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NOTES ON THE LATE CENOZOIC GEOLOGY OF THE TAOS-QUESTA AREA, NEW MEXICO

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INTRODUCTION

The Taos-Questa area is in the southeast part of the San Luis basin, the northernmost of the series of fault-block basins which make up the late Cenozoic Rio Grande structural trough (Kelley, 1956). The basin extends from the latitude of the Picuris Mountains, south of Taos, to Poncha Pass, near Salida, Colorado, a distance of about 150 miles.

In the Taos-Questa area (Fig. 1) the San Luis basin has an average width of 20 to 30 miles. It is bordered on the east by the wall-like Taos Range and on the south by the east-west trending Picuris Mountains. The west boundary is topographically inconspicuous and consists of a series of low, dissected structural uplifts.

Most of the floor of the southeastern San Luis basin is rather flat or rolling and has an altitude ranging between 6,600 and 7,600 feet above sea level. Scattered across the basin are several groups of hills and isolated peaks some of which rise abruptly several thousand feet above the general basin floor level. The Rio Grande flows southward through the east half of the basin in a narrow, steep-walled gorge which has a maximum depth of about 1,000 feet in the southern part of the basin.

The climate of the basin is cool and semiarid. The average July temperature at Taos is 68.2° F and the average January temperature is 24.9° F. The average annual precipitation is 12.09 inches. Almost one-half of the precipitation comes as brief summer thunderstorms.

The lower, central part of the basin is covered with sagebrush and grass. The basin-margin and intra-basin uplands are forested with juniper, pine, spruce, and fir.

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STRATIGRAPHY

INTRODUCTION

The Rio Grande trough had its origin in late Miocene time when a series of interconnected, roughly north-south basins began to subside intermittently along boundary faults (Kelley, 1956). As the basins subsided they were filled with fluvial sediments and volcanic rocks. Sedimentation, alternating with minor downcutting, has continued through Recent time although shifts in the basin margins have generally resulted in younger basin-fill deposits being more restricted than older ones. Except for terrace deposits and alluvium in present valleys, the basin-fill deposits make up the Santa Fe Group of Miocene to Pleistocene age (Spiegel and Baldwin, 1963).

In the southeastern San Luis basin the exposed basin-fill includes the Santa Fe Group and various younger sedimentary deposits. The thickness of basin-fill is not known but certainly is several thousand feet.

SANTA FE GROUP

The Santa Fe Group exposed in the Taos-Questa area consists of a lower sequence of tuffs and conglomerates (Picuris Tuff) which grade upward into rather well stratified sandstones and conglomerates (Tesuque(?) Formation) overlain with angular unconformity by interbedded basalts and sands and gravels (Servilleta Formation).

Picuris Tuff

The oldest basin-fill unit exposed in the southeastern San Luis basin is the 1,250- to 1,750-foot thick Picuris Tuff of probable Miocene age (Montgomery, 1953). It consists of conglomerates containing boulders of Tertiary volcanic rocks and Precambrian igneous and metamorphic rocks and water-laid tuffs. The unit is exposed along the north edge of the Picuris Mountains and in Arroyo Miranda to the east of the Picuris Mountains. In both areas it is faulted and tilted. In several places south of the Picuris Mountains it is interbedded with the overlying Tesuque(?) Formation (Montgomery, 1953).

Tesuque(?) Formation

Exposed in the canyons of the Rio Grande and its tributaries along the northwest and south sides of the Picuris Mountains is a sequence of tilted and faulted poorly consolidated sandstones and conglomerates which Montgomery (1953) mapped as the Santa Fe Formation, and which may be correlative with the middle(?) Miocene to early Pliocene Tesuque Formation of the Santa Fe area (Spiegel and Baldwin, 1963). These rocks are rather well exposed northeast of Pilar in the cliffs bordering the northwest side of U.S. Highway 64. Here they consist of interbedded pinkish gray to orange-pink conglomerates and sandstones. The conglomerates contain angular to subangular pebbles, cobbles, and small boulders of various Precambrian metamorphic rocks probably derived from the nearby Picuris Mountains. In Hondo Canyon, 3½ to 4 miles northeast of Pilar, similar deposits contain pebbles of felsite and basalt. Montgomery (1953) states that most

