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GEOMORPHOLOGY OF ESPANOLA BASIN

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INTRODUCTION

The Espanola basin is one link in a chain of six or seven similar basins which comprise the Rio Grande rift or depression and are followed by the Rio Grande from southern Colorado to southern New Mexico. In many respects, it may be considered the type basin owing to the fact that the Neogene Santa Fe Formation or Group has its type sections in the Espanola valley (Baldwin, 1956; Bryan, 1938; Cabot, 1938; Galusha and Blick, 1971; Hayden, 1869; Smith, 1938). Physiographically, the basin is rimmed by alternating ranges and plateaus (fig. 1). The Rio Grande, which is axial to the basin, comes in through a plateau gorge on the north and goes out through a gorge on the south. On the west, the basin boundary is straddled by the great Jemez Mountains volcanic pile. On the northwest, the basin is bounded irregularly by the north-northwest-trending Brazos and Tusas ranges. The northern boundary is the irregularly eroded edge of the Taos Plateau. On the east, the boundary is the Sangre de Cristo Range trending southward from the Picuris Mountains and terminating about 12 mi (19 km) south of Santa Fe. The southern end of the basin is marked irregularly by the cluster of porphyry and volcanic Cerrillos Hills and the northern rim of Galisteo River valley, an eastern tributary of the Rio Grande (fig. 2). The southwestern margin is taken at the La Bajada fault escarpment and the Cerros del Rio volcanic hills. Both the valley and the basin are centered about the confluence of the Rio Grande and its principal tributary, Rio Chama, which drains into the basin from sources along northeastern areas of the Colorado Plateau. These rims are fed in the basin area by numerous tributaries from the surrounding mountains. Notable among these are: El Rito and Ojo Caliente on the northwest; Embudo, Truchas, Santa Cruz, Pojoaque-Tesuque and Santa Fe on the east; and Santa Clara and Frijoles on the west. Altitudes along the Rio Grande through the basin are 6,050 ft (1,845 m) on the north down to 5,300 ft (1,616 m) on the south. Altitudes in the surrounding mountains range up to 13,101 ft (3,994 m) in the Sangre de Cristo Range; 11,551 ft (3,522 m) in the Jemez Mountains; and 8,602 ft (2,623 m) in the Brazos and Tusas mountains.

BASIN DEVELOPMENT

In order to understand the origin of the existing landforms, it is necessary to review development of the Neogene basin. Prior to basin development, the area was probably a part of the eastern margin of the Colorado Plateau along its junction with the Colorado-New Mexico orogenic Rockies (Kelley, 1979b). The southern part of the Espanola area appears to have been occupied by a portion of the Galisteo Eocene basin and the northern parts were highlands (Gorham and Ingersoll, this guidebook). Regional uplift of much of New Mexico during late Eocene and most of Oligocene caused widespread erosion of the region. This seemingly long period of epeirogenic stabil- ity was then followed by a change to crustal extension. As a result, the Colorado Plateau margin foundered along the roots of the early Laramide uplifts, thus producing downwarping and extensional faulting that became the Rio Grande rift. At the time of basin subsidence, uplifts such as the Nacimiento, Jemez and Brazos were present on the west and northwest. On the east, there was a more subdued and mature version of the Laramide Sangre de Cristo uplift, and its margin lay five to ten miles (8 to 16 km) west of its present position. It was from these sources that much of the Santa Fe sediments of the subsiding Espanola basin were derived.

During Miocene and early Pliocene, older sedimentary and crystalline sources were augmented by volcanics which erupted in the Jemez, Brazos and a Sangre de Cristo area some distance northeast of Espanola basin. Sedimentation continued as the basin subsided, and in particular, as the Sangre de Cristo source area slowly tilted upward. Although the basin had depositional axes generally along the Rio Grande and Rio Chama courses, the major subsidence and uplifting of borders did not come about until after most of the presently preserved Santa Fe sediments were deposited. The actions involved principally broad uptilting of the eastern side of the basin where original depositional dips of a degree or two were increased widely to 5-10 degrees. Locally along faults and along the monoclinal flexure at the Sangre de Cristo margin, dips are now up to 25-30 degrees. It was also a time of much normal faulting, and displacements appear to have been at least several hundred feet in many places. This period of late Pliocene tilting and faulting is widely present along the rift and in the adjoining eastern Rockies (Tweto, 1978). The deformation was a form of Basin and Range tectonics. For this late Pliocene deformation, the term "Santa Fe disturbance" is proposed as a culmination to the overall Rio Grande rifting.

Following the Santa Fe disturbance, widespread tectonic stability set in. Erosion of upturned beds and elevated scarps was relatively rapid and pedimentation spread widely about the basin.

