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The structure and geomorphology of west-central New Mexico--A regional setting

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THE STRUCTURE AND GEOMORPHOLOGY OF WEST-CENTRAL NEW MEXICO
A Regional Setting
by J. Paul Fitzsimmons [1]

The area included in this survey is that part of New Mexico between (and adjacent to) U. S. Highways 66 and 60 from the Rio Grande to the Arizona state line. This area is mainly in the southeastern part of the Colorado Plateau, but also it overlaps into the Rio Grande trough. This structural depression has been assigned by some writers to the Basin and Range Province, and by other writers to the Southern Rocky Mountains, or to a special zone representing a transition between the Colorado Plateau and the bordering provinces. The region contains extensive flat areas and numerous mountains or mountain ranges which are mostly volcanoes or volcanic accumulations of Tertiary age. Locally, where sedimentary rocks predominate, the landscape is one of mesas and buttes, and bench and slope topography is well developed.

Locally the effect of geologic structure is evident in the landscape. Elsewhere, where surface rocks display no great differences in resistance to erosion, major erosion surfaces have been cut across strata with little regard to attitude of the formations.

The relief of the area is nearly 7,000 feet, ranging from about 4,500 feet along the Rio Grande at Socorro to 11,389 feet at the crest of Mt. Taylor. The structural relief is much greater. Precambrian rocks crop out in the Zuni Mountains, the Ladron Mountains, and the mountains of the Socorro-Magdalena area, whereas Tertiary and Quaternary igneous and sedimentary rocks form the surface of a large part of west-central New Mexico.

That part of the Colorado Plateau lying within the field-trip area comprises a segment of the Navajo section (the southern edge with its border features) and most of the Datil section. The boundary between these sections is not distinct everywhere, being gradational and having overlapping features. It is appropriate to discuss the region in terms of structural units which have characteristics that permit them to be delineated geographically and to be examined as geologic entities. These structural units include the following (see fig. 1):

1. Zuni uplift
2. Gallup embayment
3. Acoma embayment
4. Rio Puerco fault zone
5. Lucero uplift
6. Lemitar-Socorro-Magdalena zone
7. Rio Grande trough
8. Mogollon slope

ZUNI UPLIFT

The Zuni Mountains are carved from an elongated northwest-trending structural uplift, 75 to 85 miles long and half as wide. This uplift generally is considered to be the southern boundary of the San Juan Basin, although it does not extend to either the western or eastern margins of the basin (the Defiance uplift and the Rio Puerco-Lucero zone, respectively). Around the ends of the Zuni uplift the basin stretches on to the south, dying out gradually in the Gallup (or Zuni) embayment on the west, and in the Acoma embayment on the east. Precambrian granitic and metamorphic rocks crop out and form the core of the up-

lift. These rocks are flanked by outward-dipping late Paleozoic and Mesozoic strata. These sedimentary formations are gently inclined on the north and northeast sides of the uplift, but dip steeply on the southwest side.

The structure of the southeastern end is complicated by faulting and obscured by a lava cover. The higher altitudes in the mountains reach 9,000 feet above sea level. The topographic relief is on the order of a thousand feet, but the structural relief is more than 5,000 feet. Both radial and tangential faults are associated with the uplift. The radial faults are most common on the northeastern corner of the range; the tangential faults are better expressed along the south and west. The radial faults are shorter but have greater throws than the tangential faults which may extend for several miles with no more than 200 feet of stratigraphic throw.

