural contrasts between the southern and northern parts. Some duplication of material in the first paper is included here in order to make the present paper more or less complete in itself.

Location

The San Juan Basin is located in the northeastern part of the Colorado Plateau and is approximately the eastern half of the Navajo physiographic section of the Colorado Plateau Province. It is one of several large basins that are prominently interspersed or embayed into the ranges and chains of the great Rocky Mountain area between northern New Mexico and Canada. The San Juan Basin is in a sense a structural embayment of the Colorado Plateau into the southwestern edge of the Rocky Mountains.

The lowland part of the basin embraces 15-20 thousand square miles and is underlain by 25-30 thousand cubic miles of sedimentary materials above the pre-Cambrian basement. The northern and eastern rims are structurally complex. To the south the basin merges with a volcanic plateau and on the west the margin is locally complex but elsewhere merges with the western plateau.

The boundaries of the basin in many places are sharply defined whereas in other places the basin merges gradually into adjoining depressions or uplifts. Several sub-basins, re-entrants, or embayments extend from the basin proper into the adjoining uplifts and plateaus.

The structural boundaries of the basin are diverse and differ markedly on all sides. They consist principally of (1) large elongate domal uplifts, (2) low structural platforms or arches, and (3) abrupt upthrusts.

On the northwest, laccolithic masses such as Carrizo, Ute, and La Plata Mountains are set upon a low, wide structural platform between the San Juan Basin, on the one hand, the Paradox and Sage Plain Basins on the other.

On the north, the southwestern part of the San Juan Mountains with its pre-Cambrian core rises abruptly from the basin.

On the northeast and east, a series of low, relatively narrow, linked, and en echelon structural arches rather incompletely separate the San Juan Basin from the shallow Chama Basin.

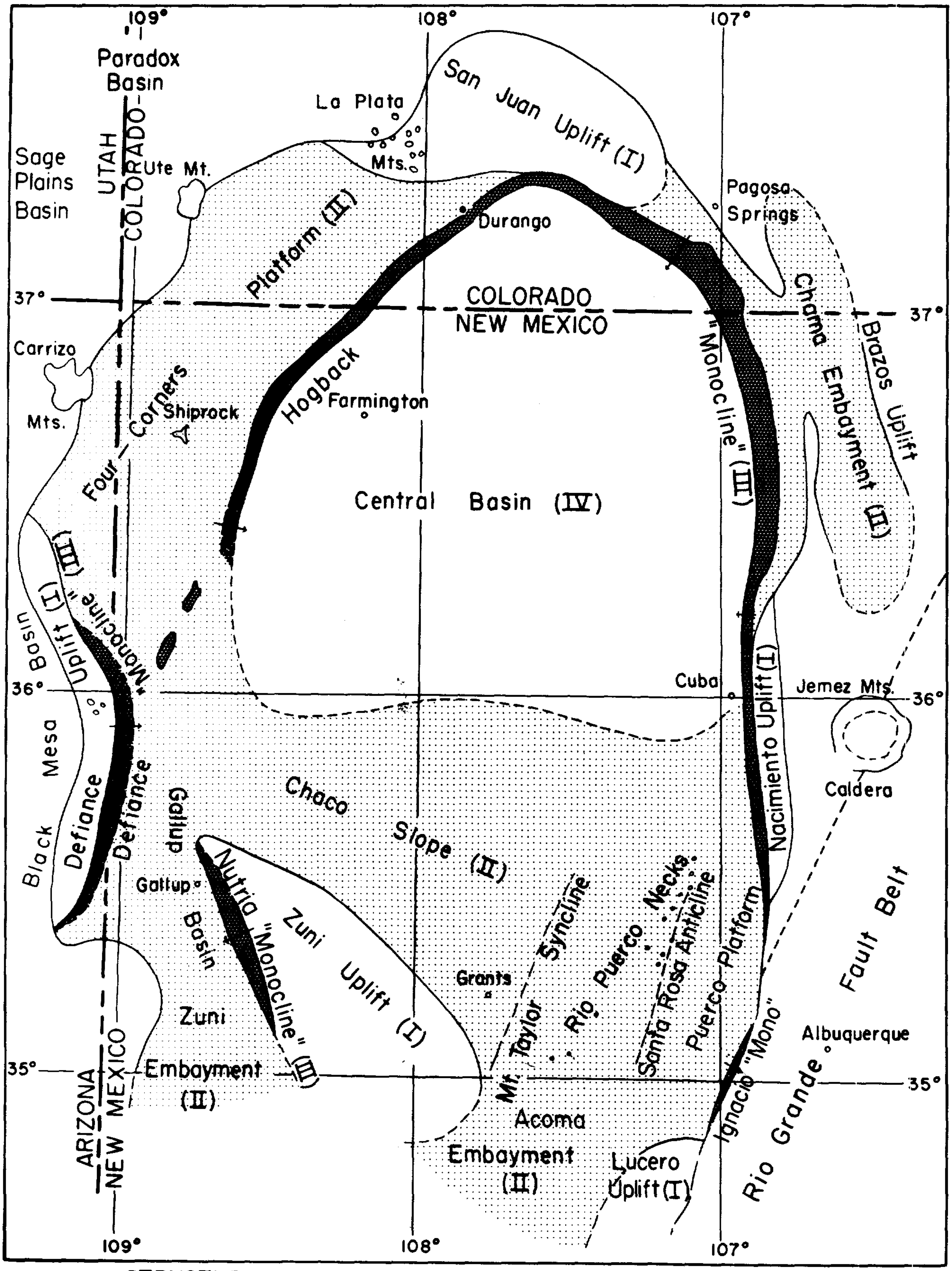
On the east, the most prominent structural boundary consists of the Nacimiento Uplift which is thrust westward at moderate to steep angles over strata of the basin.