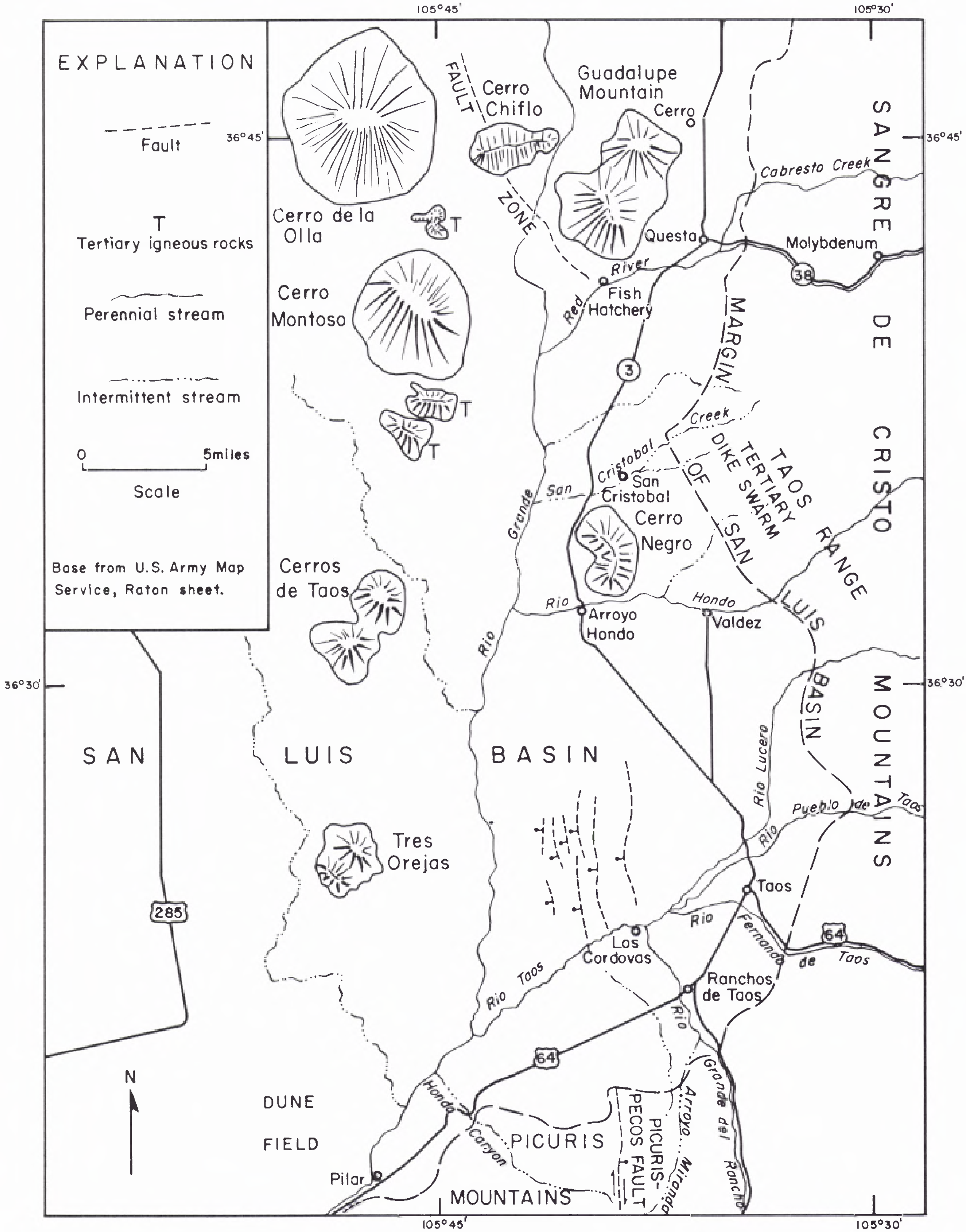

FIGURE 1.
Map of southern San Luis basin showing localities mentioned in text.

of the Tesuque(?) Formation bordering the western part of the Picuris Mountains consists of fine-textured sediments (sands and clays), and that gravels, some of which contain volcanic pebbles, are subordinate. The Tesuque(?) Formation in the southeastern San Luis basin probably totals several thousand feet in thickness (Montgomery, 1953). In the vicinity of the Picuris Mountains the formation has been much faulted and locally has attitudes approaching 90° although generally the dips are less, probably averaging 10°-30°.

Servilleta Formation

Resting with angular unconformity on the Tesuque(?) Formation near Pilar and exposed at the surface over most of the southeastern San Luis basin is a thick sequence of interbedded basalts and sands and gravels known as the Servilleta Formation (Butler, 1946; Montgomery, 1953). Its maximum thickness is not known but it exceeds 1,000 feet. In the central part of the basin basalt is at the surface or is covered by a thin veneer of basaltic alluvium and eolian sand but near the margins of the basin the basalt interfingers with, and is overlain by, a wedge of sands and gravels which thickens toward the bordering highlands. The lower part of the Servilleta Formation as exposed in the Rio Grande Gorge is dominated by basalt with thin interbasalt sands and gravels whereas the upper part (near the basin margins) is composed mainly of sands and gravels.

