ANCIENT EROSION SURFACE IN THE GALLUP-ZUÑI AREA, NEW MEXICO.

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ABSTRACT.

The surface of the plateau west of the Zuñi Mountains, New Mexico, is an exhumed erosion surface, here called the Zuñi erosion surface, of probable late Tertiary age. It bevels Cretaceous and pre-Cretaceous rocks and is overlain by dissected Tertiary beds containing limestone, marl, tuff, and bentonitic clay, and Pleistocene (?) beds containing land and freshwater mollusca. The abnormally high westward slope of the surface indicates deformation by westward tilting subsequent to the deposition of the overlying Tertiary beds.

INTRODUCTION.

The area lying between the coal town of Gallup and the Indian pueblo of Zuñi is a dissected plateau standing between 7,000 and 7,400 feet above sea level, the surface of which slopes gently westward from the Zuñi Mountains which rise 1,000 to 1,500 feet above it. It is drained by Zuñi River and the Rio Puerco of the West which, together with their tributaries, have cut canyons in it 500 to 700 feet deep. This plateau is underlain by layers of sedimentary rock which, for the most part, appear to be horizontal, but close inspection reveals dips apparent to the naked eye and a survey of the region as a whole shows that strata of several ages crop out at the surface, indicating that the surface of the plateau is controlled by erosion rather than structure. This surface cuts the Cretaceous and pre-Cretaceous beds of the area and parts of it are still covered by Tertiary and Pleistocene(?) deposits (Fig. 1).

No detailed description of this surface has ever been published. Shaler[1] and Sears[2] have prepared maps relative to local coal resources, which take cognizance of its existence. It can be seen on one of Darton's[3] structure sections. Bryan[4] has described it briefly in an unpublished report.

[1] Shaler, M. K.: "A reconnaissance survey of the western part of the Durango-Gallup coal field of Colorado and New Mexico," U. S. Geol. Surv. Bull. 316, pl. 22, p. 376, 1906.

[2] Sears, Julian D.: "Geology and Coal Resources of the Gallup-Zuñi Basin, New Mexico," U. S. Geol. Surv. Bull. 767, pp. 1-52, map, 1925.

[3] Darton, N. H.: "'Red Beds' and Associated Formations in New Mexico," U. S. Geol. Surv. Bull. 794, p. 153, fig. 59, 1928.

[4] Bryan, Kirk: "Geology of Zuñi Reservoir near Zuñi, New Mexico, and its watertightness as affected by the proposed increase in the height of the dam," pp. 7-9 (unpublished), 1928.

