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TECTONICS OF THE ZUNI-DEFIANCE REGION, NEW MEXICO AND ARIZONA

By

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TECTONIC MAP IN POCKET

INTRODUCTION

The Zuni–Defiance region as considered here embraces some 12,000 square miles of northwestern New Mexico and adjoining northeastern Arizona. It straddles the continental divide and is crossed in the southern part by transcontinental U. S. Highway 66 (Interstate 40). It is a highland area ranging from about 5,500 feet in some of the valleys to 8,000 or 9,000 in the mountainous and plateau areas.

The region lies in the south-central Colorado Plateau Province and is perhaps the most important area of the southern portion of the plateau from the point of view of population, transportation, industry, and resources. It contains most of the uranium reserves and output of the United States and significant production of coal, oil, bentonite, helium, perlite, pumice, and fluorspar.

Tectonically the region is dominated by the large Zuni and Defiance uplifts which lie staggered around the southwestern side of the San Juan Basin. These uplifts together with their intervening counterpart, the Gallup sag, essentially constitute the structure of the region. However, a small part of the Acoma sag and its McCartys syncline borders the eastern side of the area, and a considerable portion of the Chaco slope is included in the northeastern part of the region. The large San Juan Basin lies to the northeast.

Most of the contouring in the Zuni uplift is my own but based in part on geologic maps by Smith (1954 and unpublished maps), and Goddard (1966). Contouring in much of the Gallup sag is based on formation tops furnished by various private companies. George P. Woollard, Director of the Institute of Geophysics, University of Hawaii, furnished copies of original data maps from which modifications were made of the Woollard and Joesting U. S. Bouguer Anomaly Map. Curtis J. Little, Consultant, Albuquerque, New Mexico, furnished much of the data used in compiling the Pennsylvanian isopach map. Drafting was done through the courtesy of the Department of Geosciences while the author taught in the Summer Session at the University of Hawaii.

DEFIANCE UPLIFT

The Defiance uplift lies along the western part of the region, mostly in Arizona but extending locally a short distance into New Mexico. It is a north-trending uplift about 30 miles wide and 100 miles long. It is asymmetrical on the east as a result of the sharp, sinuous Defiance monocline which determines the eastern boundary. The staggared, broad crestal axes of the uplift have a maximum structural relief of 7,500 feet, some 3,000-6,000 feet of which is on the monocline. The monocline is only 1-2 miles wide between its monoclinal and synclinal bends, and dips along it range from 20°-90°. By contrast dips in the broad crestal area and along the wide, gentle western limb only very locally exceed three degrees.

The monocline is notable for its sinuosity, and its overall northerly trend is modified by several southeasterly plunging anticlinal and synclinal bowings which make the monocline right-echeloned. Lesser folds within the uplift trend either northwesterly or northeasterly. The most notable of these is the long Chuska-Toadlena buckle which bounds the uplift on the northeast. The Toadlena anticline on the northeast and the adjoining Chuska syncline on the southwest form a doubly plunging buckle 4-8 miles wide and 37 miles long. The broad part of the buckle is in the southeastern part where it is made assymmetrical to the northest by the Defiance monocline. The narrow part is the northwestern end which is made assemmetrical to the southwest by the Lukachukai monocline.

Faults are uncommon and minor, with two notable exceptions: the Tsaile graben and the Wide Ruins fault zone. The Tsaile graben in the northwestern part of the uplift is 1-2 miles wide and 15 miles long. Its northeast-trending normal faults drop Triassic Chinle one or two hundred feet between Shinarump sandstones. The Wide Ruins faults trend easterly for some 20 miles across the southern part of the uplift, and at the eastern end one of the faults effects a left offset of about four miles in the Defiance monocline just south of Hunters Point.

In the higher southern part of the uplift and in the deeper canyons of the northern part, Permian Supai and Coconino beds surface the uplift. Locally, at about 4 miles northwest of Fort Defiance and at Hunters Point, Precambrian rocks are found unconformably beneath the Permian. Gneiss and granite occur at the latter locality and quartzite at the former. Larger expanses of Triassic Shinarump and Chinle formations occur across the northern part of the uplift and peripheral to the Permian core of the southern part. In the flanking parts and outward across the Defiance monocline successively younger formations are found as high stratigraphically as Mesaverde.

ZUNI UPLIFT

The Zuni uplift is a northwesterly trending uplift asymmetrical to the southwest. The uplift is oval-shaped with a length of about 75 miles and a width of about 30 miles. Along most of the southwestern flank dips are no more than 5-20 degrees and in the gentler northeast flank dips run 3-10 degrees. The crestal axis is, overall, somewhat arcuate in the southwest direction of its steeper flank.