PEDIMENTS

Nature and Distribution

There are several pediments in the Espanola basin, but by far the most significant is the Ortiz surface, first named by Bryan (1938, p. 215). A few higher and older surfaces of local extent occur around the Jemez, Nacimiento, Brazos and Picuris areas (fig. 1), but evidence that they were widespread is not convincing. A local lower surface (Santa Cruz) that may have been a pediment is suggested by numerous concordant remnants along the eastern side of the basin (see below). The Ortiz surface and its equivalents along the Rio Grande region most certainly were recognized by geologists of the earliest surveys in the Southwest. Johnson (1903, p. 174-175) was possibly the first to note and describe this surface around the Ortiz Mountains, and Yung and McCaffery (1903, p. 353) described the gold-bearing placer gravels around the San Pedro (Tuertos) Mountains. Lee (1907, p. 11, 19) referred to the high gravels as "mesa gravels." Stearns (1953, p. 476-477)

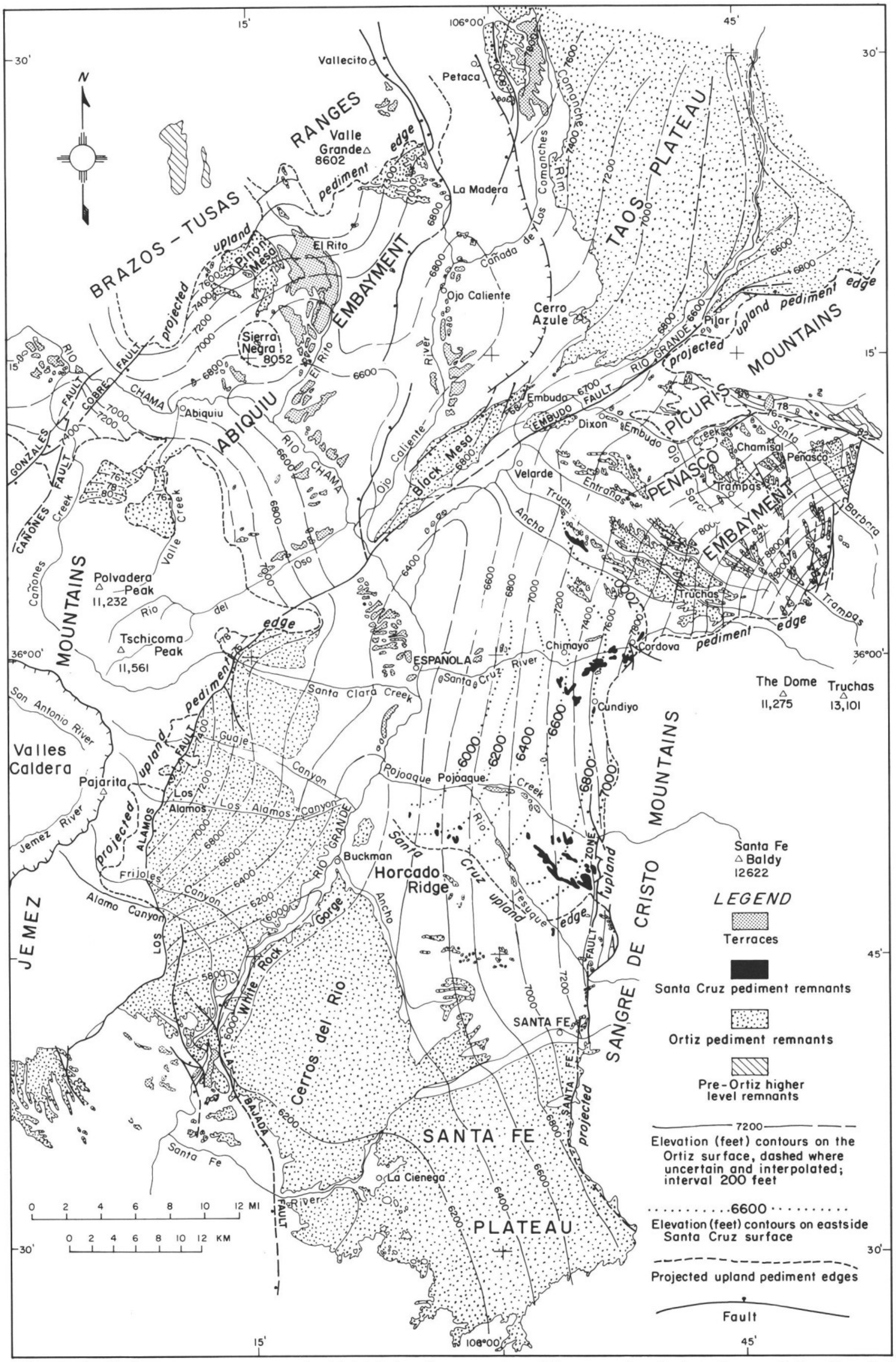

Figure 1. Pediments, terraces and old high-level remnants with reconstructed surfaces of the Española basin area. Hachured line west of Taos Plateau indicates possible erosional escarpment between equivalent surfaces of different altitudes (see text for discussion).