On the southeast, the long, gradual structural rise from the basin terminates at the highly fractured belt which marks the west side of the Rio Grande fault trough.

On the south, the principal structural boundary is the domal northwestward-trending Zuni Uplift. At the east end of this uplift the boundary is at the south end of the low and wide Acoma embayment.

On the southwest, the northwestern end of the Zuni Uplift and the southern end of the domal Defiance Uplift form prominent structural boundaries to the basin. A long, narrow synclinal embayment comprising the Gallup and Zuni "Basins" leads southward between the above uplifts.

On the west, the Defiance Uplift forms a pronounced structural barrier between the San Juan Basin and the Black Mesa Basin of Arizona.



STRUCTURAL ELEMENTS OF THE SAN JUAN BASIN

Major Structural Elements

Four major structural elements may be delineated in the San Juan Basin–uplifts (I), structural platforms (II), "monoclines" (III), and the Central Basin (IV). Each of these elements is given a Roman numeral here and on the accompanying figure for the purpose of grouping.

The uplifts (I) include the Defiance, San Juan, Nacimiento, Lucero, and Zuni. Some of the principal features of these uplifts are shown in the following table.

Uplift	Trend	Length (in miles)	Width (in miles)	Structural Relief (in feet)	Steep Limb
Defiance	North	110	50	3,500-6,000	East
San Juan	Northwest	75	35	10,000	South
Nacimiento	North	50	20	2,000-8,000	West
Lucero	North	30	14	2,500	East
Zuni	Northwest	80	35	5,500	SW

The trends are either north or northwest; the lengths are slightly more than twice the widths; and the steep limbs face the basin in all except the Zuni Uplift.

The structural platforms or embayments (II) are relatively flat, wide, and low divide areas which alternate with the uplifts around the basin. They are as follows: Four-Corners, Chama, Puerco, Acoma, and Zuni.

Most of the petroleum production to date has come from the platforms. Singly and doubly-plunging anticlines and synclines are distributed upon the platforms in irregular fashion. Their axes are mostly parallel to the structural contour of the basin. Some folds are oblique and a few are nearly normal to the regional contour of the basin. High-angle faults of irregular strike are especially numerous in the Chama and Puerco platforms on the east side of the basin. The throw on many of these faults is small in relation to their length.

The Chaco slope (II) is the southern part of the San Juan Basin that lies between the Central Basin to the north and the Zuni Uplift and Acoma-Puerco platforms to the south. In part it bears a regional relationship to the Central Basin that is similar to the platforms. It differs from them, however, in its more pronounced and continuous regional inclination toward the center of the basin and by the absence of a "monocline" separating it from the Central Basin.