The terrain in the main part of the Zuni Mountains is not particularly rugged. It is more of a rolling upland with local deepening around the margins of the central core of crystalline rocks, where stream gradients have steepended because of removal of the softer flanking sedimentary strata. Remnants of an older erosion surface may be observed in places bevelling these strata. The present cycle of erosion has developed numerous cuestas sloping gently away from the nucleus of Precambrian rocks. On the southwest along the Nutria fold where the rocks are bent downward at sharp angles, differential erosion has formed steeper hogback ridges.
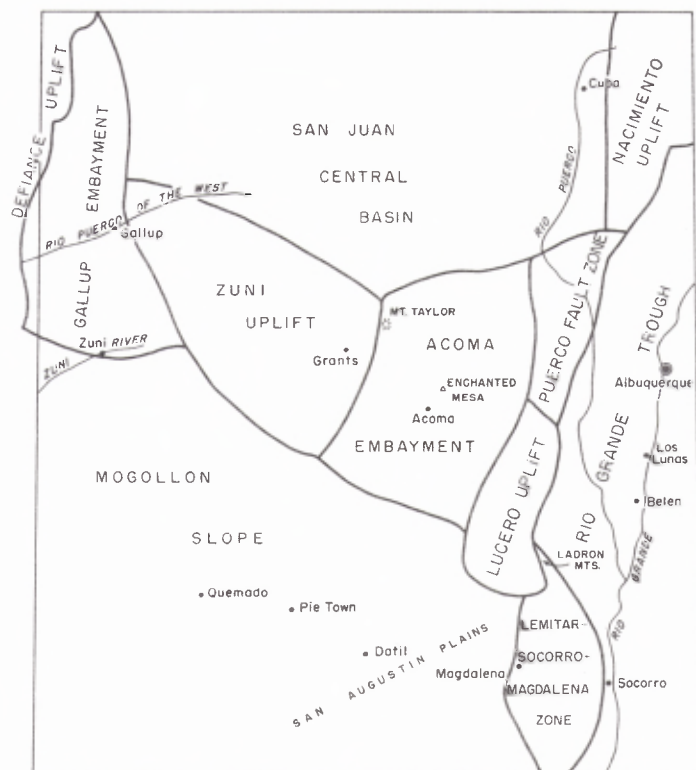

Figure 1.- Sketch map showing distribution of structural units in west-central New Mexico.

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GALLUP EMBAYMENT

The Gallup embayment occupies the area between the Zuni uplift on the east, the Defiance uplift on the west, the main part of the San Juan Basin on the north, and the Mogollon slope on the south. The embayment is elongated along a north-south axis which extends 70 or 75 miles. It is rather narrow at the north end (8 to 10 miles wide) where the Defiance monocline bulges to the east, and it broadens to the south where, in the vicinity of Zuni Pueblo, it has a width of less than 30 miles. The eastern boundary of this feature at the north is the indefinite connection between the Zuni uplift and Beautiful Mountain anticline. The embayment is a structural trough with a relatively flat bottom, the lowest line of which is on the eastern side of the trough. The plunge of the structure is to the north at about 60 feet per mile. Several small north-northwest trending anticlines and synclines modify the Gallup embayment. The principal anticlinal structures in this group are the Cedar Butte dome, about eight miles southeast of Gallup, the Defiance (Torrivio) anticline, about 10 miles west of Gallup, the Gallup dome, about 2 miles southeast of Gallup, the Ojo Caliente anticline, just south of Ojo Caliente Pueblo, and the Pinon Springs (Manuelito) anticline, along the state line. Faulting appears to have been a very minor phenomenon in this region.

A rather pronounced erosion surface in this area slopes westward or slightly southwestward and bevels Cretaceous and older strata. The Zuni Mountains to the east rise above this surface in a long irregular ridge. Within the area of the Gallup embayment the surface is now incised by the present streams and slopes to the west at an angle steeper than the gradients of the present streams such as the Rio Puerco of the West and the Zuni River. Late Tertiary and Pleistocene beds, containing fresh-water molluscan fossils, rest upon the older erosion surface and have been dissected in turn by the most recent erosion.

ACOMA EMBAYMENT

Folded and faulted Cretaceous and older strata lie east of the Zuni uplift, between that structural feature and the Lucero uplift. This zone is called the Acoma embayment or basin. There is little structural demarcation at the north where the Acoma embayment grades into the San Juan Basin proper, or at the south where the embayment dies out on the Mogollon slope. At the north beyond the Lucero uplift, this embayment gives way eastward to the Puerco fault belt. The embayment is marked throughout by features of volcanic origin. Mt. Taylor is situated in the northwest corner along the axis of McCartys syncline which is the major structural trend in this part of the embayment. Volcanic centers of smaller size are around Mt. Taylor, along the Rio Puerco, southeast of the Zuni Mountains, and farther to the south.