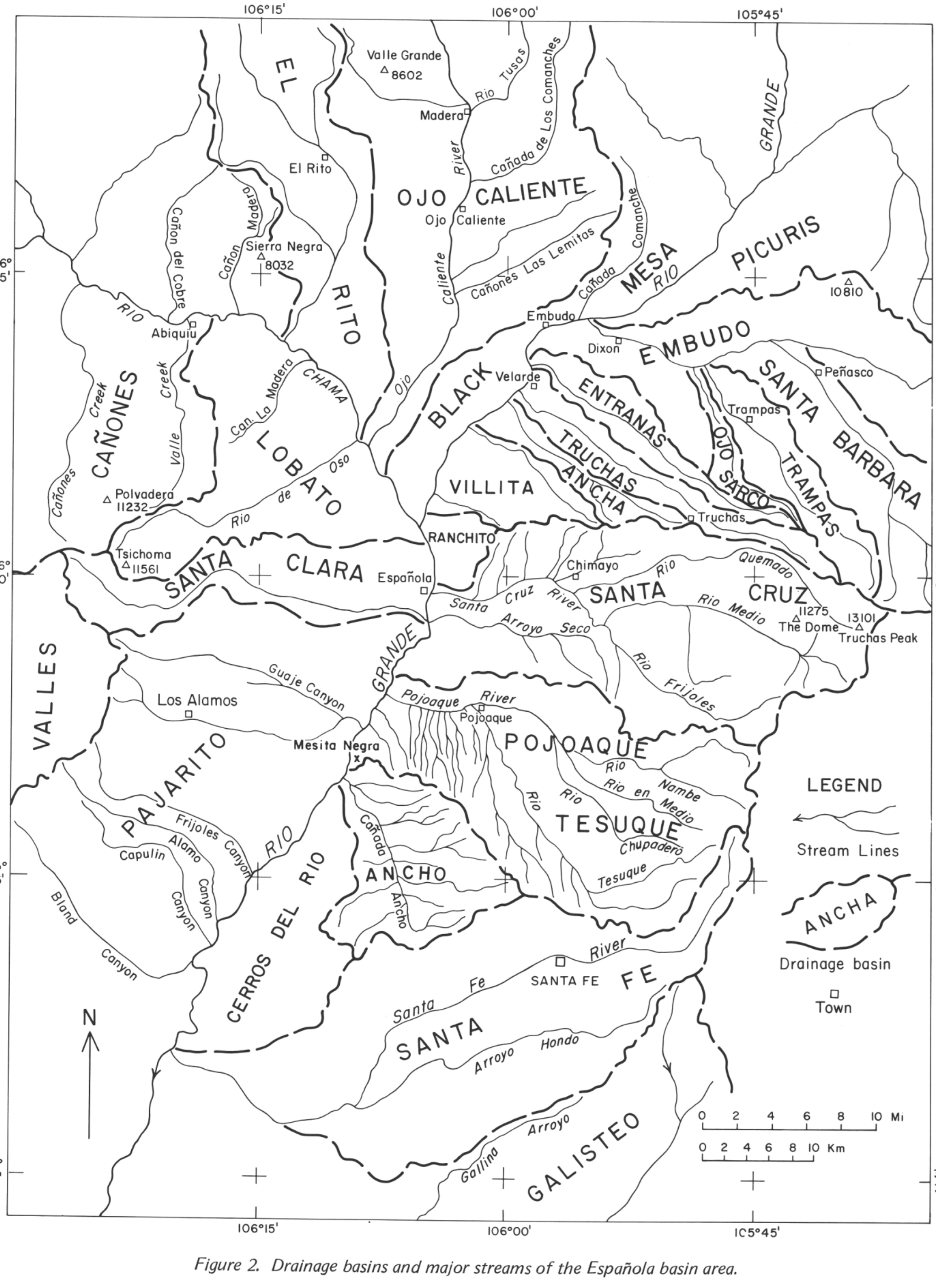

Figure 2. Drainage basins and major streams of the Española basin area.

named the gravels overlying the Ortiz surface Tuerto Gravel in the San Pedro area (Kelley and Northrop, 1975, p. 70). The term "Ortiz gravels" also has been used, and many geologists use "Ortiz surface" for the undissected tops of the covering gravels as well as the cut surface at the base (Spiegel and Baldwin, 1963, p. 49). This practice arises from the fact that the pediment cover is commonly rather thin, and that near rock fans at the head of pediments, the cover may be patchy. An additional problem is that at the bolson, playa or bajada end of the cover there may have been little or no interruption between uppermost Santa Fe and pediment covers. In this paper, the term "Ortiz surface" is used for the erosional or cut surface at the base of whatever cover there may be. In very expansive erosional surfaces, such as the Ogallala of eastern New Mexico and its extensions to mountainous western edges, the age of the cut surfaces may vary from early Pliocene in the east to possibly the present at a few preserved western margins. However, in the Rio Grande area, the Ortiz surface is not likely to have such time spans because of the nearby mountains. Nevertheless, a few remnants still exist next to uplands where minor Ortiz pedimentation may be going on at present. The covering gravels and/or volcanics could be every age from the oldest cut surface to the present.