The "monoclines" (III) are perhaps the most distinctive features of the basin. They are the Nutria "monocline" on the southwest side of the Zuni Uplift, the Defiance "monocline" on the east side of the Defiance Uplift, and the Hogback "monocline" which borders the Central Basin on all sides except the south. The Nutria and Defiance "monoclines", facing each other, bound the Zuni embayment. By some the Hogback "monocline" is considered to be the principal boundary of the San Juan Basin and the feature is so pronounced that it has the effect of at least marking a basin within a basin. No other basin in the plateau or mountain provinces, with the possible exception of the Powder River Basin of Wyoming, has such a long continuous, and clearly marked "monoclinal" feature. In only a few places on the west side of the basin is the feature precisely a monocline. In most places the feature is a combination of an outer anticlinal bend and an inner synclinal bend. It is the steep flexure between these two axes that is designated as the "monocline" on the accompanying figure. In some places the dip of the upper limb of the anticlinal bend is only slightly less than that of the "monocline". It is common, however, for the inner limb of the synclinal bend to be quite flat or locally slightly reversed in direction of dip, but in many places it simply continues its basinward inclination only slightly less steep than the "monocline". The abrupt and nearly complete flattening of the inner limb is an especially noticeable feature of the structure. Along the Nacimiento thrust the "monocline" is associated only with the synclinal bend.

The Central Basin (IV), as designated on the accompanying diagram, is the floor or bottom of the basin. It lies inside the "monocline" by which it is bounded on all sides except the south. The Central Basin has a very long, low-dipping south limb and a relatively short north limb. The axis of the basin strikes northwesterly about through Governador. In terms of the "height" or top of the "monocline" the Central Basin has a depth of 2,500-8,000 feet. The outcropping rocks of the Central Basin area are largely the San Jose, Nacimiento, and Animas formations of early Tertiary age. Folds are fewer in the Central Basin than on the platform, and where present they are apt to be broad with gentle dips.

Special Features of the South Side

Owing to the fact that the Second Field Conference of the New Mexico Geological Society deals largely with the southern part of the San Juan Basin, certain of the major structures that are crossed along the route are described below.

The trip begins in the Rio Grande Valley which is part of a belt of intense fracturing extending north and south from Albuquerque for more than one hundred miles in either direction. The belt is 45-50 miles wide in the latitude of Albuquerque as shown on the accompanying map. The Plains province to the east of the belt and the Colorado Plateau provinces to the west are little deformed by comparison with the Rio Grande fault belt. The central strip of the belt is generally occupied by late Cenozoic sand, silt, gravel, and clay in a manner which has largely obscured "bedrock" structures of Laramide or Cascadian ages. However, dozens of faults and associated small folds are exposed along the margins of the belt, and it is possible that fracturing along the central part of the belt is more intense than along the margins. The strikes of the faults are in many places en echelon to the edges of the belt. In no place is this more strikingly illustrated than along the margin of the San Juan Basin west of Albuquerque as shown on the accompanying map. The individual faults of the en echelon set terminate or die out along a remarkably straight and nearly north line for about 25 miles.

