New Mexico Geological Society Guidebook, 46th Field Conference, Geology of the Santa Fe Region, 1995

FIRST-DAY ROAD LOG, FROM SANTA FE TO NAMBÉ, CUNDIYO, ESPAÑOLA, ABIQUIU AND GHOST RANCH

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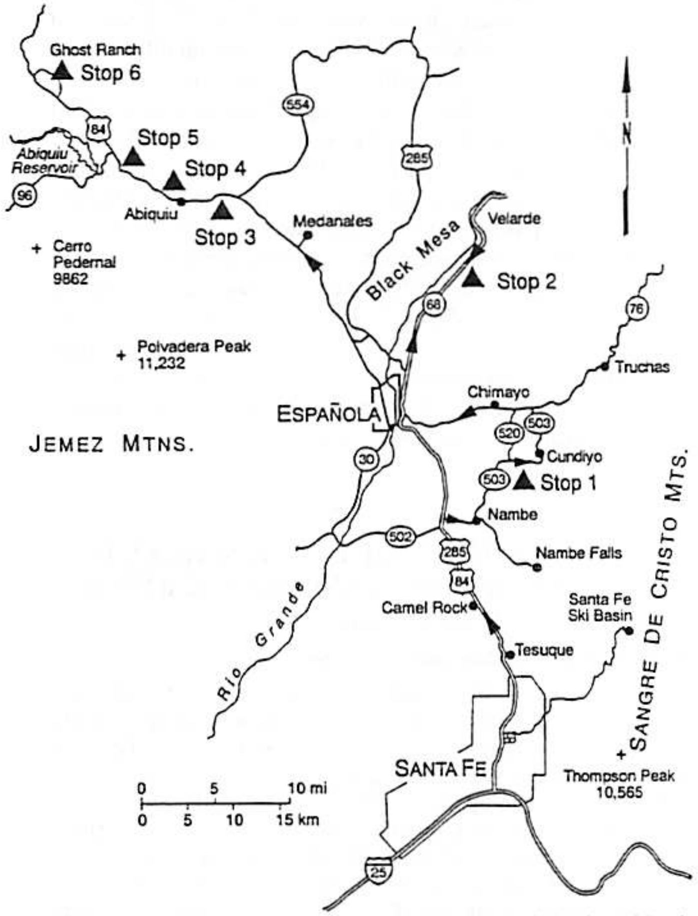
THURSDAY, SEPTEMBER 28, 1995

Assembly point:	**High Mesa Inn parking lot, Cerrillos Rd., Santa Fe.**
Departure time:	**7:30 a.m.**
Distance:	**91.6 miles**
Stops:	**6**



Summary

The first day of the field conference examines the stratigraphy and structure of the Española Basin and Abiquiu embayment parts of Rio Grande rift and border rocks of the Sangre de Cristo Mountains and Colorado Plateau. The trip begins by heading north from Santa Fe within the eastern Española Basin. Supplemental Log 2 leads to Nambé Falls and Nambé Lake where Proterozoic and Pennsylvanian rocks of the Sangre de Cristo Mountains are exposed adjacent to and beneath Miocene rift-basin fill.

Stop 1, south of the historic village of Chimayo, provides an overview of the boundaries of the Rio Grande rift and the rift-filling Tesuque Formation. The route then skirts along the depositional contact between the Tesuque Formation and the Proterozoic rocks of the Sangre de Cristo Mountains near the village of Cundiyo. The trip then turns westward down the valley of the Rio Quemado and Santa Cruz River to Española. North of Española, in the village of Alcalde, participants will visit the Adobe Factory (Stop 2) and learn about the process of making New Mexico's most well known building material. The route returns to Española and then heads westward across the Rio Grande into the Abiquiu embayment along the Rio Chama. Stop 3 provides an overview of the Tertiary stratigraphy of the Abiquiu embayment, Quaternary evolution of the Rio Chama valley, and an opportunity to visit a pre-Columbian ruin. Farther west, at Stop 4, participants will examine the Abiquiu Formation, backdrop to many movie scenes and Georgia O'Keefe paintings, and also representing the distal sedimentary record of middle Tertiary volcanism in the San Juan Mountains and Latir volcanic fields.

Stop 5 is located at the well-exposed western margin of the Rio Grande rift, where the basin fill is faulted against flat-lying Permian and Mesozoic rocks of the Colorado Plateau. Unconformities between Jurassic and Eocene strata and between the Eocene strata and the Abiquiu Formation provide evidence for an earlier Laramide ancestry for the rift-bounding Cañones fault zone and arguable evidence for Oligocene subsidence of the Abiquiu embayment. The field-trip route then continues westward onto the Colorado Plateau to Ghost Ranch, nestled amongst picturesque mesas of Triassic, Jurassic, and Cretaceous strata and home to New Mexico's state dinosaur, the small

theropod *Rioarribasaurus* (nee *Coelophysis*). After a barbecue and tour of Ghost Ranch museum and dinosaur quarry, we return to Santa Fe.

Mileage

0.0 Intersection of St. Francis Drive (US–84/285) and Cerrillos Road (NM–14) in Santa Fe. **Drive north on US–84/285.** Cerrillos Road subparallels the buried Santa Fe River fault zone that trends E–NE beneath the Pliocene–Pleistocene Ancha Formation, which is the "bedrock" under the High Mesa Inn. Thin sands and gravels of the erosional-constructional Airport surface cap the Middle terraces, and then as St. Francis Drive crosses the Santa Fe River just south of Alameda Street, we drop onto Recent alluvium, a half-mile-wide strip mainly north of the river.