Precambrian rocks are exposed in several large areas along the crest of the uplift. Foliation trends in the various gneisses and schists are northwesterly, easterly, and northeasterly (Goddard, 1966). Surrounding the Precambrian outcrops a wide band of Permian strata surfaces the principal part of the uplift. Outside the Permian outcrops Mesozoic rocks form valleys, hogbacks, and mesas which essentially mark the outer limits of the uplift (Smith, 1954, p. 5-19).

Approximately the northern two-thirds of the uplift is bounded on the west by the Gallup sag along the Nutria monocline. The Nutria is about 32 miles long and 1-2 miles wide with dips ranging from low to steeply overturned. The uplift along the remainder of the southwestern and southern margin is bounded imperceptibly by the broad, nearly flat structure that merges southward into the Mogollon slope. On the east the uplift may be terminated at the McCartys syncline, or at the locally steep part of the syncline, termed the Grants monocline.

The northeast flank of the uplift merges with the Chaco slope along an arbitrary boundary which more or less coincides with the Dakota rim some 6-10 miles north of U.S. Highway 66.

The Zuni uplift is the most faulted of the uplifts on the Colorado Plateau (Kelley and Clinton, 1960, fig. 7) and its pattern of faults and joints is diverse. In the high eastern part the pattern is semi-radial in the manner of an epianticlinal system, but the long gently plunging western or northwestern part lacks such a system. However, unlike typical epianticlinal systems, several of the faults in the apial, or Mt. Sedgwick area are large, and blocks have been tilted and horsted markedly above the otherwise smooth arch of the uplift.

The main axis of the uplift swings eastward in its course as it approaches the Mt. Sedgwick area. It follows closely the northward downthrown Dan Valley fault which lies just to the north of the crest. The highest part of the uplift, however, is to the north of the Dan Valley fault around Mt. Sedgwick (Elev. 9256′).

The Sedgwick block, even though north of the axis of the uplift, is tilted up sharply on the arcuate Sedgwick fault which curves around Mt. Sedgwick from easterly trend to southeasterly where it parallels the uplift axis to its termination.

Structure contouring over the Precambrian around Mt. Sedgwick is uncertain, but assuming no great erosion above the peak, throw on the Sedgwick fault may be 3,000-4,000 feet. Southeastward along the crest of the southeastward plunging end of the uplift, Precambrian is uplifted between Permian limbs in a horst 3-6 miles wide and 17 miles long.

The northeastern sector of the Zuni uplift is broken by a large system of faults dominated by a N-NNE set which includes more or less straight faults 18-30 miles long. Dip separations on these faults, such as Bluewater, Big Draw, Ambrosia, and San Mateo do not exceed 100-200 feet, but on the San Rafael fault zone the dip separation approaches 1,000 feet. A less persistent set of NE-ENE faults which lies between, or branches from, the master set are also present, especially in the Ambrosia Lake area.

In the western part of the uplift there are two high-angle reverse faults, Fort Wingate and McGaffey. The faults occur in accompaniment with abrupt upwarping of the southwestern flank of the uplift in and above the Nutria monocline. However, it is noteworthy that neither the throw on these faults nor the rise on the Nutria monocline exceeds the throw on the Sedgwick fault.

GALLUP SAG

The Gallup sag is a narrow embayment extending from the San Juan Basin southward between the Zuni and Defiance uplifts. The sag is about 70 miles long and 8-28 miles wide (Kelley and Clinton, 1960, p. 78-79). It is bounded sharply by the sinuous Defiance monocline on the west and the Nutria monocline along part of its eastern margin (Howell, 1875, fig. 121). It plunges into the central San Juan Basin across the Chaco slope to the north and fades imperceptibly into the low-dipping Mogollon slope to the south.

The northern half of the sag is narrowed by the abrupt eastward shift of the Defiance monocline at the Todilto Park anticline, and the boundnary on the east with the Chaco slope is chosen along a rather low, vague, northward continuation of the Zuni axis.

The trough of the sag, the Allison-Nakaibito syncline, is nearer to the eastern (Zuni) side, and its eastern limb is shorter and of slightly less structural relief than its western limb. The sag plunges northward at about 60 feet per mile. The rather flattish bottom of the sag is modified by several short anticlines and synclines that strike roughly north-northwesterly (Sears, 1925, pl. 1). The largest of these, the Pinon Springs anticline, strongly modifies the southwestern part of the sag (Darton, 1925, pl. 52). Late Cretaceous Mesaverde sandstone and shale beds surface the sag everywhere. The sag is well depicted by negative Bouguer gravity anomalies (Tectonic Map, Insert A).