A number of anticlines and synclines modify the structure of the southern part of the Acoma embayment. The general trend of these folds is northerly to northwesterly, although a few trend northeastward locally. Most of the folds exhibit faulting of differing intensities. The principal anticlinal structures at the southern end of the Acoma embayment are, from west to east, Cow Springs anticline, Red Lake anticline, Upper Red Lake anticline, La Cruz anticline, Payne anticline, Field anticline, Miller anticline, and Lawson anticline. A major north-trending fault cutting the Red Lake anticline brings Triassic beds into contact with sandstone of the Mesaverde group. The folded and faulted structures listed here are found in the upper drainage of Alamosa Creek and the Rio Salado. The regional dip of the strata here, (excluding local dips of the modifying folds) is to the southwest at a modest angle. At the southeast corner of the embayment the dips are more to the east and southeast and are steeper. At the north end of the Acoma embayment the general dip is one or two degrees to the north into the main part of the San Juan Basin.

An old erosion surface graded to some stage of the ancestral Rio Grande is preserved in numerous remnants throughout the region of the Acoma embayment. The most prominent erosion surface borders Mt. Taylor and is armored by a protective layer of basalt on Mesa Chivato and similar smaller surrounding mesas. During the most recent cycle of erosion the older surface was dissected, and it is represented now by numerous broad, flat valleys, and by numerous mesas and buttes such as Acoma Mesa and Enchanted Mesa which are monolithic residuals of Zuni sandstone.

RIO PUERCO FAULT ZONE

The east side of the Colorado Plateau is marked along much of its length by large structural features. Between the Nacimiento uplift at the north and Lucero uplift at the south the margin is much less definite and precise. Here it is marked by a transitional zone—the Rio Puerco fault zone—between typical Colorado Plateau structure and the Rio Grande trough. Inasmuch as the Nacimiento uplift is tilted to the east and the Lucero uplift is tilted to the west, a zone of adjusment between them is to be expected. At the south end of the Rio Puerco zone the faults are mostly north-trending, or nearly so. On the north end the trend shifts to the northeast and ranges from N 20° E to N 30° E. The zone as a whole, however, has a northerly trend, and the faults terminate en echelon along the western margin where they are oblique to this northerly trend. The eastern margin of the zone is in great part obscured by a mantle of Tertiary sedimentary rocks.

The faults are mostly normal, with the downthrown side on the west. However, because the Paleozoic and Mesozoic strata dip to the east, any particular stratigraphic horizon occurs at greater and greater depth toward the Rio Grande trough despite the partially compensating effect of blocks upthrown to the east. Displacements along the faults generally are small; however, displacements along a few faults may be as much as two thousand feet.

The erosion surface noted in the Acoma embayment is represented also in this zone by remnants. The Rio Puerco and its tributaries have dissected this surafce extensively. The positions of small hogbacks and cuestas at a few places appear to have been controlled by faulting. A principal erosional feature along the Puerco drainage is a series of volcanic plugs which form prominent peaks above the softer Cretaceous sediments.

LUCERO UPLIFT

The Lucero uplift separates the southern part of the Acoma embayment from the Rio Grande trough. The Lucero uplift is asymmetrical and trends nearly north. The strata bend down sharply into a fault zone on the east side, but they dip gently to the west on the wesern side. The north end of the uplift is broken by a series of faults that mark the south end of the Rio Puerco fault zone. The formations that appear at higher elevations along the main axis of the Lucero uplift are depressed by the Rio Puerco faults. The south end of the Lucero uplift merges also with a fault zone that depresses the crestal formations of the uplift.

The Lucero uplift is about 40 miles long and it averages about 10 miles in width. The topographic relief on the east side is not large, but the overall structural relief may be on the order of 20,000 feet. The fault or fault zone along the east side where overturning has been observed was thought by Kelley and Wood (1946) to be a thrust. Duschatko (1953) stated that the overturning might be due to a landsliding type of gravity adjustment along a normal fault.

Remnants of an old erosion surface are preserved on the higher part of the Lucero uplift. This surface appears to have been continuous once with the surface preserved under the lava flows of Mesa Chivato. There are, in fact, lava flows along the crest of the Lucero uplift which protect the remnants of the erosion surface in this locality. The present relief of the Lucero upland above the surrounding region is due in great part to erosion in latest Tertiary and Quaternary time. The relatively soft sediments on which the eastern continuation of this surface was cut, probably in late Tertiary time, were eroded later and only the lava-capped remnants on the Lucero uplift were preserved.