Cabot (1938, p. 95-103) recognized four surfaces, but the lower ones may be terraces. His highest, no. 1 pediment, he termed the Truchas surface for the remnants at Truchas. The no. 2 surface, somewhat lower, he thought was correlative with the Ortiz. It appears, however, that the surface (Cabot, 1938, fig. 2) near Santa Cruz dam is what Manley (1978, p. 204-206) termed Santa Cruz.

For purposes of simplicity, the term Ortiz surface is applied here to all the remnants mapped as such on Figure 1. The choice of these, especially in the Abiquiu embayment, is by my correlation or choice largely based on reasonable altitude concordance. Because of weakness of Santa Fe beds, few remnants would exist today were it not for the capping gravels and basalt flows. In the Ortiz Mountain type-area, the Ortiz surface is preserved by Tuerto or Ortiz gravels; in the Santa Fe Plateau and Cerros del Rio areas, the surface is protected by Ancha gravel and Cerros del Rio volcanics. In the Penascoembayment, the Ortiz (Truchas) surface is preserved by Ancha gravels (Miller and others, 1963, p. 51, 53). North of the Picuris Mountains and in the southern Taos Plateau, the surface is overlain by Servilleta gravel and basalt (Montgomery, 1953, p. 53) that lap onto the older Hinsdale volcanics (Butler, 1971, p. 299). In the Abiquiu embayment, unnamed gravels cap three possible correlatives, i.e., Valle Creek, Pirion Mesa and La Madera of the Ortiz surface (fig. 1). In the Penasco embay- ment, Manley (1978, p. 206) has identified three surfaces, Oso, Entranas and Truchas, from the highest in the northeast to the Truchas in the southwest. As she noted, the capping boul- dery gravels are rather thin and nowhere near the thicknesses of 300 ft (91 m) suggested by Miller and others (1963). The gravels do, however, thicken northwestward downslope from the 9 ft (3 m) given by Manley (1978) to about 50 ft (15 m). There is little doubt about the existence of several similar and closely associated surfaces in the embayment area, but whether they represent distinctly different pediments is still open to question. Some of the differences in altitude are due to faulting (Kelley, 1978) and others are due to the puzzling ways that they have been terraced with some slope resurfacing during Quaternary canyon cutting. It is also true that most large pediments are multiple or compound surfaces which may be arched or fanform and be at different altitudes along the bases of successive mountain spurs and canyons. More than two-thirds of the original surface has been removed (fig. 1) and it is not surprising, therefore, that higher and lower parts may appear to be of different ages. The modification of the sur- faces during the canyon cutting is discussed further below.

Ortiz Correlation and Reconstruction

Figure 1 shows the surface outlines of the correlated Ortiz remnants and their estimated or projected upland edges. The extensive horizontal gaps among the Ortiz remnants pose uncertainties as to whether they were once continuous. Along the eastern half of the basin, general correspondence in altitude among the Santa Fe, Penasco, Black Mesa and Taos areas lends considerable credibility to correlation and projection of the Ortiz surface contours through the areas where former existence is inferred. By contrast, on the western side of the Espanola basin around the Jemez country and in the Abiquiu embayment, correlatable remnants are fewer and smaller. Contour reconstruction of this surface yields a very considerable anomaly or lack of correspondence with the altitudes in the Taos Plateau and Black Mesa. This anomaly is shown by insertion on the map of a hachure line which is meant to indicate an erosional escarpment between what may have been time-equivalent surfaces at considerable differences in altitudes. This difference ranges from what may have been little more than 100 ft (30 m) southeast of Ojo Caliente to as much as 600-700 ft (180-210 m) east of La Madera. Part or all of this difference may be ascribed to post-Ortiz faulting and tilting. The faults are La Madera-Cerro Colorado, Ojo Caliente and Comanche. Some easterly tilting is possible along the western side of the Taos Plateau and southeasterly tilting of about 2° is clearly evident in the southern part of Black Mesa. The long southwesterly trend of Black Mesa suggests that the basalt may have followed the ancestral Rio Grande-Ortiz valley axis. Before the basalt eruption, it is possible that the upper reaches of the Ojo Caliente and Tusas rivers flowed to junctions with the Rio Grande near Embudo or Velarde. The Black Mesa flow diverted the Ojo Caliente River to the Chama-Ortiz-surface axis. It is also possible that pedimentation in the Abiquiu embayment may have developed at a lower altitude because of lower surrounding uplands and because more resistant older (5.4 m.y.) Hinsdale basaltic flows were already present beneath the Ortiz surface in the Taos Plateau area.