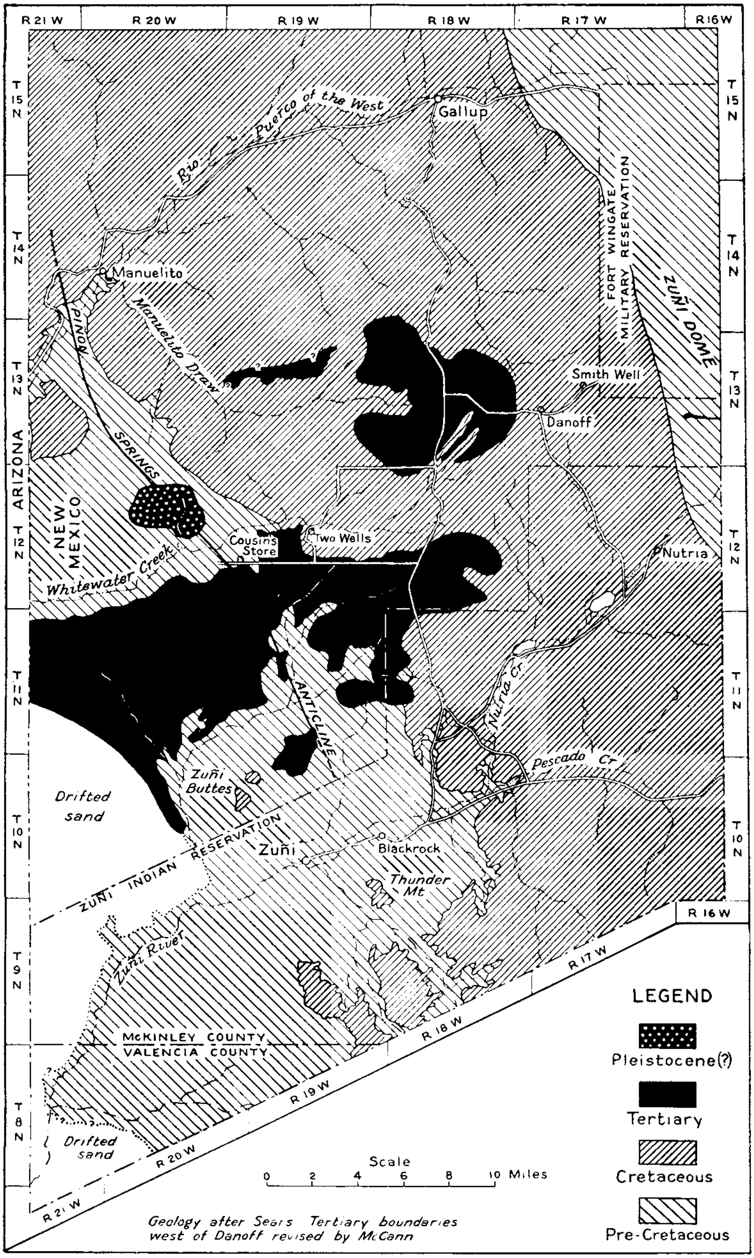

Fig. 1. Generalized geologic map of Gallup-Zuñi area, New Mexico.

A number of factors combine to make the area interesting for those persons concerned with the late Tertiary and early Pleistocene history of Arizona and New Mexico. There has been no apparent deformation here since the deposition of the Tertiary beds save westward tilting and probable minor differential warping. This gives significance to the estimated amount of uplift of the Zuñi Mountains since the deposition of the Tertiary beds, a figure reached by comparing the present high westward slope of the surface with the much lower gradient of the present streams. The presence of limestone, marl, tuff, and bentonitic clay in the Tertiary beds makes possible a tentative correlation with similar beds in adjacent areas and consequent tentative age assignment. The presence of Pleistocene(?) mollusca in certain lake or spring deposits adds materially to the knowledge of local Pleistocene climate, a

Fig. 2. Tertiary beds at locality A (Fig. 8), showing clay beds overlain by cliff-forming, white tuff and tuffaceous sandstone. Note blocks of white tuff lying on slope in foreground.

matter of general and present interest to anthropologists[5] as well as to geologists.

The Tertiary and Pleistocene(?) deposits of the Gallup-Zuñi area are much less resistant to erosion than the underlying Cretaceous and pre-Cretaceous beds. The streams in the area, by headward erosion, tend to strip these less resistant post-Cretaceous beds completely from the Zuñi erosion surface (Fig. 3) and then dissect the surface itself. Because of this method of attack, the surface is either completely concealed or virtually destroyed save at the margins of the Tertiary and Pleistocene(?) areas (Figs. 1, 8). Here the conditions are especially favorable for examination of buried monadnocks and determination of the slope of the surface since the angular unconformity between post-Cretaceous and the older rocks (which is also the edge of the Zuñi erosion surface) is exposed for considerable distances. The gradient of the surface has been determined by means of points of known elevation (Fig. 8), all of which are located on the unconformity save for that on Thunder Mountain, 7,356 feet, which is on a monadnock above the surface, and that at Nutria, 7,406 feet, which is on the highest Cretaceous outcrop in the vicinity yet below the surface. These and other elevations not shown on Fig. 8 were measured in several ways. Wherever practical a level line was run by means of plane table and telescopic alidade from a bench mark established by the United States Coast and Geodetic Survey or the United States Geological Survey. In other cases, a barometer traverse was run from these same bench marks and checked by return traverse, and if possible rechecked with a Brunton compass.

STRATIGRAPHY OF THE PRE-TERTIARY ROCKS.

The stratigraphy and structure of the pre-Tertiary rocks of the Gallup-Zuñi area have been so adequately described by Sears[6] and Darton[7] that only an outline seems necessary here. The following account is drawn largely from these two sources.

The core of the Zuñi Mountains is composed of a pre-Cambrian crystalline complex, exposed only in the central part of

[5] Eiseley, Loren C.: "Index mollusca and their bearing on certain problems of prehistory: a critique," Philadelphia Anthropological Society, Twenty-fifth Anniversary Studies, pp. 77-93, 1937.

[6] Op. cit.

[7] Op. cit.

the mountains, on which lie approximately 6,000 feet of sedimentary rocks. The oldest of these sedimentary rocks consist of beds of sandstone and limestone, about 175 feet thick, which belong to the Chupadera formation of Permian age. Above these beds lie two great bodies of Triassic shale, the Moenkopi and Chinle formations, separated from each other by the relatively thin Shinarump conglomerate. The maximum thickness of Triassic rock is approximately 1,880 feet.

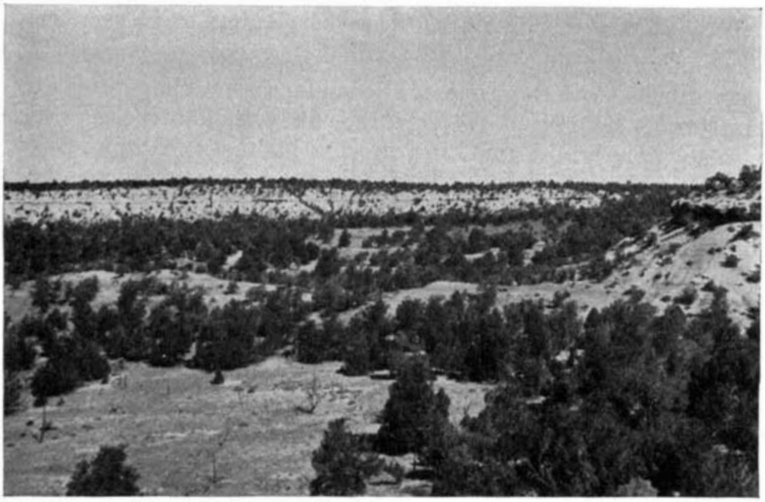

Fig. 3. View near locality B (Fig. 8), showing stripped erosion surface in foreground, exposed by waters of Manuelito Draw, a tributary of the Rio Puerco of the West.