The flat-lying basalts of the Servilleta Formation are well exposed in the walls of the Rio Grande Gorge where an aggregate thickness of at least 600 to 700 feet can be seen. According to McKinlay (1956, 1957) the flows range from 20 to 55 feet in thickness and are basaltic to andesitic in composition. Most of the basalts are rich in olivine. The vents from which the basalts were erupted have mostly been destroyed by erosion or covered by younger flows. Generally only the final vents have been preserved and these make up the majority of the hills and peaks of the San Luis basin. One older vent, a cinder cone completely buried by younger flows, is well exposed in the walls of the Rio Grande Gorge approximately 4 river miles upstream from its junction with Red River. All the exposed vents are central-type vents rather than fissure-type. No dikes within the basalt are exposed in the Rio Grande Gorge, suggesting that the older volcanoes were also central-type.

The volcanic cones of the San Luis basin include a variety of sizes and types. Some are quite large mountains and appear to be rather typical shield volcanoes. Some are small and seem to be composed mainly of pyroclastic material, whereas others appear to be combinations of shield volcanoes and cinder cones. All of the volcanoes are moderately dissected by radial canyons. Following is a brief description of the major volcanic centers. For their locations, see Figure 1.

TRES OREJAS. Altitude, 7,959 feet. Height, 750 to 800 feet. Basal diameter (including older northeast cone), about 2 to 3 miles. Tres Orejas ("three ears") is a partly eroded cinder and lava cone surmounted by three incipient volcanic necks (the "ears"). The necks are about 50 feet high and 75 to 100 feet across and are arranged along a slightly curved northwest-trending line. Driblet (welded scoria) is present on the upper slopes and a southwest-dipping basalt flow is exposed on the southwest side of the cone. The middle and lower slopes are covered with red scoria much of which may be derived by erosion from the driblet on upper slopes. Immediately to the northeast of this cone is an older cone with a truncated crater rim. This older cone was partly destroyed by the eruption of the younger cone, accounting for its truncated crater.

CERROS DE TAOS. Altitude, southwest cone, 8,008 feet; northeast cone, about 7,900 feet. Height, southwest cone, 600 to 700 feet; northeast cone, 600 to 700 feet. Basal diameter, southwest cone, about 2 by 3 miles; northeast cone, about 2 miles. Cerros de Taos consists of two adjacent cones, one northeast of the other. Both cones appear to be composed of pyroclastics and lava flows. On the basis of degree of erosion the southwest cone appears to be the older. It has an incipient volcanic neck at its top. The northeast cone has a breached crater which contains a small cinder cone.

CERRO MONTOSO. Altitude, about 8,600 feet. Height, 1,000 to 1,100 feet. Basal diameter, about 4 miles. Cerro Montoso is a larger volcano than those of Tres Orejas and Cerros de Taos. At its top are two partially joined craters oriented along a northeast line. Each crater contains a partly eroded cinder cone with an incipient volcanic neck.

CERRO DE LA OLLA (Pot Mountain). Altitude, 9,450 feet. Height, 1,750 to 1,800 feet. Basal diameter, about 5 to 6 miles. Cerro de la Olla has the third greatest altitude of the volcanoes of the San Luis basin. Only San Antonio Peak (10,935 feet) and Ute Mountain (10,120 feet) have greater altitudes. Both are outside the area considered in this paper. Cerro de la Olla is a moderately dissected shield volcano surmounted by three, and possibly four, shallow pit craters. The youngest crater is on the northwest side of the summit and contains a shallow intermittent lake. Scoria is rather common in places on the summit. The volcano is nearly bisected by a 3-mile long northeast-trending fault which extends from the southeast side to the northeast side of the volcano. The fault is represented by a northwest-facing scarp 50 to 75 feet high. A vertical southeast- and east-trending dike, 10 to 15 feet wide and several hundred feet long, is exposed in the central summit area southeast of the youngest pit crater.

CERRO NEGRO AND GUADALUPE MOUNTAIN. Both of these groups of hills represent local buildups of basaltic material, but they are highly dissected and appear to have no original constructional surfaces remaining. Consequently, they may be among the oldest of the exposed Servilleta vents.

Except for local deposits of possible axial gravels along the Rio Grande Gorge, all the sands and gravels overlying the basalts have been derived from the bordering highlands and deposited by tributaries of the Rio Grande. They make up a partially dissected piedmont alluvial plain and attain their greatest thicknesses near the basin margins. As might be expected, their composition is quite variable, reflecting bedrock lithologies in the mountain segments of the depositing streams. In addition to compositional variations, however, there are two very different textural facies which can be distinguished in places.

One of these facies, here informally called the sandy gravel facies, is typically a yellowish, poorly consolidated, sandy pebble and cobble gravel with minor interbedded sand, silt, and clay layers. Generally, the gravel particles are subrounded to rounded. Pebbles and cobbles of some rock types, such as hornblende-bearing metamorphic rocks and coarse-grained igneous rocks, are extremely decomposed by weathering and can be crushed between the fingers. The sandy gravel facies is the dominant rock type of the piedmont alluvial deposits between Rio Hondo (north of Taos) and the intermittent stream 1½ miles west of Ranchos de Taos, and north of Red River for an undetermined distance. It is present locally in the area between Rio Hondo and Red River, and west of Rio Grande near its junction with Rio Hondo.