A number of faults have cut the Ortiz surface (Kelley, 1978). Most of the smaller ones are not shown on Figure 1. The most significant faults that are shown to affect the surface are La Bajada, Los Alamos and Embudo.

Lower Surfaces

Several lower surfaces in the basin suggest at least one pause in the late Quaternary dissection to the present state. One of these may be termed the Santa Cruz pediment. It is shown reconstructed along the Sangre de Cristo front between the Ortiz remnants west of Truchas and the Ortiz remnants northwest of Santa Fe (fig. 1). Its projection takes the form of a broadly concave surface that centered about the present Santa Cruz, Pojoaque and Tesuque drainage systems. Cabot (1938, p. 97) noted that this surface was about 500 ft (150 m) lower than the Truchas surface. By comparing the intersections of the Ortiz and Santa Cruz contours, it may be seen that the Santa

Cruz surface ranges from as little as 100 ft (30 m) lower than the Ortiz surface near the mountains between the Pojoaque and Tesuque drainages to as much as 800 ft (240 m) lower in the Chimayo, Cordova, Cundiyo triangle. In reconstructing the Santa Cruz surface, I also have correlated the north-sloping gravel patches north of Horcado Ridge on the basis of general altitude concordance.

Another younger, rather local, area of pedimentation may be the two highest gravel patches (shown as terraces on Figure 1) surrounding the Sierra Negra upland northwest of Abiquiu. Sierra Negra is capped by a high older basalt, and this appears to have preserved the mountain as an upland above the Ortiz as well as the two lower surfaces that are located like remnants of a loose collar on the southwest and northeast (fig. 1). The southwestern remnant is 6,200-6,400 ft (1,890-1,950 m) in altitude and the northeastern remnant is 6,400-6,800 ft (1,950-2,070 m), both sloping southeasterly in accordance with the slope of the Abiquiu embayment. The upper end of the northwestern remnant is only about 100 ft (30 m) below the lower end of the Ortiz surface only about 1 mi (1.6 km) to the west. These two surfaces could be correlatives of the Santa Cruz and further corroborate the pause in downcutting of the basin in post-Ortiz (Santa Cruz) time.

Another surface is preserved in the Comanche drainage area beneath the Comanche rim of the Taos Plateau (fig. 1). This surface is a pediment remnant about 6 ml (10 km) long and ranging from 7,600 ft (2,320 m) at the north to 7,300 ft (2,230 m) at the eroded south edge. At the northern end, it is only about 50 ft (15 m) above Canada de Los Comanches; at the southern end, it is about 200 ft (60 m) above the Canada. It is about 300-400 ft (90-120 m) below the surrounding basalt-capped Hinsdale surface. All three of these lower pediments may have been contemporaneous with some of the higher terraces found along the present drainage system throughout the basin. A few such correlations are pointed out below.

CANYON CUTTING

Inner valleys of Quaternary age have been eroded into the Rio Grande depression. Nowhere, however, is this dissection as great as in the Espanola basin. Many of the canyons in the bordering uplifts, which were eroded principally during basin subsidence, were deepened by several hundred feet during the period of basin pedimentation. In the basin proper, erosion developed valleys and gorges with as much as about 1,000 ft (300 m) of relief. Aridity coupled with the weakness of the Santa Fe beds yielded great arrays of badlands and numerous sand- and gravel-bottomed arroyos. The large valley bottoms of the Rio Grande and Rio Chama, and several of the major tributaries such as Santa Cruz, Pojoaque and Tesuque have floodplains locally.

Initiation of the regional erosion of the inner valleys is likely to have resulted from broad regional uplift. In the case of the Rio Grande, the cutting most likely progressed northward through New Mexico. However, in the Espanola basin, there was a local added impetus produced by late Quaternary throw on the La Bajada fault. Formation of the escarpment, which crosses the Rio Grande, appears to have been caused by downthrow on the western, downstream Albuquerque basin side (Kelley, 1979a). Prior to the development of the La Bajada escarpment, there was essentially no inner valley either immediately downstream or upstream. As the fault scarp grew and while the Cerros del Rio basalt flows were not breached, waterfalls may have existed at the escarpment. However, as soon as the resistant basalts were breached, the White Rock Gorge undoubtedly propagated rapidly into the uncapped area from about the Pojoaque River junction northward. Prior to the eruption of the Bandelier Tuff from the Valles caldera, the Rio Grande canyon in its early stages was locally a short distance east of its present position (Kelley, 1948, p. 10). During this detouring of the river course, a short period of damming behind the thick tuff sheets created temporary lakes and low waterfalls at the point downstream where the river reentered its early-formed canyon. During most of the gorge development, there may have been no eastern (Ancho) tributary at Buckman owing to the fact that the Cerros del Rio lavas probably connected with the Mesita Negra outlier south of the Pojoaque junction.