The Jurassic is represented by the Wingate sandstone, and by rocks previously considered as correlatives of the Todilto formation, and the Navajo sandstone. The local "Todilto" and the "Navajo" are now considered part of the Morrison formation[8] of probable Jurassic age. The "Todilto" includes limestone and some gypsum. The Wingate and "Navajo" sandstones are massive, cross-bedded, and pink or red in color. These beds have a maximum thickness of 1,025 feet.

[8] Baker, A. A., Dane, C. H., and Reeside, J. B. Jr.: "Correlation of the Jurassic Formations of parts of Utah, Arizona, New Mexico, and Colorado," U. S. Geol. Surv. Prof. Paper 183, pp. 17, 63, 1936.

On the geologic map (Fig. 1), all the beds older than the upper Cretaceous have been shown under one symbol as "pre-Cretaceous."

The upper Cretaceous beds have a maximum thickness of 3,125 feet and consist of massive, buff sandstones and dark shales which overlie unconformably all the older beds. These include the Dakota sandstone, the Mancos shale, and the Mesa Verde sandstone.

STRUCTURE OF THE PRE-TERTIARY ROCKS.

After the deposition of the upper Cretaceous beds, the Zuñi Mountains were arched up in a broad dome and the sedimentary rocks immediately to the west were warped down to form a broad, shallow syncline or structural basin (Fig. 1) with minor folds. Both dome and basin trend northwestward and the basin plunges gently in the same direction.

THE TERTIARY DEPOSITS.

The Tertiary deposits of the Gallup-Zuñi area consist of loosely consolidated alluvial and lacustrine beds of high tuffaceous content which vary widely in texture and lithology. Locally they appear to be horizontal, but regional relationships reveal a slight dip to the west. Sears[9] dismisses these beds briefly as "unconsolidated reddish sand and clay, some soft white sandstone, light-gray clay shale, and gravel, lying unconformably upon the older formations." More detailed investigation indicates that there is, in addition, limestone, marl, white tuff, sandstone with a considerable content of tuff, and bentonite or related clay mineral. A small area (Fig. 1) of alluvium and black silt, which was included by Sears in the Tertiary, is here considered to be Pleistocene(?).

The beds west of Danoff (A-E, Fig. 8) range in thickness from 50 to 150 feet. At A and B, they are composed of variegated clays capped by a layer of scarp-forming white tuff (Fig. 2) in close association with thin, brown to red sandstones which are also scarp-forming and tuffaceous. The series at A includes three thin layers of bentonitic clay below the white tuff and above it a somewhat thicker layer of gray tuff containing glass fragments so angular and quartz-free as to suggest an ash-shower not reworked by water. The

[9] Op. cit., p. 18.

index of refraction of this glass is 1.502 which indicates[10] a silica content of 70 per cent and therefore a glass of rhyolitic composition. The bentonitic clay is considered to be decomposed volcanic ash and the presence of fresh ash above decomposed ash would seem to indicate a lowering of the water-table during the deposition of these beds.

The beds at C resemble those at A and B save that the clay has a slightly higher percentage of sand and the bentonitic clays are absent, but the beds at D and E are quite different. The white tuff disappears, there is a notable increase in the percentage of sand and limy sandstone, and a thin, resistant limestone appears, indicating the presence of a small, temporary lake. There is a thick layer of gray bentonitic clay at E.

The white tuff, in association with brown, nodular, resistant, tuffaceous sandstones, which may be found both above and below the white tuff, seems to hold up the present surface of the plateau here save at D and E. These beds may be seen at numerous points along the Gallup-Zuñi Road, the Danoff Road, the Two Wells (Correction Line) Road and the trails which lead off from them, for the tuff and sandstone are used for road metal in the vicinity and shallow pits have been opened for this purpose along the roads named. Apparently, these beds, on account of the porosity of the white tuff and the hardness of the brown sandstone, resist erosion until the underlying clays are worn away at the bordering cliffs, and the white tuff, thus undermined, breaks off in great blocks (Fig. 2). In this manner, headward-working tributaries of Whitewater Creek and the Rio Puerco of the West are slowly stripping off the Tertiary cover (Fig. 3). Tributaries of the Zuñi River perform a similar function in a less spectacular manner in the Tertiary area south of Cousins Store.