The other facies, here informally called the gravelly silt facies, is characterized by an abundance of fine clastic material (clay, silt, fine sand) and angular to subangular gravel particles. The fine-textured sediments occur in the gravel matrix and as separate beds. In places, beds of clay, silt, and fine sand are more common than gravel. Because of the beds of finer textured material, stratification is generally more apparent in the gravelly silt facies than it is in the sandy gravel facies. The gravelly silt facies is generally yellowish to pink but not so bright a yellow as that seen in the sandy gravel facies. The gravelly silt facies is the dominant rock type of the piedmont alluvial deposits between Rio Hondo (north of Taos) and Red River, and at the north base of the Picuris Mountains. In the vicinity of both Rio Hondo and Red River the sandy gravel facies and the gravelly silt facies can be seen to interfinger and intergrade with one another over horizontal distances measured in tens of feet. Interbedding of the two facies can be seen in an arroyo about 1¼ miles northwest of Valdez, and in a road cut along the Lama road about 1½ miles southwest of Questa (SE¼ sec. 1, T. 28 N., R. 12 E.).

Some evidence as to the origins of these two contrasting facies can be gained by considering the nature of the sediments being deposited by the present streams. The sediments in the channels of such perennial streams as Rio Grande del Rancho, Rio Fernando de Taos, Rio Taos, Rio Pueblo de Taos, Rio Lucero, Rio Hondo, Red River, and Cabresto Creek are commonly better rounded and better sorted than the sediments in smaller intermittent or ephemeral streams issuing from the mountain front. Consequently, it would seem likely that the sandy gravel facies was deposited by perennial streams with rather large drainage basins whereas the gravelly silt facies was deposited by intermittent or ephemeral streams with relatively small drainage basins. The interfingering and intergradation of the two facies are due to frequent shifting of subparallel intermittent and perennial streams with resulting overlapping and reworking of the deposits.

The distribution of the two textural facies of the Servilleta Formation indicates that the present pattern of perennial and intermittent streams (see Fig. 1) had been established by at least late Servilleta time and has existed relatively unchanged since.

The age of the Servilleta Formation has not been determined except very generally. Butler (1946) and Montgomery (1953) considered it to be late Pliocene or early Pleistocene. McKinlay (1957) stated that he could not date the basalts exactly but regarded them tentatively as late Tertiary to Quaternary. More recently Spiegel and Baldwin (1963) have noted that the Servilleta Formation may be correlative with the Ancha Formation of the Santa Fe area which they considered to be late Pliocene or early Pleistocene on the basis of physiographic evidence. The mere presence of the moderately eroded Servilleta volcanoes suggests that the upper part of the formation is no older than early Pleistocene.

PRE-SERVILLETA IGNEOUS ROCKS

Intermediate to silicic fine-grained igneous rocks crop out in several places in the San Luis basin. They generally make up small groups of hills rising above the general basin-floor level. Presumably these hills represent remnants of a pre-existing landscape that was inundated by Servilleta basalt. These rocks are generally considered to be of Tertiary age.

Cerro Chiflo is composed of andesite which has been considered Tertiary by some workers (see Dane and Bachman, 1965) and Quaternary by others (McKinlay, 1957). The contact between the andesite and Servilleta basalt is exposed in the Rio Grande Gorge at the east end of Cerro Chiflo. The nature of the contact, however, is obscure, and McKinlay noted that it is difficult to tell whether the andesite intrudes the basalts or represents a pre-basalt hill. McKinlay suggested that the andesite may be an extrusive dome which intruded the lower basalt flows and was later partly buried by younger basalt flows.

YOUNGER SEDIMENTARY ROCKS

Overlying the Servilleta Formation, and in places difficult to distinguish from it, are various fluvial, eolian, and lacustrine deposits that are probably nowhere more than a few hundred feet thick and generally are much less. Some of these probably belong to the Santa Fe Group, according to the definition of Spiegel and Baldwin (1963), whereas others do not. Several of these deposits are mentioned briefly below.

In the vicinity of Taos and north of Questa the sandy gravel facies is overlain in many places by a thin (5- to 30-foot thick) but widespread veneer of sandy gravel. As a rule it is easily distinguished from the yellowish, weathered sandy gravel facies by its fresh, unweathered appearance. (Gravel pit owners in the vicinity of Taos prefer this gravel to the sandy gravel facies because of its unweathered "hard" particles.) These gravel veneers represent channel deposits of laterally eroding, nearly graded, streams. Covering both the sandy gravel facies and the gravel veneers in some areas in the vicinity of Taos and north of Questa are brown silts and silty sands rarely more than 5 to 6 feet thick. Their fluvial origin is suggested by their occurrence in places in channels in the underlying rocks. Narrow, steep alluvial-fan aprons up to 1 mile wide border the Taos Range near Taos and Questa. They are only slightly dissected. Similar aprons also border the intra-basin hills. The basalt in the central part of the basin is generally covered by several feet of eolian sand and locally derived basaltic alluvium. As many as three or four alluvial and/or bedrock terraces are present in some of the larger valleys such as those of Rio Taos, Rio Hondo, San Cristobal Creek, and Red River.