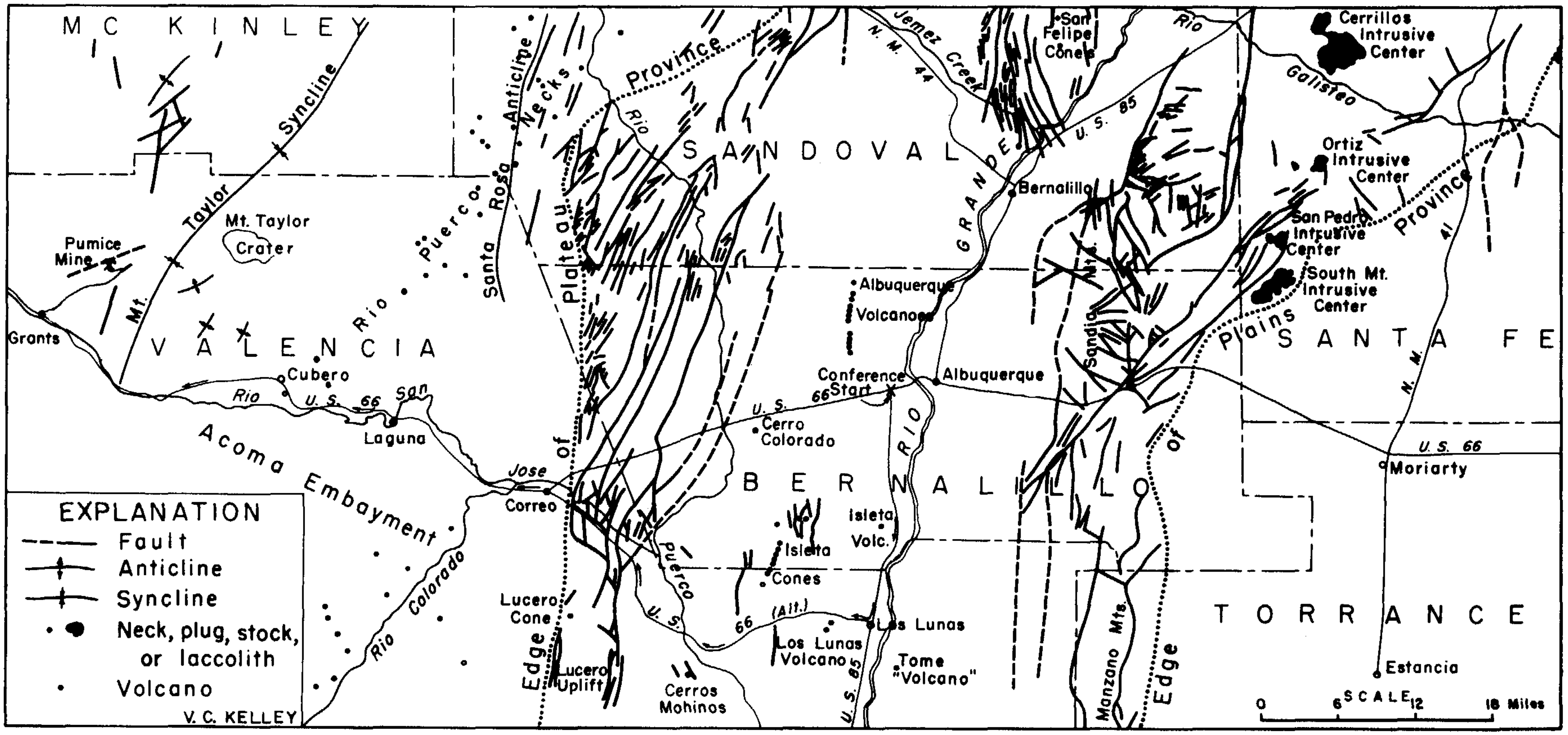
The Rio Grande fault belt has a complex history. Its development probably began in early Tertiary time when mostly thrust faults and sharp folds were formed. High-angle rifts and normal faults formed during late Tertiary time. The total pattern is shown on the accompanying map and no attempt is made to differentiate between the several types and ages of faults. The structure is complex and in some places it is troughlike and in others trenchlike.

West of the Rio Grande fault belt and the Lucero Uplift along the conference route is the wide Acoma embayment. In the Acoma embayment the beds are nearly flat but a gentle regional dip of about two degrees to the north prevails. The embayment from the San Juan Basin proper lies largely south of U.S. Highway 66. It is about 33 miles wide and possesses a flat profile in a traverse or section between Lucero and Zuni Uplifts. Somewhere in the Acoma embayment, probably near the center and of northwesterly trend the thick Magdalena group (Pennsylvanian), which is about 2,000 feet thick in the Lucero Uplift and nearly absent in the Zuni Uplift, wedges out.

In the southeastern part of the San Juan Basin and north of the Acoma embayment the regionally broad and flat structure is interrupted by the relatively large Mount Taylor syncline and Santa Rosa anticline together with numerous smaller folds and faults. Most of these features are of north-northeasterly trend. One of the most striking geologic features of this area is the belt of basaltic plugs known as the Rio Puerco necks. It is to be noticed that the trend of the belt of necks forms an acute angle with the axis of the Santa Rosa anticline which it crosses.