The Tertiary deposits south of Cousins Store (Fig. 1) have the greatest areal extent but not the maximum thickness for the Gallup-Zuñi area. Here the maximum thickness is 135 feet (Fig. 8, J). There is no white tuff, but a white bentonitic clay, one to two feet thick, may be found at G and H (Fig. 8). A notable percentage of gravel is present at G and J (Fig. 8). The pebbles which are found in the gravel are largely derived from the Zuñi Mountains to the east. There are a few granite pebbles which must have come from the core of the mountain and many pebbles of quartz, quartzite, jasper, flint and red

[10] Grout, Frank F.: "Petrography and Petrology," p. 114, 1932.

chalcedony which are probably derived from conglomeratic zones in the steeply-dipping pre-Cretaceous beds near the base of the mountain. The quartzitic pebbles are well rounded and have shapes obviously related to some pre-Tertiary cycle of erosion. They also show small faults which were acquired in the deformation of their parent beds, presumably during the pre-Tertiary uplift of the Zuñi Mountains. The percentage of sand is much greater and the percentage of clay much less than in the area west of Danoff.

The angular unconformity separating these beds from the

Fig. 4. Tertiary beds at road metal quarry, about 5 miles southeast of Sanders, Arizona. Note bed of white bentonitic clay at base of scarp.

underlying Cretaceous and pre-Cretaceous is apparent only in the vicinity of the Piñon Springs anticline (Fig. 1) where they overlap the uparched Wingate sandstone, decreasing in thickness from 75 to 20 feet in the space of 200 yards. Its presence is further indicated by the succession of rocks from Cretaceous to pre-Cretaceous, from east to west, each bed neatly beveled and overlain by the Tertiary cover (Fig. 1). The overlap just described indicates an initial irregularity in the Zuñi erosion surface. The measured sections produce additional evidence of irregularity. At G (Fig. 8), 35 feet of sand and limy sandstone separate the white bentonitic clay from the underlying Cretaceous shale, while at H (Fig. 8), two feet of yellow clay separate this bed from underlying Cretaceous sandstone.

The Tertiary sediments continue westward across the New Mexico-Arizona line, and southwestward they grade into drifted sand. This sand has been reworked in post-Tertiary time, but part of it may represent the top of the Tertiary cover at this point. Neither continuation was studied in detail. A reconnaissance trip into Arizona indicates that the Tertiary beds continue westward for at least 50 miles. One section, seen at a road-metal quarry (Fig. 4) about five miles southeast of Sanders, Arizona, includes a bed of white bentonitic clay, two to three feet thick, which is the source of the road metal. It resembles the white bentonitic clay found at G and H (Fig. 8) and may be the white tuff decomposed. Another section

Fig. 5. Tertiary beds exposed in Beacon Light Ridge, about 14 miles south of Sanders, Arizona.

(Fig. 5) observed at Beacon Light Ridge, on the Sanders-Witch Wells Road (State Highway 81), about 14 miles south of Sanders, shows approximately 300 feet of fine, buff sand carrying lenses of resistant, concretionary, limy, gray to buff sandstone and thin beds of brown clay, with a layer of gray to white marl, two to six feet thick, near the top of the series. This marl is similar to one found at I (Fig. 8).

THE PLEISTOCENE(?) DEPOSITS.

The Pleistocene(?) beds (Fig. 8, F) west of Two Wells differ in thickness and lithology from the Tertiary beds, and contain land and freshwater mollusca. They are relatively thin, having a maximum thickness of 50 feet. At the base is a coarse, limy conglomerate (Fig. 6), five to 20 feet thick, showing marked cross-bedding and channeling. The coarser material is a crudely sorted mass of rock fragments ranging in size from sand to slabs of sandstone three feet across. It contains well rounded pebbles of white marl, clearly derived from Tertiary beds, numerous fragments from the underlying Navajo-Wingate sandstone, and minor amounts of quartz, quartzite, jasper, flint and red chalcedony. Above the conglomerate lies a thin, soft, brown sandstone which also contains pebbles of red chalcedony. On top of the sandstone rests a layer of black to gray, limy silt and clay, two to three feet thick, containing two species of land gastropods and several species of freshwater mollusca. This layer dips downstream at about the same rate as the present stream gradient and also exhibits slight irregularities in dip (Fig. 7). This seems to be due to irregularities in the surface of the underlying conglomerate and sandstone on which it was laid down. Above the black silt is six to ten feet of loose, brown silt which may have been deposited by water in a swamp or distributed by the wind over a grassy area.

It seems likely that the molluscan layer represents a spring rather than a lake deposit. There are several springs existing in this part of the Zuñi plateau at the present time. The arroyo along whose banks this layer is exposed is a spring arroyo in whose bed is a black muck, masked by a thin veneer of sand, very like the shell layer.

The mollusca found in the shell layer include the following forms, kindly identified by Mr. William J. Clench of the Harvard Museum of Comparative Zoology:

Freshwater gastropoda.