Deposits of eolian sand underlie much of the surface in the southwest part of the basin, and include a 50- to 100-square-mile field of stabilized to partially stabilized northeast-trending longitudinal dunes. Some of the dunes are as much as 2 miles long and several hundred feet wide. The sand has been derived from an area southwest of the dune field where tributaries of the Rio Ojo Caliente have greatly dissected the Santa Fe Group. Eolian silt and sand is probably present as a minor component in most of the younger sedimentary units. Lacustrine sediments are present in collapse depressions in areas underlain by younger basalt flows.

Their topographic position and relatively small degree of dissection suggest that the deposits described here as "Younger Sedimentary Rocks" are late Pleistocene to Recent in age.

STRUCTURAL GEOLOGY

Broadly speaking, the geologic structure of the southeast San Luis basin is simple. The basin has been let down several thousand feet relative to the bordering highlands and faults are the principal structural features. The latest fillings of the basin (Servilleta and younger rocks) are essentially horizontal and are undisturbed except for minor intra-basin faults. The Picuris Tuff and the Tesuque(?) Formation, on the other hand, have been considerably deformed by basin-margin faults where they are visible along the Picuris Mountain front.

BASIN-MARGIN FAULTS

Partly on the basis of geophysical evidence, McKinlay (1956, 1957) estimated 7,000 feet of throw on the fault zone separating the southern San Luis basin from the Taos Range, but a consideration of stratigraphic thicknesses suggests that it is much greater, perhaps as much as 15,000 to 20,000 feet (C. B. Read, oral communication). Although most of this zone is covered by alluvium its presence is indicated by zones of crushed rock at the western edge of the Taos Range and by fault scarplets in basin-fill near the mountain front.

One such area of deformed Pennsylvanian sandstone and siltstone is exposed 0.3 to 0.4 mile north of the mouth of the canyon of Rio Fernando de Taos, and 0.2 to 0.3 mile east of the Quaternary-Pennsylvanian contact. Here the Pennsylvanian rocks have been locally crushed, sheeted, and bleached in zones 200 to 300 feet wide. Trends of fault surfaces and slickensides in these zones are highly variable. In one outcrop, fault surfaces are near vertical and range in strike from N 75° W to N 80° E. Rake of the slickensides is quite low ranging between 0° and 15°. Strike of the Pennsylvanian rocks is also variable but the dips seem to be gentle; none greater than 15° was noted.

Several fault scarplets in basin-fill border the mountain front near Taos and north of Questa. About half a mile west of the mouth of the canyon of Rio Fernando de Taos, a low scarp 25 to 50 feet high and 0.8 to 0.9 mile long is present in younger gravel overlying the sandy gravel facies. The north part of this scarp has a northeast trend and parallels the mountain front. To the south it turns southeastward and intersects the mountain front. The scarp is unrelated to stream terracing and there is little doubt that it is a very young fault scarplet. Other, similar scarps parallel the mountain front about 1 mile northeast of Taos. Upson (1939) mentions similar scarplets parallel to the mountain front 12 to 18 miles north of Questa.

Faults related to basin-margin faulting are rather well exposed in places along the Picuris Mountains front. These faults make up a 1- to 2-mile wide complex system characterized by anastomosing faults between Precambrian and Tertiary rocks, within the Tertiary rocks, and between the Tertiary and Quaternary rocks. Most of the faults seem to be normal faults but a low-angle reverse fault within the Tesuque(?) Formation is exposed in a U.S. Highway 64 road cut on the northeast side of Hondo Canyon (northeast of Pilar).

INTRA-BASIN FAULTS

A 3-mile wide zone of north-south nearly vertical normal faults extends north from Los Cordovas 5 to 6 miles (not all of the faults in this zone are shown in Fig. 1). In areas of greatest displacement in this zone Servilleta gravels have been downthrown on the west against Servilleta basalt. Elsewhere, the faults are wholly in gravel. Stratigraphic throw is difficult to measure but probably does not amount to more than a few tens or hundreds of feet. The trace of one of the fault planes is well exposed in an arroyo 1½ miles southwest of Los Cordovas. This exposure is near the southward termination of the fault and the dip separation, as measured on a basalt layer, is small, only 5 or 6 feet. The fault surface is a 1-foot wide zone of crushed and bleached rock and dips 89° west. In the present cycle of erosion the Servilleta gravels are being eroded from the fault surfaces and the faults are commonly represented in the topography as prominent west-facing basalt scarps 50 to 100 feet high. The Los Cordovas faults appear to be related to a major structural feature of the bordering uplifts. The faults are directly on trend with the large strike-slip Picuris-Pecos fault which extends from the north front of the Picuris Mountains south to near Glorieta—a distance of about 53 miles (Miller and others, 1963). To the north the west front of the Taos Range is about on this same trend.