LEMITAR-SOCORRO-MAGDALENA ZONE

The Lemitar-Socorro-Magdalena zone is by no means a structural unit, but the parts occupy a geologic segment, and they have several features in common that permit their being discussed together. They occupy the southeastern part of the field-trip area and form the border of the Rio Grande trough in that district. The Lemitar-Socorro segment of the unit extends southward from the Ladron Mountains, which are a connecting link between this segment and the Lucero uplift to the north. The Lemitar-Socorro unit is separated from the higher Magdalena uplift by La Jense basin and the Snake Ranch trough. These structures are the northern representatives of a series of uplifts and troughs arranged en echelon along the western border of the Rio Grande depression. South of Socorro these structures trend approximately northwest, but at the Magdalena segment and continuing through the Snake Ranch trough and the Socorro-Lemitar-Ladron unit, the trend swings to nearly north.

The Magdalena uplift and the Socorro-Lemitar uplift are fault block structures. The Snake Ranch trough and La Jense basin form a graben between the uplifts. The Magdalena block has been uplifted much more than the Socorro-Lemitar block. This district is characterized also by extensive volcanic deposits. Shallow intrusions, flows, and pyroclastics all are abundant.

In the Magdalena district several pediments represent different stages of uplift. Farther north, near the northern end of the Lemitar-Socorro segment, a number of erosion surfaces are said to be graded to the level of the "current" Rio Grande (Denny, 1941). There seems to be little doubt that uplift in late Tertiary and Quaternary time was spasmodic, and it is equally sure that streams would attempt to adjust themselves to the new conditions. Knowledge of faulting in the region causes some suspicion of the conclusions regarding erosion surfaces. It is not yet clear how many of the surfaces may be new surfaces, cut to new positions of base level, and how many are only remnants of a former surface tilted to new angles by the deformation that presumably led to renewed itensity of stream erosion. Surely, some of the surfaces are remnants of an older erosion surface corresponding with the surface that topped Mesa Lucero and Mesa Chivato.

RIO GRANDE TROUGH

The Rio Grande trough is a structural unit in the broad sense, but does not consist of a single graben or axial depression. Most of the structures that border it, and in a sense produce it, are arranged en echelon and trend generally northwest. The structures within the main depression are similarly arranged. The present Rio Grande valley may be considered as an intergrated system of linked basins. Some of these basins are very deep, some rather shallow; all have been filled to the present level by sand, silt, and mud eroded from the neighboring highlands. The basin-filling sediments are classed generally together as the Santa Fe formation or Santa Fe group. Because of the differences in depths of the basins, the thickness of the Santa Fe formation is variable. In places the strata appear to be deformed only slightly. Elsewhere they are gently inclined, and locally they may be tilted nearly to vertical along the bases of bordering fault blocks. Except for local accumulations of caliche and gravel the strata are more or less uniform in resistance to erosion and, consequently, structural control on landscape patterns is minor. The main part of the Rio Grande valley has been lowered below the previously mentioned erosion surface which appears to have been graded to some stage of the ancestral Rio Grande. West of Albuquerque, along the border between the Rio Grande trough and the Puerco fault zone, a remnant of this older erosion surface is preserved on the divide between the Rio Grande and the Rio Puerco. The remnant is about 70 miles long and 12 miles wide, and is called the Llano de Albuquerque. Its western margin, especially along the northern half, is coextensive with the en echelon faults of the Rio Puerco fault zone. Southward the western margin of the Llano de Albuquerque is not so precisely related to the fault zone.

The margins of the Rio Grande trough, especially the western margin, are marked by aligned volcanic centers. Small fissure eruptions and small volcanic centers along the lines of these fissures are numerous. Except for these, the principal feature of the Rio Grande valley is a fairly broad floodplain cut below the level of the older erosion surface. Remnants of the older surface are now terraces above the present valley. This line of terraces is being dissected by numerous intermittent tributaries of the modern Rio Grande. Locally, resistant basalt lies on the older erosion surface and small basalt-capped mesas and buttes are being developed as surrounding softer sediments are eroded away. Isolated volcanic cones have been dissected very little since their formation.