Between Grants and Gallup the Zuni Uplift forms the southern margin of the San Juan Basin. The Zuni Uplift is a structural island in the southern end or part of the basin. If the Zuni Uplift did not exist the southern limit of the San Juan Basin would surely be chosen many miles to the south. Without the Zuni Uplift the San Juan Basin would be shaped like a slightly inclined, elongate spade with its point to the north. Its long north-trending axis would be more evident than it is now.

West of Gallup another nearly flat-bottomed embayment intervenes between the Zuni and Defiance Uplifts. This is known as the Gallup syncline at the north end and the Zuni embayment at the south end. In the latitude of Gallup hogbacks formed by the Nutria and Defiance "monoclines" bound the flat-bottomed embayment or syncline. The embayment plunges very gently northward.



TECTONIC MAP OF PART OF THE SAN JUAN BASIN AND THE RIO GRANDE TROUGH

General Tectonic Evolution

The San Juan Basin has had a long tectonic history much of which is reflected in its sedimentary record. Mobile axes of uplift were developed along parts of its border as early as late Paleozoic time, and although recurrent uplift and minor deformation took place at various places and from time to time during the Mesozoic era, it was probably not until very late Cretaceous and early Tertiary time that the principal present structural features began to form. The great Hogback "monocline" which largely outlines the Central Basin was initiated during this early Laramide interval. The large bordering uplifts such as the Defiance, Zuni, San Juan, and Nacimiento which had been active recurrently during Paleozoic and Mesozoic time were accented along their present lines in Laramide time. Locally on several sides of the basin the lower as well as the upper beds of the Paleocene and Eocene rocks lap across plicated edges of Upper Cretaceous beds. In other places the Tertiary beds appear conformable with the uppermost Cretaceous strata in the "monoclinal" flexures. Thus, uplift of the outer rim areas appears to have begun locally in very late Cretaceous time, but the deformation spread gradually to the inner rim of the basin at the end of Eocene time when the Laramide orogeny culminated. Pre-Cambrian fragments first appear in abundance in the lower Tertiary beds and constitute evidence of the profoundness of the uplift, the vigor of erosion, and the relative thinness of the sedimentary cover along the axes of the uplifts. Although the evidence is not conclusive there is some suggestion from the nature of early Tertiary beds beyond some of the bordering uplifts and outside the basin that at least parts of the San Jose formation may have extended beyond the limits of the present basin probably in great structural or erosional embayments. Thus parts of the San Jose formation may have extended across the present sites of the Nacimiento, Jemez, Zuni, Defiance, and San Juan Uplifts during Eocene time.

Middle and late Tertiary sediments or volcanic rocks rest upon rather mature surfaces cut across older rocks including wide areas of pre-Cambrian rocks exposed in the cores of some of the earlier uplifts. Some of these rocks in the San Juan Mountains attain thicknesses of several thousand feet immediately bordering the basin. Volcanic dust and alluvial material from the volcanic centers may have covered the entire basin during parts of middle and late Tertiary time. According to Atwood and Mather (1932) the San Juan Mountains were domed and broad-tilted eastward in Pliocene time and it appears that the entire San Juan Basin area together with the Colorado Plateau and much of the central part of the continent were widely elevated by the end of Pliocene time. As a result of this great uplift drainage lines from east and west of the continental divide encroached upon the basin and removed the relatively thin, late and middle Tertiary layers as well as uppermost early Tertiary beds from the central part of the basin.

On the basis of stratigraphic relations found very locally in some of the uplifts bordering the basins and indirectly by analogy with known tectonic events in adjoining areas of New Mexico and Colorado it appears very probable that some deformation and uplift occurred around the San Juan Basin during middle Tertiary time. Such activity was probably sporadic and recurrent but not synchronous around the basin. In any event the middle Tertiary deformation is less manifest than that which appears to have culminated toward the end of late Tertiary time. It appears that the San Juan Basin may have been given an additional relative downwarp during the very broad late Tertiary uplift of the entire region, and at the same time certain of the bordering uplifts were markedly accented. This is especially true of the Nacimiento Uplift which was probably elevated on the Nacimiento thrust under the action of profound rifting which is so prominent along the Rio Grande fault belt.