North of the gorge, at least during about the first one-third to one-half of its development, the inner valleys of the Rio Grande and Rio Chama were much narrower than at present. On the west, the Pajarito Plateau was much less dissected and the present cliffs held up by the Puye gravels were probably much nearer to the Rio Grande than now. To the east, a great array of only youthfully indented mesas, held up by a widespread Ortiz surface and its gravel caps, formed the eastern slopes of the inner valley. To the north, the inner valley probably headed a short distance north of Velarde at waterfalls over the lava cap at the then southern edge of the Taos Plateau. The curious left deflection of the Rio Grande northwest of Velarde may have been determined by very early meandering of the river along low areas on the basalt field and the fact that the Embudo fault had elevated a southeastern strip of the basalt up to about 100 ft (30 m) above the downthrown part to the northwest. The river then poured over the side of the lava flow toward Velarde. The southern end of Black Mesa may have been 1-2 ml (1.6-3.2 km) south of its present end, and this may have restricted greatly the size of the inner valleys of the Abiquiu embayment. The remainder of the dissection of the inner valleys followed, in general, the early pattern except for considerable shifting of divides as the major tributaries took their turns in vigorous headward erosion.

In the early stages of dissection, the northern rim of the Ortiz surface of the Santa Fe Plateau extended eastward and southeastward along the southern and southwestern sides of the Pojoaque-Tesuque drainages. As erosion progressed along the White Rock Gorge, the narrow divide which connected Cerros del Rio to Mesita Negra was cut through, and a new drainage basin, Ancho, developed along the northeast side of Cerros del Rio volcanic cap about to lat. 350 45' north (fig. 2). Strong eastern tributaries to Ancho nibbled away rapidly into the west-sloping (100 ft/mi, 19 m/km) Ortiz surface and finally destroyed all but small scattered patches along the highest ridges in the Ancho drainage basin. There is a sharp drainage contrast between the west-draining arroyos into Canada Ancho and the numerous, small and straight north-draining arroyos into Pojoaque Creek. The Pojoaque arroyos parallel the strike of the Santa Fe beds as though lithology differences controlled their spacing and straightness. The southern tributaries to Tesuque Creek also flow northward but are deeper and longer than the corrugated set down the north side of Horcada Ridge.

In this southeastern part of the basin, considerable differences are apparent in the Holocene vigor of erosion in the several drainage basins. On the south is the basin of the Santa Fe River in which erosion is slow owing to the resistant older beds through which the river flows, especially in the canyon area through the La Bajada escarpment. On the north, the Ancho and Tesuque drainages are eroding headward into the Santa Fe divide. But toward the east, where the Ancho and Tesuque systems meet, the Santa Fe is sapping the Ancho owing principally to the generally greater surface flow from the Sangre de Cristo for both the Tesuque and Santa Fe drainage areas. The long, straight northwesterly flow of Rio Tesuque is suggestive of some structural control, but none is evident. The most likely explanation is the longer preservation of the Ortiz surface between the Tesuque and Cerros del Rio, as explained above.

Some of the most unusual geomorphic features of the basin occur in the Periasco embayment. These are in the northwesterly trending canyons: Ancha, Truchas, Entrarias, Trampas, Santa Barbara and the curving westerly flowing Embudo Creek which lies along the southern margin of the Picuris Mountains. The Ortiz pediments on the divides between these canyons have been described above. General contouring of this surface reveals a northwesterly downstream fan form. Furthermore, the canyons and remnant pediment strips tend to focus in an apex in the southeast corner of the embayment into the large canyons which head in the northern sides of the highest peaks, Dome and Truchas, of the Sangre de Cristo Range. In this area, Embudo Creek plays the part of an axial peripheral stream to the radiate system. The periphery here is the perimeter of the Santa Fe fanglomerates where they abutted and lapped onto the south side of the Picuris Precambrian uplands. When canyon cutting set in, Embudo in particular (Cabot, 1938), and Santa Barbara and Trampas locally were superposed onto Precambrian basement.

There is a sequence of development of drainage and dissection from north to south. The oldest is the Embudo basin in which the drainage of the southern tributaries extended themselves in a S5-30E direction into the distributaries of the predissection fan form. The tributaries of the western part from about Dixon to Ojo Sarco drained northerly (fig. 3) and those east of the Ojo Sarco basin drained northwesterly.

The next younger tributaries grew easterly from the Rio Grande near Velarde in a direction of S55E and include a group of three, long narrow basins, Ancha, Truchas and Entrafias (figs. 2, 3). In their upper courses, they early captured the northerly flowing arroyos of the Embudo basin. As this process proceeded, the beheaded arroyos one after another added to the flow of the capturing streams. The Truchas and Ancha, and possibly the northernmost of the Vellita group of streams (fig. 3), may have reached all the way to the Sangre de Cristo upland corner.