TECTONIC EVOLUTION

Despite exposures of Precambrian rocks in the Zuni and Defiance uplifts, the deformational history of pre-Paleozoic time as well as the early and middle Paleozoic is poorly or not at all known in the region. Lower Paleozoic beds probably covered all the region only to be stripped by late Devonian time. Mississippean inundation likely followed and was accompanied by wide epeirogenic warping. Subsequent stripping, through possibly early Pennsylvanian time, was followed by domal uplift which shed sediment

to Des Moinesian seas in the adjacent areas (Curtis Little, oral communication).

Throughout the the remainder of the Pennsylvanian period and into Permian time the region was overlapped and buried during broad regional subsidence. The configuration of the highland in late Pennsylvanian time together with the depositional wedging of the Pennsylvanian beds is shown on the Tectonic Map (Inset B) in the pocket.

In late Permian time the region was broadly positive and stable while it underwent long weathering and/or widespread stripping. For the Zuni-Defiance area a similar situation continued through early Triassic while deposition occurred on the downwarping Moenkopi plains to the west. During late Triassic time the entire region subsided as it received continental Shinarump and Chinle sediments from rising highlands to the south, or far to the north.

During Jurassic time the subsidence continued north of the gradually rising Mogollon highlands to the south. From post-Entrada time on, volcanism and rejuvenation in the rising Mogollon highland to the south are evidenced by conglomerate and tuff fed to the Zuni area above the Entrada and at several horizons in the Morrison.

The above paleotectonic interpretation is based on the composition of the sediments, as there are few unconformable truncations or overstepping relations within the formations. The Mogollon rise of late Triassic and Jurassic time lay some distance to the south of the Zuni area, but in latest Jurassic and Early Cretaceous times uplift and erosion reached the Zuni and nearby areas as indicated by widespread bevelling of all the formations from Morrison down to the Permian Abo formation. The evidence for this uplift and planation lies in the regionally unconformable overstepping of the Cretaceous Dakota beds.

North of about Grants the Dakota rests widely in near conformity on the Morrison, but to the south the Dakota descends stratigraphically, downward across an east-west belt some 150 miles wide. Thus, the hinge line of uplifting of the Mogollon moved northward in latest Jurassic and Early Cretaceous time to a position of about the latitude of Grants.

The crest of the broad upwarp far to the south probably rose some 3,000 feet with respect to the unwarped area to the north. During the upwarping, as well as locally within the Morrison, minor folds of various trends were formed and truncated before deposition of the Dakota (Moench and Schlee, 1967, p. 36-38).

One of the questions still left largely unanswered is what became of the sediment eroded from the uplift. Could it be the higher Morrison to the north? Could it have been modified and incorporated into the Dakota and overlying beds? Could it have by-passed much of the area to contribute to the Cedar Mountain or Burro Canyon beds? Could it have been removed to the south into the Lower Cretaceous of that region? The Cedar Mountain beds have many aspects of the Morrison, and the Dakota has debris derived from underlying beds. Removal to the south would require rather abrupt uplift along some such line as the present Mogollon Rim followed by northward pedimentation toward the Grants region.

The regional correlations within the Morrison are far from agreed upon and it may be that the Morrison is more the product of the bevelling of the Mogollon highlands than is recognized. Perhaps some combination of a Morrison disposal and a southern Lower Cretaceous disposal may be involved.

During Dakota and subsequent Cretaceous time the region was downwarped on floodplains and adjoining seaways by several thousands of feet as evidenced by the presence of thick Mancos and Mesaverde beds. This rather drab sequence of events, aside from indicating uplift and erosion in source areas to the south and west, was the prelude to the ensuing more vigorous events of the Laramide which gave rise to most of the existing or modern structures of the region.

The Zuni and Defiance uplifts, the Defiance, Nutria, and other monoclines, the Gallup sag, the San Juan Basin, and most of the Colorado Plateau structures formed during the Laramide interval of Late Cretaceous through Eocene time. At the beginning of this deformation the area was covered by some 6,000 to 10,000 feet of sediment. If the deformation was late Eocene there may have been additional cover of latest Cretaceous and Paleococene beds spread into the area from nearby early Laramide uplifts. However, no sediment is known in the Zuni-Defiance region that could be considered a product of, or directly related to, the deformations.