The details of deformation in the platforms and flanks of the uplifts are the result of complex "splitting" and deflection of the large forces as they moved the major structural yield units such as the uplifts with their irregular and diverse cores. It is difficult, of course, to satisfactorily orient the major forces, and whereas they may have been east-west in early Tertiary time, they may have been northerly in late Tertiary time. Either of these major forces may have given rise to local secondary and tertiary directions as they motivated the major yield units.

One of the principal secondary forces set up during basinal downwarp is tangential to the rim and it results in shrinkage of the perimeter of the basin. As downwarping proceeds the outer parts of the beds are "pulled" toward the center of the basin and therefore must occupy a smaller area. One would expect radial fold axes from this action, and they are indeed present, especially in basins that approach circularity, such as the San Juan. On the other hand, tangential fold axes (parallel to the rim) result from either a push from a rising and expanding uplift or from differential confinement of the strata in the flanks of the uplift area. Both may work together. Upthrusts of basement or other competent masses may furnish an abutment against which basin sedimentary units move differentially up the flanks of the basin with respect to the underlying units. If an upthrust confinement is formed, the differential movement in the sedimentary units tends to fold the upper units somewhat more than the lower ones. Theoretically at least, the differential movement results in a decollement and the formation of allochthonous folds which terminate abruptly on a lower unit or "floor" of less crowded and possibly more competent rock.

In addition to confinement by upthrusts, confinement to the differential up-dip movement in younger units results from stratigraphic pinchouts, overlaps, and local unconformities all of which are common in the beds along the flanks of old geanticlines. Buckling or warping of the confined strata and overlying beds may result.

A characteristic feature of San Juan Basin structure is an apparent localization if not a concentration of folds "behind" or just outside the Hogback "monocline". If the "monocline" results largely from vertical force, this localization becomes difficult to understand. If, on the other hand, the "monocline" is the result of inward directed forces from the uplifts, the development of folds on the platforms "behind" the "monocline" is easier to understand. Some possibility exists that the Hogback "monocline" on the west side of the basin overlies a steep outward-dipping thrust at depth. From another point of view the Hogback "monocline" may represent the early deformational stage and the Nacimiento thrust the late stage. Additional mapping at the north end of the Nacimiento thrust may demonstrate what is already suggested there, that the thrust passes gradually on the surface and at depth into the "monocline" which bounds the Chama platform on the west. The structures along the east side are undoubtedly the result of several deformations.

The cause and mechanics of formation of intermontane basins are rather imperfectly known or understood. One of the fundamental questions is whether the activating forces of basin formation arise within the basin or in the bounding uplifts. Fanshawe (1947, p. 180) envisions that the uplifts are the result of deformation initiated in the basin and that the uplift structures are the "by-product" of competition between adjacent basins. Aside from the relative nature of the movement between the uplifts and the basin, it is important to recall that both have been elevated on a broad regional base on the order of about one mile since late Cretaceous time. In view of the marginal thrust faults on the east and the inward facing "monoclines" it appears more likely that the basin results from the crowding action of the uplifts and platforms under horizontal compressive forces.

In summary, the tectonic evolution of the San Juan Basin began at least as early as late Paleozoic time. The present basin is a result of geologically slow growth along very old mobile belts. The northern or Uncompahgre geanticline was regenerated repeatedly whereas the southern geanticline in the area of the Zuni and Defiance Uplifts was probably much less active. The early formed arches controlled the position and nature of the more intense late Cretaceous and Cenozoic deformation. The modern aspect of the basin began developing in late Cretaceous time. During late Cretaceous and early Tertiary time the deforming mobile rims widened and progressively encroached upon the basin. Viewed broadly the basin is a downwarp resulting from the upward bulge and outward spread of uplifts which were active recurrently throughout Cenozoic time. It appears probable that the present structural elements including the domal uplifts, the platforms, and the "monoclines" were largely developed by middle Tertiary time. Some basinal downwarping and local marginal uplift probably recurred during middle Tertiary time and additional downwarping and accentuation of the uplifts on the north and east sides appears certainly to have taken place in late Tertiary time.

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