The third dissection to affect the area of the Periasco embayment (fig. 2, 3) is that of the Santa Cruz River. It dissected the Ortiz surface from the west. Figure 3 very strikingly shows the beheading of the northwesterly flowing older second group, especially for Ancha and Truchas drainages.

Recognition of the above sequence of basin dissections is a key to what appears to be slight tilting or possibly step faulting of the pediments of the Ancha to Entrarias group. The appearance of tilting and faulting is instead the natural result of broad diagonal capture of the original, small northerly flowing arroyos of the Embudo drainage basin. The gradients of these arroyos probably were only a few feet per mile and sheet runoff may have been possible. As shallow gulleys of the upper reaches of the Ancha-Entrahas set cut the older slope, their predominant source of water was from the south sides and these sides were steepened by headward gullying and sheet erosion. The northern sides of the capturing streams had less and less area and shorter steepened slopes. As a result, with canyon deepening, the streams tended to "hug" the north banks, steepened their slopes, and shifted the stream courses gradually north as deepening proceeded (fig. 4). The result was development of terraces only on the south sides of these canyons. There are up to 4 levels of terraces preserved in places. Although most of these are flattish benches, some are slopes, especially the higher ones, and they appear to have developed that way or been modified that way partly perhaps by filling of the back sides and partly by the same processes of sheet erosion as described above for the Ortiz remnants.

TERRACES

Terrace gravels are scattered widely along both the Rio Chama and Rio Grande. They are also common along many of the tributaries such as El Rito, Ojo Caliente, Santa Cruz, Pojoaque and Tesuque, and in the long narrow canyons which head in the Pefiasco embayment. The most abundant terrace remnants are in the Abiquiu embayment (fig. 1). The largest are those along El Rito valley beginning at the town of El Rito and southward. Four terraces can be identified between the river on the east and the Pilion Mesa surface which is correlated as an Ortiz surface. As with all the terraces, they slope toward and down river. The lowest one is only about 20-50 ft (6-15 m) above the river. The highest or fourth terrace is 200-300 ft (60-90 m) above the river. Toward the southern end of the group, faults may be responsible for a few of the separate levels (Kelley, 1978). In this stretch of El Rito Creek, no terraces exist on the east side beyond the low fields just above the river. Southeast of Sierra Negra, the terraces switch to the east side of El Rito Creek. These extend to the junction with Rio Chama where they extend along its north side to near the divide between the El Rito and Ojo Caliente

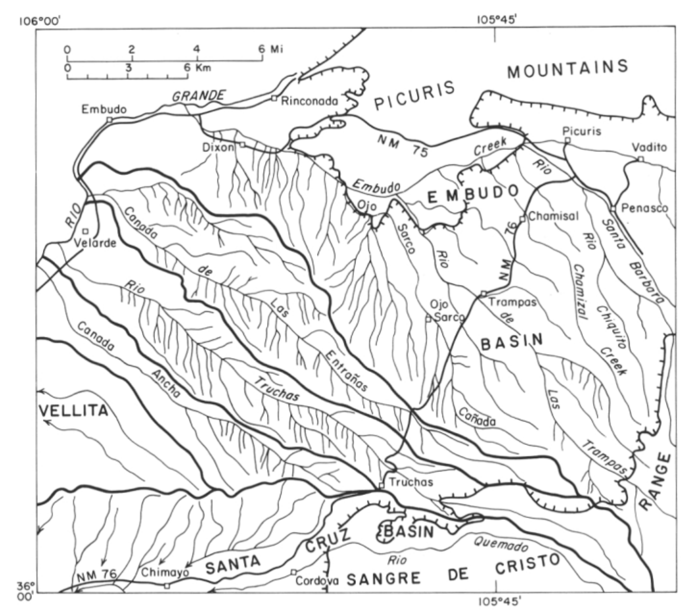

Figure 3. Drainage basins and stream patterns of the Peñasco embayment.

basins (fig. 2). Two levels are present, one 125 ft (40 m) and the other 270 ft (80 m) above the valley bottoms. The long northeasterly trending strip in the middle of the patch descends nearly 250 ft (75 m) from its upper to lower end on the second terrace. It is separated very slightly by faults in its lower part, as are the terrace remnants along El Rito Creek just to the north.