A fault zone consisting of five northwest-trending en echelon normal faults can be traced from the Red River Fish Hatchery to Cerro Chiflo, a distance of 4½ to 5 miles. McKinlay (1957) has shown several of these faults on his map. The faults have displaced Servilleta basalts and possibly younger gravels. Four of the faults are downthrown to the northeast and are represented by northeast-facing basalt scarps. One is downthrown to the southwest. The faults are well exposed where they are crossed by Red River and the Rio Grande. In the gorge of the Red River, 0.2 to 0.3 mile downstream from the fish hatchery, the vertical trace of one of the faults is seen to be slightly curved and dips 85° northeast. The fault zone is 20 to 30 feet wide and consists of crushed basalt. Dip separation, as measured on an interbasalt gravel, is about 75 feet. This fault zone may represent a basinward extension of a prominent northwest structural trend in the Taos Range east and northeast of San Cristobal. The fault zone is roughly parallel to a Tertiary rhyolite dike swarm, a thrust(?) fault, and a major northwest-trending re-entrant in the mountain front (see McKinlay, 1957).

A single northeast-facing basalt scarp, probably a fault, extends about 2 miles northwest from near the west end of Cerro Chiflo. It is roughly on trend with the five en echelon faults described above and may represent an extension of that fault zone. At its northwest end is a small, eroded cinder cone the basal diameter of which is about 0.3 to 0.4 mile.

OTHER STRUCTURAL FEATURES

Structural control of volcanism

The general north-south alignment of the volcanoes Tres Orejas, Cerros de Taos, Cerro Montoso, and Cerro de la Olla strongly suggests structural control of these major volcanic centers. The east-west cluster of volcanoes across the basin in the latitude of Questa may represent a basinward extension of the east-west structural trend associated with the Red River graben. Most of the vent complexes (Tres Orejas, Cerros de Taos, Cerro Montoso, Cerro de la Olla) have cones, craters, or faults oriented along northeast-southwest lines indicating secondary structural control in this direction.

Lineaments

A study of the geologic map of New Mexico and Army Map Service aerial photograph mosaics suggests that a major northeast-trending lineament which extends 250 miles from Zuni Salt Lake, New Mexico, to the Moreno Valley east of Taos has influenced several geologic features in the vicinity of the southern San Luis basin. The northwest front of the Picuris Mountains, which lies along this lineament, has diverted the south-flowing Rio Grande to a southwestward course which the river maintains to its junction with Rio Chama. The courses of Rio Taos and certain valleys in the Taos Range appear to be influenced by this lineament also. Farther to the southwest, the Valles [Jemez] Caldera and Mt. Taylor are on the same lineament.

GEOMORPHOLOGY

GEOMORPHIC SUBDIVISIONS

Upson (1939) subdivided the San Luis basin into five geomorphic units on the basis of similar topography and similar geologic history. These include the Alamosa basin, roughly the north half of the San Luis basin and wholly in Colorado; the San Luis Hills in the central part of the basin just north of the State line; the Culebra Re-entrant, a re-entrant in the Sangre de Cristo Mountains, also just north of the State line; the Costilla Plains, the undissected piedmont alluvial plain east of the Rio Grande and north of Red River; and the Taos Plateau, all the New Mexico portion of the San Luis basin except the Costilla Plains. Of these, only the latter two are present in the Taos-Questa area.

Upson applied the name Taos Plateau to that part of the southern San Luis basin which is trenched by the gorges of the Rio Grande and its tributaries. As such it includes not only the areas underlain by basalt but also the slightly to highly dissected areas of piedmont alluvium south of Red River. The piedmont zone can be further subdivided on the basis of degree of dissection although the boundaries are somewhat arbitrary.

The moderately dissected piedmont alluvial plain bordering the north front of the Picuris Mountains is characterized by several north-northwest-dipping (100 to 400 feet per mile) surfaces below which northwest-flowing intermittent streams have cut valleys 50 to 75 feet deep. This piedmont alluvial plain is underlain mainly by the gravelly silt facies of the Servilleta Formation.