Aplexa hypnorum Linn.
Physa virginea Gould.
Lymnaea (Galba) humilis modicella (Say).
Lymnaea (Galba) palustris (Mull).
Succinea retusa Lea.

Land gastropoda.

Vertigo ovata Say.
Gyraulus parvus Say.

Pelecypoda.

Sphaerium sp.

The vertical range of these mollusca is so great (pre-Tertiary to present) that these specimens can in no sense be regarded as index fossils and indicative of precise age. They do, however, seem to indicate a somewhat colder, more humid climate than exists on the Zuñi plateau today and on that account may be Pleistocene. Mr. Clench regards this assemblage as essentially a cold-water fauna and characteristic of relatively clear, shallow waters of the present north temperate and sub-arctic zones. The pupillid, *Vertigo ovata* Say, is especially hardy and while it ranges as far south as northern Mexico, it is also found as far north as southern Alaska. Still, this evidence must be regarded as inconclusive inasmuch as the present range in temperature on the Zuñi Plateau may be great and the seasonal rainfall considerable. The mean winter temperature is about 30 degrees Fahrenheit, the reservoir at Blackrock freezes nearly every winter and heavy snows on the plateau are not uncommon. The average annual rainfall is 14 inches. The Zuñi Indians irrigate their fields along the Zuñi River, yet there is sufficient moisture on the plateau during the summer months to enable the Navajos to produce a successful bean crop by dry-farming methods. The presence of *Aplexa hypnorum* Linn furnishes the most satisfactory, positive evidence for a colder, more humid climate at the time this layer was deposited. This gastropod is not known to live today south of Utah and Colorado but is found living in considerable quantities in northeastern United States, north of the southermost boundary of the Wisconsin ice.

The record of Pleistocene events in the areas covered by Tertiary deposits is largely buried beneath a cover of fine detritus which is partly alluvial and partly wind blown. No fossils were found there nor are there any changes in lithology which might bear on this point with the possible exception of the presence of quartzitic gravel (Fig. 8, G, J), some of which may be Pleistocene. It seems likely that the sand cover west of the pueblo of Zuñi (Fig. 1) represents the top of the Tertiary at that point reworked by the wind during Pleistocene and Recent time. Along Zuñi River, much sand is at present being spread out by the river and its tributaries and transported by the wind a short distance from their floodplains. When the river grade was at the level of some of the high terraces, this process may have been much more effective and may account for some of the windblown sand to the north. There is a small amount of windblown sand in the Tertiary area west of Danoff (Fig. 1), in T.13 N, R.18 W, Section 9. In the Tertiary area south of Cousins Store (Fig. 1), the presence of a few windcut stones and low hills which have the appearance of old dunes indicates the reworking of the top of the Tertiary series there by the wind. Much of this sand was moved in the past, but there is a small area in T.12 N, R.19 W where sand is still being moved by the wind at the present time. This suggests that the top of the Tertiary cover throughout the Gallup-Zuñi area may have been reworked by the wind in Pleistocene and Recent time.

ZUÑI EROSION SURFACE.

The period of uplift, during which the Zuñi Mountains were domed and the Cretaceous and pre-Cretaceous rocks of the Gallup-Zuñi area warped down, was followed by a period of quiescence when an erosion surface, here called the Zuñi erosion surface, was formed, sloping gently westward from the Zuñi Mountains which then rose as residuals 500 to 1,000 feet above it. The considerable extent of the surface, as indicated by Fig. 8, presupposes that the period of quiescence was relatively long. The contours of Fig. 8 are carried from the immediate areas of the Tertiary beds by extension over the surface of the plateau according to the best available topographic information. The low relief found wherever the surface is both exposed and preserved, as on the margins of the remnants of Tertiary beds (Fig. 3), suggests that it was a smooth and well-developed erosion surface. It seems likely that both rill-wash and the lateral planation of streams flowing westward from the Zuñi Mountains played important parts in the development of the surface, but the absence of the surface in the key area at the immediate base of the Zuñi Mountains makes their relative importance a moot question. Irregularities, both in detail and in the trough-like basin in the central portion of Fig. 8, are characteristic of even a well-developed erosion surface and do not necessarily indicate warping. However, the difference between the present high slope and the probable low initial slope of the surface furnishes strong evidence of westward warping.

It seems likely that the original slope of the Zuñi erosion surface westward from the residual Zuñi Mountains was low, because the bulk of the Tertiary deposits which still partly mantle it have a fine texture. Also the limestone and marl imply that temporary lakes of considerable extent were present. Such lakes could exist only on a surface of low gradient.

The present westward slope of the surface is relatively high.

Where the elevations have been determined (Fig. 8), its inclination is about 30 feet to the mile. Where the surface crosses into Arizona, it continues to slope westward at about the same rate. If the Tertiary beds in the vicinity of Sanders, Arizona, are the same age as those of the Gallup-Zuñi area, then the surface at that place has dropped to about 6,000 feet above sea level.