MOGOLLON SLOPE

The Mogollon slope is the southern part of the Colorado Plateau and, in many ways, is a rather nondescript structural unit. In general the sedimentary rocks in this unit dip gently to the south. The slope is dotted by accumulations of volcanic rocks of many types. Along the south end only volcanic rocks, or sedimentary deposits derived from them, are to be found. At the north end, older sedimentary rocks may be observed in places, and the volcanic rocks form local ranges or indivdual mountains. The precise southern boundary of this unit is not easy to delineate everywhere. Along the Mogollon Rim, where faulting has produced a prominent escarpment, the margin is drawn closely. But in much of New Mexico the volcanic accumulations are so thick that, although faults are present, a sharp line cannot be perceived.

The structural character of this part of the Mogollon slope in New Mexico played an important part in controlling distribution of sediments, especially in early Paleozoic time. A positive element here held the seas of the Ouachita trough south of this region. Little is known of the effect of this positive element on early Paleozoic sedimentation, but it appears certain that the distribution of Cambrian, Ordovician, Silurian, and Devonian rocks was controlled by this feature. The area of the present Mogollon slope appears to have been distributed in Mississippian time when seaways in New Mexico were more erratic than at any other time earlier in the Paleozoic. In Pennsylvanian time the area had certain positive aspects, but it was modified strongly by the development of a well-defined basin (the Quemado-Cuchillo axis) during the Permian. In part, however, it continued to control distribution of sediments into the early or middle part of Triassic time. A considerable thickness of Late Triassic sediments were deposited upon the area of the Mogollon slope. However, after the deposition of these sediments, the area of the Mogollon slope, or a part of it, developed into a more definitely positive area than before, and it became a primary source of much of the Late Triassic and Jurassic sands that lie to the north.

At present, Tertiary volcanic rocks upon the surface obscure older rocks of much of the region. A detailed geologic history of this area awaits more detailed work, especially drilling. An area with such a geologic history deserves more attention than it has received thus far.

Topographic features on the Mogollon slope are chiefly constructional; they are due principally to volcanic accumulations. A prominent surface that draws the eye of anyone travelling through this region is the large, enclosed, alluvium-filled basin known as the San Augustin Plains. It is surrounded by hills and mountains, most of which are volcanic in origin. The basin was occupied by an ancient lake, and shore features are especially well displayed at the south end of the hills south of Horse Springs. These features are wave-cut cliffs and gravel beaches. Other remnants are found in several places, especially along the southern shore. The total area of the lake was about 255 square miles and the maximum depth of water was about 165 feet at the highest stage. The lake occupied about 13 percent of the total drainage area of the basin.

Some writers have considered the basin to be a fault basin, of the Basin-and-Range type. Others think it to be a basin more or less by accident as the result of the piling up of volcanic material in a ringing barrier. A few have considered the possibility that this is a great caldera, principally because the bordering volcanics are notably acidic and because this type of rock is thought to be associated often with the last gasp of volcanic activity in or bordering calderas. Future investigations with these possibilities in mind may supply an answer to the origin of the basin.

GENERAL GEOMORPHOLOGY OF WEST CENTRAL NEW MEXICO

The Mogollon slope exhibits no overall erosion surface. It is an area of individual ranges dissected by the streams draining them, and of depositional slopes and flats. The mountains and mountainous districts are flanked by alluvial fans many of which, in the region of former Lake San Augustin, are encroaching on the level lake floor.

To the north, individual volcanic centers also strongly modify the landscape, but remnants of regional erosional surfaces are found preserved in many localities. In general,

these erosion surfaces may be related to two principal drainage systems: the Colorado (and Little Colorado) River; and the Rio Grande. One erosion surface obviously slopes westward, and the other surface slopes eastward (or southeastward). The westward-sloping surface is best developed in the region west of the Zuni Mountains near Zuni Pueblo south of Gallup, but has been recognized also on the summit of the Chuska Mountains and on the northeastern part of Black Mesa. The present grade on this surface is between 25 and 30 feet per mile. This gradient is almost twice that of the streams that now flow across the region. The streams which have been incised in many places expose the surface beneath the mantle of sediment that accumulated upon it.

This surface, called the Zuni surface, truncates Cretaceous and older strata and is overlain, where it is still preserved, by late Tertiary and Quaternary(?) deposits consisting of flood-plain sediments, alluvial fans, volcanic ash-falls, and local paludal and lacustrine beds. Regional warping caused rejuvenation of the streams, probably in several episodes, inasmuch as the Zuni River and the Rio Puerco of the West display several terraces along their courses. These streams and their tributaries exhumed the earlier surface at a number of localities. Elsewhere, where the streams have cut through it, the surface appears as a mere trace in arroyo walls. The present streams flow at levels 600 to 700 feet below this ancient Zuni surface.