Bordering the Taos Range south of Rio Hondo is a slightly dissected alluvial plain underlain mainly by the sandy gravel facies of the Servilleta Formation. North of Rio Taos this plain is characterized by a gently convex, fan-shaped surface which slopes southwestward 30 to 300 feet per mile. It is drained by intermittent streams flowing in shallow valleys. South of Rio Taos and Rio Lucero the plain slopes westward and northwestward at 65 to 200 feet per mile and is crossed by the perennial streams Rio Lucero, Rio Taos, Rio Pueblo de Taos, Rio Fernando de Taos, and Rio Grande del Rancho, all flowing in wide, flat-bottomed valleys 50 to 100 feet deep. West of Los Cordovas Rio Taos has cut below the piedmont alluvium and flows through a basalt gorge to the Rio Grande.

Between Rio Hondo and Red River the eastern part of the basin is characterized by several northwest-, west-, and southwest-sloping surfaces (200 to 600 feet per mile) which have been almost completely dissected by intermittent streams in canyons up to 300 feet deep. This highly dissected geomorphic unit is underlain mainly by the gravelly silt facies of the Servilleta Formation. At the north and south edges of this unit respectively, Red River and Rio Hondo emerge from the mountain front in deep, flat-bottomed terraced valleys which abruptly change to deep narrow gorges to the west where they have cut below the piedmont alluvium and into the underlying basalt. San Cristobal Creek, a large intermittent stream in the south half of this unit, has a similar morphology.

Bordering the Sangre de Cristo Mountains north of Red River is Upson's (1939) Costilla Plains, an almost completely undissected alluvial plain which slopes gently westward from the mountain front to the Rio Grande Gorge with a gradient of 40 to 300 feet per mile. In the vicinity of Questa the Costilla Plains are underlain mainly by the sandy gravel facies of the Servilleta Formation. Farther north lack of exposures makes it difficult to determine what rocks underlie this geomorphic unit.

That portion of the Taos Plateau underlain by basalt lies almost entirely west of the Rio Grande and has a flat to rolling surface which slopes gently eastward toward the Rio Grande. The area is drained by intermittent streams tributary to the Rio Grande. Shallow closed depressions are present locally, especially north of Cerro de la Olla and Cerro Chiflo. Some of these represent collapse depressions in the younger basalt flows. Rising above the plateau surface are Servilleta volcanoes and hills of pre-Servilleta igneous rocks.

Origin of the Piedmont Landforms

As noted above, the piedmont zone of the southeastern San Luis basin is characterized by surfaces at several levels in various stages of dissection. The nature and origin of some of the landforms is fairly well understood but others are poorly known. Almost nothing is known concerning their ages.

True pediments (a piedmont surface that cuts across the rocks of the mountain range, Tuan, 1959) make up only a very small part of the total piedmont area. Along the east side of the southeastern San Luis basin the principal basin-margin fault zone is only a short distance west of the base of the mountains, and the pediments are confined to a narrow strip less than a few tenths of a mile wide between the fault zone and the mountain front. One such pediment, just north of the mouth of Rio Fernando de Taos Canyon, is about 0.3 mile wide and is cut on gently dipping Pennsylvanian limestone and arkose. It has a westward slope of about 650 feet per mile and is dissected by narrow arroyos 20 to 30 feet deep. It is overlain by 5 to 20 feet of poorly sorted sandy gravel containing pebbles, cobbles, and boulders of locally derived material. The origin of the pediment is unknown. This particular pediment is bordered on the west by a straight scarp 20 to 30 feet high which appears to be a relatively young fault scarp.

Surfaces cut on the deformed and undeformed basin-fill sediments are more common than surfaces cut on mountain rocks in the southeastern San Luis basin. Along the north front of the Picuris Mountains several such surfaces cut on tilted poorly consolidated sandstones and conglomerates of the Picuris Tuff and Tesuque(?) Formation seem to be fan shaped and may represent rock fans as described by Johnson (1932). About 3½ to 4 miles northeast of Pilar a faulted, well-preserved fan-shaped surface is present at the mouth of Hondo Canyon and has been bisected radially by a 250-foot deep arroyo. The surface slopes northwestward about 300 feet per mile. In the walls of the arroyo and in several of the road cuts along U.S. Highway 64 an erosion surface can be seen beveling dipping rocks of the Tesuque(?) Formation. The erosion surface is overlain by 10 to 30 feet of sandy gravel which has a fan-shaped (i.e., convex upward) upper surface suggesting, though certainly not proving, that the underlying erosion surface is also fan shaped. Similar landforms and relationships can be seen farther east along the Picuris Mountains front. Johnson (1932) described rock fans in several parts of the Southwest and concluded that they were the results of lateral planation by streams emerging from the mountain front. It seems likely that the Picuris fans had such an origin.