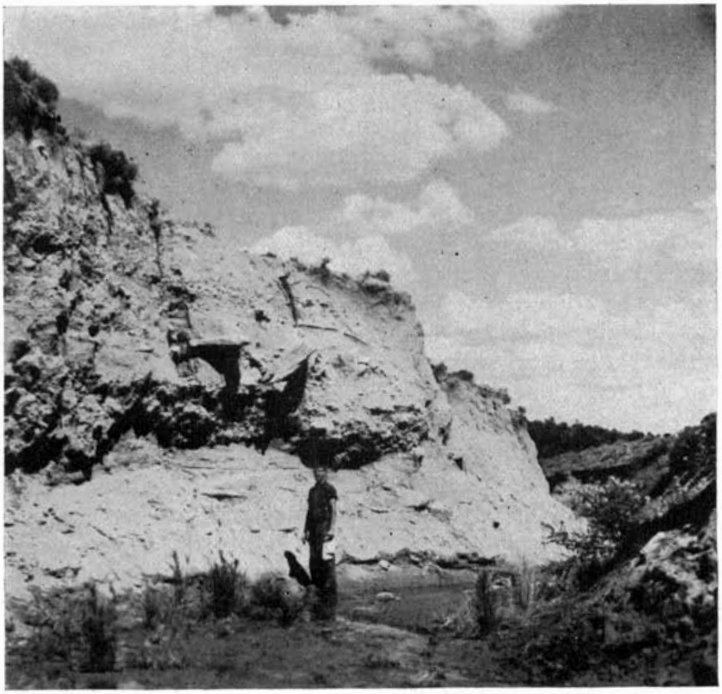

Fig. 6. Coarse conglomerate comprising basal member of Pleistocene(?) series at locality F (Fig. 8).

This is 2,000 feet in 50 miles from the 8,000-foot contour (Fig. 8) to Sanders, or a slope of 40 feet to the mile. From C (Fig. 8) to Sanders, the distance is 40 miles, the difference in elevation 1,150 feet, and the slope 29 feet to the mile. Even if the steepened part of the surface just west of the base of the Zuñi Mountains (Fig. 8) is excluded and the lower gradient of the main part of the surface is considered, the slope is still too high for the type of stream that must be postulated as the depositing agent for the clay and fine sand of the Tertiary beds. The gradient of the Santa Fe railroad tracks between Gallup and Sanders is about 16 feet to the mile and since the tracks are laid on the floodplain of the Rio Puerco of the West, the present gradient of this stream must approximate this figure. The gradient of Zuñi River in the vicinity of the pueblo of Zuñi is approximately 17 feet to the mile. Since the Tertiary deposits resting on the Zuñi erosion surface are, on the whole, finer than those being laid down at present by these two streams, it seems probable that the original slope of the surface was less than 16 feet to the mile. Detailed investigation by the Middle Rio Grande Conservancy along the Rio Puerco of the East shows that its gradient is about 12 feet to the mile in the first 67 miles of its course, from its mouth to the abandoned village of San Ygnacio, where the stream is graded and unbroken by hard-rock ledges. Assuming that the climate of the late Tertiary was similar to that of the present, an initial westward slope of 12 feet to the mile seems not unreasonable. If, however, the late Tertiary climate were more humid, as seems likely, the gradient of such an erosion surface and the streams on it would be even less.

If the original slope of the surface were 12 feet to the mile, the Zuñi Mountains must have been uplifted at least 700 feet since the surface was formed. The probably lower original slope and the steepening of the contours (Fig. 8) east of Danoff and south of the pueblo of Zuñi indicate that the amount of uplift may have been much greater and of sufficient magnitude to have an important bearing on the whole regional structure.

Thus far the westward downwarping has been assumed to be of equal intensity throughout the area. This need not necessarily be true. The bowing of the contours (Fig. 8) near the northern boundary of the Zuñi Indian Reservation indicates that the movement may have been of unequal intensity and greater there than to the north and south. However, the overlapping of Tertiary beds on pre-Cretaceous,[11] local differences in the thickness of Tertiary beds below a key horizon,[11] and the probable existence of Thunder Mountain (Fig. 8) and Zuñi Buttes as monadnocks above the surface indicate initial

[11] Supra, p. 266.

irregularity, and this basin-like shape may be original and due to erosion rather than secondary and induced by deformation. It seems likely that these factors combined to produce this depression.

AGE OF THE ZUÑI EROSION SURFACE.

The Zuñi erosion surface must be younger than the youngest beds it cuts, which are Cretaceous, and older than the oldest beds resting upon it, which are here regarded as middle or upper Pliocene. In the absence of fossil content, the age deter-

Fig. 7. Pleistocene(?) beds, locally irregular, resting against the upturned edges of the Wingate sandstone. Hat shows horizon of molluscan shells.

mination of these beds must be based on their physical characteristics and can at best be only approximate. If these beds are middle or upper Pliocene, the erosion surface on which they rest is probably early or middle Pliocene, or possibly late Miocene.