The age of the Zuni surface is thought to be middle Pliocene. Later erosion surfaces are undoubtedly present, but none seems to be extensive enough to be of regional correlative value. At the time the Zuni surface reached its greatest development, the Zuni Mountains apparently stood above the truncated strata in a long ridge of crystalline rocks. Recent dissection of the surface and its mantle of poorly consolidated sediments has permitted tributary streams to cut down into the Cretaceous and older strata and to etch out subsequent features—cuestas, hogbacks, buttes, and mesas.

On the eastern side of the late Tertiary continental divide, another erosion surface developed. This surface (in the field-trip and adjacent areas) sloped generally to the southeast from a highland area in the central part of the present San Juan Basin toward the ancestral Rio Grande. This river occupied a geographic position similar to its present course, although it has undoubtedly shifted laterally throughout Tertiary and Quaternary time.

This erosion surface—generally called the Ortiz surface after the conoplain developed around the Ortiz Mountains—truncates a number of strata of different ages, the youngest of which belong to the Santa Fe formation of Miocene-Pliocene age. Some writers consider the Santa Fe formation to include all basin-filling sediments in the Rio Grande valley and tributary valleys, and thus to embrace sediments ranging in age from Miocene to Recent. However, the sediments cut by the Ortiz surface appear to be chiefly pre-Pleistocene in age.

As noted in the discussions of individual sections, remnants of this erosion surface may be found beneath the lavas of Mesa Chivato and Mesa Lucero, on the upland of the Llano de Albuquerque, and in several less extensive areas. The history of the Ortiz surface is similar to that of the Zuni surface, and the Ortiz surface also has been dissected by rejuvenated streams flowing across a region subjected to warping. The valleys of the Rio Grande and the Rio Puerco have been cut to levels below this surface.

Detailed work on correlation between the Ortiz surface and the Zuni surface remains to be done. It has been suggested that they are contemporaneous, and this seems logical in view of the time and the necessary stability required to develop such surfaces. In regard to ages of strata affected by the erosional process, the Zuni surface may appear to be somewhat the older, but a synchronous age for the two is not contradicted by any evidence now at hand.

SUMMARY OF STRUCTURAL AND GEOMORPHIC DEVELOPMENT

The structural and geomorphic features to be observed within the field-trip area are principally Cretaceous and Cenozoic. Pre-Cretaceous history has left little direct imprint on the landscape. The positive area that occupied the site of the present Mogollon slope controlled the distribution of early Paleozoic sediments and served, in part, as a source area during Mesozoic time. Such early history is now obscured, however, by superposed accumulations of volcanic material and by sediments derived locally from the individual centers of volcanic accumulation. The Zuni positive area was probably in existence during much of Paleozoic time. There is no evidence of early Paleozoic deposition on this positive area, and not until Permian time was sedimentary accumulation of any great consequence. From then until Late Cretaceous time, the Zuni positive area was low and received considerable thicknesses of clastic debris, and was covered by the sea during Permian time and also during Cretaceous time, although the thickness of marine sediments over the Zuni axis is not as great as in neighboring regions. With the beginning of Laramide disturbance, the Zuni positive area reasserted itself and began to develop the domal structure we observe today. However, deformation was not as severe here as in other districts marginal to the San Juan Basin. Uplift, which began in Late Cretaceous time, continued spasmodically through the Tertiary, and lasted into Quaternary time.

The general features of the landscape, as we see them today, began to appear in Cretaceous time, as a consequence of incipient Laramide deformation. The first deformation may have been warping principally, but faulting soon followed. Mountainous areas were formed to the north and the Rio Grande depression began to appear on the east in middle Tertiary time. Erosion of the highlands caused filling of the basins and, as the mountains were worn down, erosion surfaces developed across the bevelled edges of older and younger beds alike. Subsequent uplift has caused streams to cut into these surfaces, and to initiate at lower levels new erosional surfaces which have not yet had sufficient time to become large regional features.

Faulting and accompanying volcanic eruptions have occurred throughout Tertiary and Quaternary time. Lavas intercalated between basin-filling sediments and faulted lavas and basin sediments attest to continued and contemporaneous faulting, sedimentation, and volcanic activitiy.

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