West of the junction of El Rito Creek and Rio Chama, there are several terraces of different levels mostly along the north side of the Chama. These range from 110 ft (35 m) to 350 ft (105 m) above the river. Several local terraces too small to be shown on Figure 1 are present along the south side, and the village of Abiquiu is on two of these, one at 110 ft (35 m) and one at 170 ft (50 m) above the river. South of the Chama-El Rito junction, there is one principal level of remnants along the south side of Rio Chama toward Rio del Oso. These are 400 ft (120 m) to 430 ft (130 m) above the river and are distinctly higher than those across the valley on the north side of the river. Up the north side of Rio del Oso, two sets of terraces are preserved largely by cappings of Lobato basalt boulders. The lower patches of this string of terraces are about 120 ft (35 m) above Rio del Oso and higher remnants are at about 270 ft (80 m) above the canyon bottom.

Near the junction of the Rio Grande and Rio Chama, the western slopes are covered with a cluster of remnants. These are principally north of Santa Clara Creek. Up to four levels are present ranging from 110 ft (35 m) to 380 ft (115 m) above the floodplain.

Along the Ojo Caliente River valley, numerous terraces, mostly along the eastern side, are present between Ojo Caliente and the steep escarpment of Black Mesa on the south. Up to three levels are present in the eastern strip between 100 ft (30 m) and 240 ft (75 m) above the river. The few on the west side differ some in altitude from those on the east.

The terrace remnants from El Rito to west of Espanola form an irregular band (fig. 1). The capping gravels consist of an assortment of resistant lithologies but with an abundance of quartzite boulders that may have come from the Tertiary outcrops of the Ritito Conglomerate and El Rito Formation in El Rito Canyon (Kelley, 1978). The Ojo Caliente terraces also have quartzite gravels which may have come from the Precambrian terranes northwest of La Madera. Both of these sources may have supplied some of the terraces and conglomerates in the uppermost Santa Fe beds in the northern part of the Albuquerque basin. As pointed out above, some of the higher terraces in the Abiquiu embayment and west of Espanola may be related in some way to the Santa Cruz pediment.

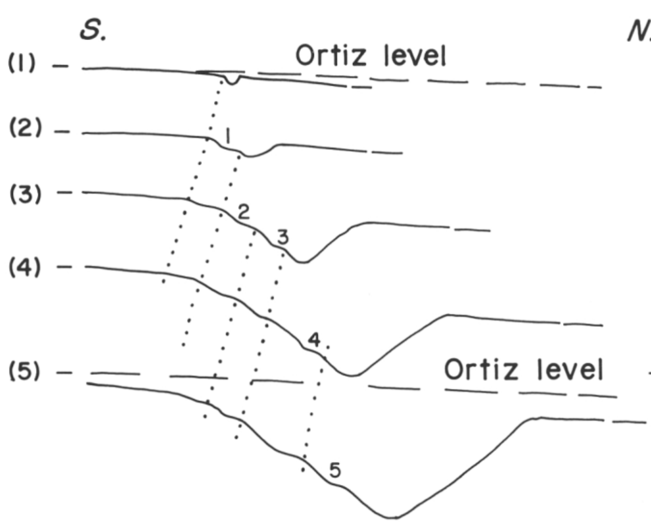

Figure 4. Ortiz surface profiles showing slope modification, north shift of canyons, and one-side development of terraces.

Scattered small terraces are distributed widely along the Rio Grande north of its junction with the Rio Chama. Those off the southeastern slope of Black Mesa are 50-100 ft (15-30 m) above the river. A few others occur near Pilar and Dixon; others locally along the Santa Cruz, Pojoaque and Tesuque are similar. Those in Entralias and Truchas canyons, where up to four levels are present, have been mentioned above (fig. 4). The low valley-bottom terraces of 10-30 ft (3-9 m) above the river, especially along the Rio Grande and Rio Chama, have been omitted in Figure 1. These also include the low benches in the Penasco embayment along the Santa Barbara and Embudo rivers, especially those south of the town of Pehasco.

BADLANDS AND LANDSLIDES

Given the semiarid climate, the friable sandstone, and nonresistant mudstone lithologies, the prevalence of badlands with their meandering miniature drainage patterns is not surprising. Badlands dominate hundreds of square miles throughout the Santa Cruz and Tesuque drainage basins especially at altitudes below about 6,500 ft (2,000 m). In the Abiquiu embayment, badlands are very widespread. Exceptionally good areas are in the Ojo Caliente Sandstone terranes south of Rio Chama between Abiquiu and Espanola, and around Abiquiu in the Abiquiu Tuff areas. Almost the entire divide area between the El Rito and Ojo Caliente valleys is badland topography. Finally, the areas of Bandelier Tuff in canyons cut into Pajarito Plateau have many areas of tent rocks, pinnacles and balanced rock pedestals.

Landslide terrain is another common form of badlands. In Española basin, the rock combination that results in landslides most often is basalt on Santa Fe beds. The largest of these areas lies along the eastern slope of Black Mesa and on both sides of the Rio Grande Canyon from Velarde to well within the Taos Plateau. Others occur around the Cerros del Rio along White Rock gorge, and in the Cationes and Lobato divides along the northern flanks of the Jemez Mountains.

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