The Tertiary series in the Gallup-Zuñi area contains a well-defined and easily recognizable white tuff and associated brown to red sandstones, marl, and bentonitic clay, in addition to some limestone and much sand and clay.

Such a series has sometimes been regarded as early Tertiary in age. Dutton[12] considered a somewhat similar series in the

[12] Dutton, C. E.: "Mt. Taylor and the Zuñi Plateau," U. S. Geol. Surv. Sixth Ann. Rept., p. 140, 1885.

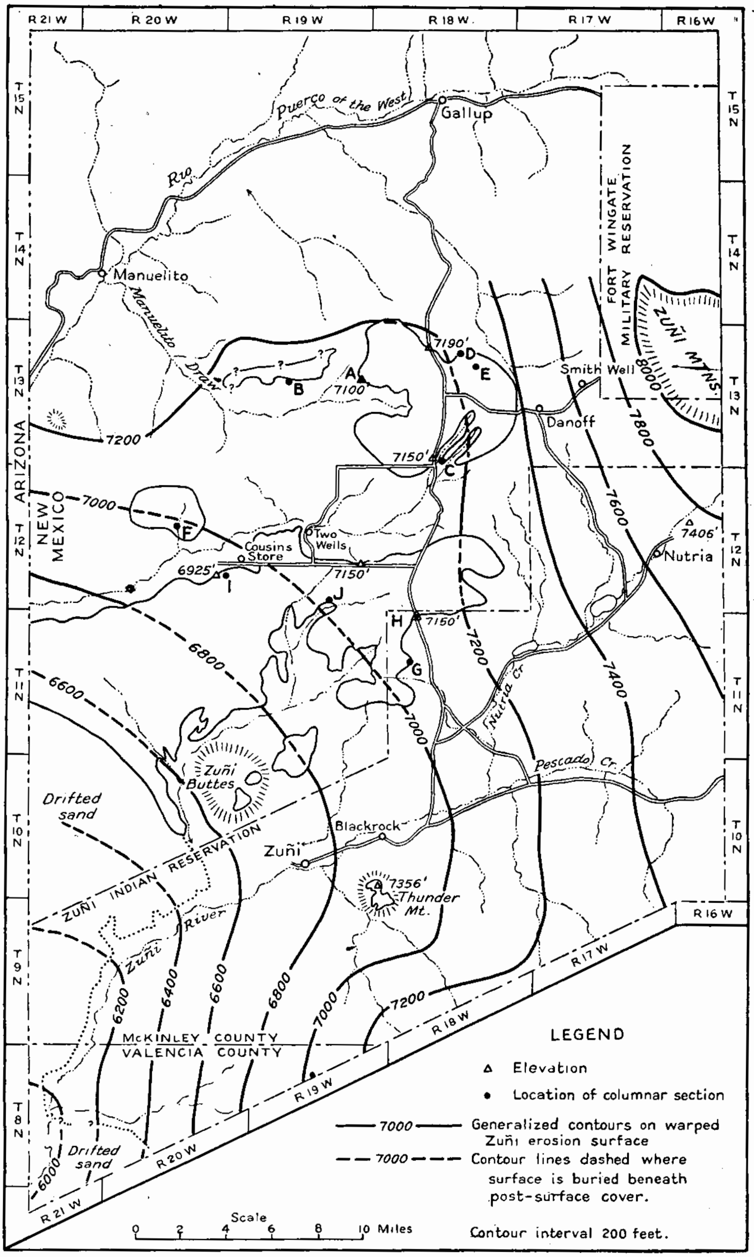

Fig. 8. Contour map of Zuñi erosion surface in Gallup-Zuñi area, New Mexico.

Chuska Mountains to the north as being Eocene, and Shaler[13] thought the same beds Eocene or post-Eocene. Gregory[14] likewise assigned the beds in the Chuska Mountains to the Eocene on the basis of lithology and stratigraphic position, but refused to date the series of sandstones, shales, marls and tuffs in the Hopi Buttes region to the West other than to call it Tertiary.

Recent information indicates that the beds in the Hopi Buttes region are younger than Eocene, and the same may be true of similar beds in neighboring regions, including those in the Gallup-Zuñi area. Reagan[15] collected freshwater mollusca from beds near the Hopi Buttes, identified them as Unio, *Planorbis trivolvis* Say, *Limnaea stagnalis appressa* Say, and referred them to the Pleistocene or Recent. Childs Frick[16] is reported to have assigned to the Pliocene a species of huge camel which he collected there from related beds. Howel Williams[17] collected vertebrates from the same beds which yielded Reagan's mollusca and these he considers of middle or upper Pliocene age. Obviously the matter has not been finally settled, but the evidence seems to indicate that the beds at the Hopi Buttes are middle or upper Pliocene and if the similar beds in the Gallup-Zuñi area are of the same age, as seems likely, the Zuñi erosion surface on which they rest is probably early or middle Pliocene, though possibly late Miocene.