As noted above, the Servilleta Formation over much of the southeastern San Luis basin is overlain by thin gravel veneers which represent channel deposits of laterally eroding, nearly graded or graded streams. The surface beneath the younger gravel is obviously an erosion surface and in areas where this relationship exists the piedmont surface can, for practical purposes, be considered an erosion surface. Such a relationship appears to exist over much of the piedmont zone north of Rio Taos and Rio Lucero and south of Rio Hondo, and in parts of the Costilla Plains near Questa and Cerro. In the highly dissected piedmont area between Rio Hondo and Red River the gravel veneers, if present, are difficult or impossible to distinguish but it seems likely that at least some of the graded surfaces in this section had a similar origin.

Throughout most of the piedmont zone there is a close correlation between basin-fill lithology and degree of dissection. The relatively undissected area between Rio Hondo and the intermittent stream 1½ miles west of Ranchos de Taos, and the undissected southern Costilla Plains in the vicinity of Questa and Cerro, are underlain mainly by the sandy gravel facies of the Servilleta Formation. On the other hand, the moderately dissected piedmont zone north of the Picuris Mountains and the highly dissected piedmont zone between Rio Hondo and Red River are both underlain mainly by the gravelly silt facies of the Servilleta Formation. These relationships suggest that the lithology of the basin-fill has played an important role in the origin of the two contrasting types of landscapes. It seems likely that the lower permeability of the gravelly silt facies leads to greater runoff and dissection than occur in areas underlain by the more permeable sandy gravel facies. Other factors have probably been important also and these may have included differences in available relief in different parts of the piedmont zone, differential uplift in the piedmont zone, and local base levels within the piedmont streams.

Most of the perennial streams in the piedmont zone are bordered by alluvial and bedrock terraces. Commonly as many as three or four can be distinguished. All are probably late Pleistocene to Recent in age. Unfortunately, they have been removed, or were not formed, in the mountain-canyon segments of these streams and so cannot be traced upstream to glacial deposits in the Taos Range.

Asymmetrical valleys cut by intermittent streams in basin-fill sediments are rather common in two areas in the southeastern San Luis basin. In one area, north of U.S.

Highway 64 and west of Ranchos de Taos, the valleys of north-and northwest-flowing tributaries of Rio Taos have steep west-facing slopes and gentle east-facing slopes. Most of the valleys are 0.2 to 0.4 mile wide (ridge crest to ridge crest) and 40 to 60 feet deep. In most cases the asymmetry is remarkably developed. In the other area, on the fan-shaped surface south of Rio Hondo, the valleys of west- and southwest-flowing tributaries of the Rio Grande have steep south-facing slopes. Farther south, the valleys of southwest- and south-flowing tributaries of Rio Taos have steep west-facing slopes. The valleys in this area are about the same size as those in the other area.

None of the standard explanations for valley asymmetry such as homoclinal shifting, meandering, differences in slope microclimate, tectonic tilting, or Coriolis force, seem to apply to these valleys as a group, although one or more of these explanations may apply to those valleys with similar orientation and morphology.

THE RIO GRANDE GORGE

The gorge of the Rio Grande begins as a shallow trench near Alamosa, Colorado. At its junction with Costilla Creek, just south of the State line, it has a depth of about 200 feet (Upson, 1939). At the Rio Grande Gorge bridge on N.M. Highway 111 and at its junction with Rio Taos it has a depth of about 600 feet. At Embudo, near its southern end, it is about 1,000 feet deep. Between the State line and Embudo, a river distance of about 66 miles, the average gradient is 23 feet per mile. The New Mexico portion of the gorge is cut in Servilleta basalt, except at its southern end near Pilar and Embudo where it is in Precambrian metamorphic rocks and the Tesuque(?) Formation.

The specific factors initiating gorge-cutting and the exact date at which it began are not known. The gorge postdates deposition of at least part of the sandy gravel facies of the Servilleta Formation. Typical yellowish gravels of this facies containing rocks derived from the Sangre de Cristo Mountains are exposed west of the gorge in road cuts along old N.M. Highway 111 about 1 mile north-northwest of Dunn's Bridge (about 3 miles northwest of Arroyo Hondo). A date on this part of the Servilleta Formation would provide a maximum date for the beginning of gorge-cutting.

Large slump blocks are very common in parts of the gorge and in some areas landslides of this type are the principal method of valley widening. (One of these landslide areas is illustrated on page 104 of Thornbury's (1954) textbook, "Principles of Geomorphology." An oblique aerial photograph shows a south-facing view of the gorge near the confluence of the Rio Grande and Rio Taos.) There is some evidence that large-scale slumping, at least in the vicinity of the Rio Taos confluence, is not an active process at present. In this part of the gorge, and well shown in Thornbury's photograph, the gorge consists of a narrow inner gorge relatively free of slump blocks, and a much wider outer gorge where slump blocks are numerous. Obviously slumping has been at a minimum during the time of cutting of the inner gorge, but was much more active earlier. It seems likely that these alternating periods of maximum and minimum slumping are climatically controlled. Perhaps maximum slumping occurred under Pleistocene periglacial conditions whereas little or no slumping has occurred under present climatic conditions.

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