The oldest post-Laramide sediments are either late Miocene or Pliocene and consist of the Chuska Sandstone, Bidahochi Formation, and volcanics of the Mt. Taylor type. These all lie conformably across the Laramide structures and are either undeformed or slightly tilted or faulted. The Chuska rests on rocks ranging in age from Triassic to Late Cretaceous, and diagonal across the Defiance monocline on a smooth surface at an elevation of 7,800-7,900 feet.

The high Mt. Taylor volcanics rest on beds ranging in age from Permian in the Zuni uplift to Late Cretaceous around Mt. Taylor, in altitudes ranging from about 7,300 to 8,100 feet. Small outliers of volcanics similar to some of the Mt. Taylor rocks occur on the Zuni uplift at 9,100 feet and on the high Dakota ridge north of Thoreau at 8,700 feet (Tectonic Map).

The Bidahochi, lying mostly in Arizona, rests on beds ranging in age from Permian to Late Cretaceous along the western flanks of the Zuni and Defiance uplifts, and in the Black Mesa basin at generally lower altitudes than the above units.

The principal Laramide deformation of the region lies in the Defiance and Nutria monoclines. Since these roughly face one another across the Gallup sag, this is also to say that the Gallup sag is the principal structural element of the region. The Bouguer gravity anomaly map (Inset A, Tectonic Map) brings this out. The gravity map was modified from the 1964 U. S. map to fit the known

structure but still adhering to data from original maps furnished by Woollard.

The Black Mesa basin is a slight positive anomaly. The Zuni uplift, on the other hand, is a fair positive anomaly, especially in its structurally high eastern part. The San Juan Basin is shown only very poorly by an irregular negative anomaly. It is the Gallup sag and in particular the Nutria monocline and adjacent sag axis that are most clearly reflected in the gravity data.

The Bouguer values are as negative along the sag axis as they are over much of the San Juan Basin where structure is 5,000-7,000 feet lower and the sedimentary section is much thicker. The better gravity agreement with structure in the sag than in the basin may be due in part to a more pronounced gravity difference between the sedimentary and basement rocks in the sag than in the basin where much more Paleozoic section is present. The lack of a more pronounced negative-anomaly correspondence with the San Juan Basin may be due also to a polymorphic or other concentration of dense rock at the crust-mantle level which could give rise to an isostatic basin.

The very considerable sinuosity on the Defiance monocline was pointed out long ago (Gregory, 1917, p. 111) and the possibility of right shift at depth as a cause of the irregularity was pointed out by the author (1955, p. 67). Inset C (Tectonic Map) fortifies this conclusion further by left offsetting a regional facies line between the Zuni–Cow Springs sandstones and the Morrison mudstones.

The line is drawn so that there are essentially no mudstones south of the line in the Zuni–Cow Springs stratigraphic interval. A similar offset may be shown for the Todilto limestone wedge edge, but the intersection with the monocline is more acute and hence less definitive. Offset of the Morrison facies lines is about eight miles, and this is in agreement with the structural shifting as estimated by comparing the extra length along the monoclinal bowings over that of a straight line.

The principal bowing lies between Hunters Point and the steep northeastern limb of the Toadlena anticline. South of Hunters Point, or the offset on the Wide Ruins fault, the monocline is straight or might even be considered to have left-echelon bowings in contrast to the right-echelon on the Defiance between Wide Ruins fault and the swing of the monocline to the northwest around the Toadlena anticlinal nose. Similar though less pronounced right-echelon bowing occurs on toward the northeast across the nose of the Beautiful Mountain anticline and far beyond along the Hogback monocline (Kelley, 1955, fig. 2).

The right shift on the highly sinuous Defiance monocline may include (1) right slip on Wide Ruins fault, south of Hunters Point, (2) right shift along the monocline, and (3) northeastward "nodding" or rotation of the steep limb to the Toadlena anticline. Combined deformation on the three elements involves an upward and eastward movement of a 50-mile central segment of the Defiance uplift.

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West flank of the Chuska Mountains viewed from Navajo Highway 12, about 8 miles north from Window Rock. The highway is traversing the Owl Rock Member of the Chinle Formation. The lowest cliffs to the right of the road, along the edge of the valley, are developed in the Rock Point (lower) and Lukachukai (upper) Members of the Wingate Sandstone. The Entrada Sandstone overlies the Lukachukai and is overlain by the Cow Springs Sandstone. The Recapture (lower) and Westwater Canyon (upper) Members of the Morrison Formation underlie the Dakota Sandstone which forms the caprock of the mesa at the middle-right edge of the photograph.

Photograph by H. L. James