TERTIARY AND EARLY(?) PLEISTOCENE HISTORY.

So far as the record in the Gallup-Zuñi area reveals Tertiary history, the earliest event recorded is the formation of the Zuñi erosion surface. Since this surface appears to have been relatively well-developed, and the Zuñi Mountains were reduced to a narrow ridge largely eroded on the granite core and not over 1,000 feet above the surface at its west base, the cutting probably occupied all of early Tertiary time through latest Miocene or, more probably, early Pliocene. This was followed by differential movement of slight intensity when fine sedi-

[13] Op. cit., p. 378.

[14] Gregory, H. E.: "Geology of the Navajo Country," U. S. Geol. Surv. Prof. Paper 93, pp. 79-82, 1917.

[15] Reagan, A. B.: "The Tertiary-Pleistocene of the Navajo country," Kansas Acad. Sci. Tr., Vol. 35, p. 258, 1932.

[16] Williams, Howel: Pliocene Volcanoes of the Navajo-Hopi Country," Bull. Geol. Soc. Am., Vol. 47, p. 130, 1936.

[17] Williams, Howel: op. cit.

ments were laid down on the surface. The white tuff contains very little quartz and has not been much reworked, suggesting at least one local ash shower of enough magnitude to overload the streams in the vicinity. Too little is known of the petrology of these Tertiary deposits to warrant a comparison of the relative importance of overloading of streams and downwarping of the area in accounting for their existence. However, their fine texture, the presence of some limestone and marl, and the high proportion of clay, silt and sand indicate that they were deposited on floodplains or in great alluvial fans through which springs occasionally broke to form swamps or small, shallow lakes.

A period of uplift and warping, probably at the end of Pliocene time, followed during which large portions of the Pliocene beds were partially stripped off, especially between the present Tertiary areas and the residual ridge of the Zuñi Dome (Fig. 1), and including the locality west of Two Wells, now covered with Pleistocene(?) deposits. Following this movement, the heavy conglomerate containing pebbles of white marl and the other Pleistocene(?) beds were deposited on the stripped surface.

Zuñi River and the Rio Puerco of the West are now flowing 600 to 700 feet below the level of the Zuñi erosion surface. This down-cutting might conceivably be related solely to a continued period of gentle warping. However, the existence of well-developed terraces along Zuñi River[18] indicates that the warping was interrupted by several periods of standstill.

CORRELATION OF ZUÑI EROSION SURFACE WITH NEIGHBORING SURFACES.

Major Tertiary erosion surfaces have been described from various parts of the Colorado Plateau Province. It seems quite possible that all of them, including the Zuñi erosion surface, were formed at approximately the same time. Dutton[19] described one from the Grand Canyon district which he considered Miocene. Huntington and Goldthwait[20] have described a surface from the boundary between the High Plateau

[18] Bryan, Kirk: op. cit.

[19] Dutton, C. E.: "Tertiary History of the Grand Canyon District," U. S. Geol. Surv. Monograph II, pp. 206-230, 1882.

[20] Huntington, Ellsworth, and Goldthwait, James W.: "The Hurricane Fault in the Toquerville District, Utah," Bull. Mus. Comp. Zool. Harvard Coll., Vol. 42, Geol. Survey, Vol. 6, No. 1, pp. 226-245, 1903.

Province and the Basin and Range Province, to which they have given the place name "Mojave peneplain" but assigned it to no particular epoch. Robinson[21] considered a number of remnants in the Plateau Province, including one in the Mt. Taylor region. He believed them all part of one surface which probably was not complete before late Pliocene time. Dutton and Johnson also have considered the surface underlying the lavas of Mt. Taylor. Dutton[22] thought it quite ancient, referring the lavas which cover it to early Miocene time. Johnson[23] described the surface briefly, but appended no epoch name. Bryan and McCann[24] think this surface relatively young, probably the Ortiz of Bryan's classification, and part of the surface which bevels Santa Fe (late Miocene or early Pliocene) beds in the Ceja del Rio Puerco which lies just within the Basin and Range Province.

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[21] Robinson, H. H.: "The Tertiary Peneplain of the Plateau District, and Adjacent Country, in Arizona and New Mexico," This Journal, Vol. 24, pp. 109-112, 1907.

[22] Dutton, C. E.: "Mt. Taylor and the Zuñi Plateau," op. cit., pp. 177-178.

[23] Johnson, D. W.: "Volcanic Necks of the Mt. Taylor Region, New Mexico," Bull. Geol. Soc. Am., Vol. 18, pp. 307-309, 1907.

[24] Bryan, Kirk, and McCann, Franklin T.: "The Ceja del Rio Puerco: a border feature of the basin and Range Province in New Mexico," Jour. Geol. XLVI, p. 11, 1938.

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