The fault zone has a stratigraphic displacement about 1800 ft in the foothills. To the northwest, north of the river valley, badlands carved in the Miocene Tesuque Formation extend westward from the foothills. To the southeast, only a few patches of Tesuque outcrops border the foothills. Most of the southern plains are underlain by Ancha Formation, capped by thin scattered alluvial gravel. In the foothills along the Santa Fe River (Canyon Road in easternmost Santa Fe city), Proterozoic rocks on the south face downdropped Pennsylvanian strata on the north. This fault zone may be the eastern extension of Cather's (1992) Santa Ana accommodation zone. **1.6**

GEOLOGIC SYNOPSIS OF LA VILLA REAL DE LA SANTA FE DE SAN FRANCISCO DE ASSISI

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Agua es vida, water is life in semi-arid New Mexico. Thus the first Spanish settlement of Santa Fe in 1609, was just west (at the present Plaza) of a cienega (marshy area) on the north side of the Santa Fe River flood plain. The cienega was fed by springs at the foot of nearby bluffs (Ft. Marcy area) of west-dipping Tesuque Formation. Most of the pre-1950 city west of the foothills is built on the (1) WSW-trending flood plain and lowest terrace of the Santa Fe River; (2) the medium-level terrace, which borders the river to the south; and (3) the Airport and Plains surfaces farther south, which are cut on the Ancha Formation. Canyon Road goes eastward into the foothills, paralleling the Santa Fe River fault zone (SFRf), which near Twomile Reservoir shows Mississippian–Pennsylvanian strata on the north downthrown against Proterozoic granite gneiss on the south.

North of the river valley the piñon-covered dissected piedmont is cut in the westward-dipping Tesuque Formation beds and is the site for rapidly expanding mansion developments, such as the Governor's Mansion. Along a north-trending line from the west side of Cerro Gordo north to Bishop's Lodge, the west edge of the foothills, along the Cerro Gordo fault, the Tesuque is downdropped to the west against Mississippian–Pennsylvanian strata or Proterozoic rocks to the east. East of the fault zone a 2-mi-wide, east–west, 4-mi-long, north-south block, of mainly Pennsylvanian and Proterozoic rocks, is in turn down-dropped along the Aztec fault against upfaulted Proterozoic to the east, higher in the foothills.

South of the SFRf, in the foothills, Proterozoic rocks crop out, with only a few small horsts of Pennsylvanian strata along Camino Santander, Apodaca Hill, and Camino Militar. Many of the ancient adobe casas along the river's canyon are built on the Middle terrace (20–30 ft above the river, possibly correlative with Pinedale Glaciation on Lake Peak and Santa Fe Baldy) or on the few remnants of the High terrace (45–60 ft above the river, possibly Bull Lake Glaciation outwash).

In general, this southwest corner of the Sangre de Cristo Mountains is a westward-dipping ramp with Cenozoic sediments lapping eastward onto remnants of late Paleozoic strata and the main mass of Proterozoic rocks. There are many minor (200–1000 ft) down-to-the-west faults near the mountain front. North of the SFRf the faults trend north; to the south the trends are NW to NNW, and with larger displacements. Stratigraphic displacement along the SFRf is perhaps 2000 ft near Twomile Reservoir, but gravity surveys near High Mesa Inn suggest only 200± ft of throw. Similar relationships could be caused by 2 mi of right-lateral movement.

1.6 Veterans cemetery on right is in Tesuque Formation of the Santa Fe Group. Three physiographic surfaces form the piedmont west of the Sangre de Cristo Mountains. Developed on the Ancha Formation south of the Santa Fe River and on the Tesuque and Ancha (farther west) Formations north of the river, they are partly erosional and partly constructional. The Divide surface is the highest (at the top of the divide 2 mi ahead), the Airport surface is the lowest, and to the south, a slightly higher Plains surface forms the interstream divides.

Glacial moraines at the base of the glacial cirques on Lake Peak and Santa Fe Baldy (high peaks to the east) were identified by Richmond (1963) as pre-Wisconsinan, Bull Lake Glaciation, Pinedale Glaciation, and a Neoglacial moraine. The Santa Fe River and Rio Tesuque head in these cirques. In the foothills, four alluvial terraces and outwash deposits younger than the Airport surface were mapped by Kottlowski and Baldwin (Spiegel and Baldwin, 1963). Two low alluvial terraces are upper Holocene, with the lower possibly related to Neoglacial events. The Middle terrace, 20–30 ft above Santa Fe River channels, may be associated with the Pinedale Glaciation, and the High terrace, 45–60 ft above channels, may correlate with Bull Lake deposits. Erosion and modern construction have obscured the two lower terraces. **0.8**

2.4 From 12:00 to 5:00, on skyline, are Proterozoic rocks of the southern Sangre de Cristo Mountains. The Governor's Mansion is 0.75 mi to the southeast amid the other costly haciendas. In the foothills, 1.5 to 3 mi to the east, a 4-mi-long, N–S outcrop of Mississippian and Pennsylvanian strata forms a faulted, downdropped, W-tilted block, mostly poorly exposed amid piñon forest and home construction.

Mississippian strata are thin and discontinuous beneath the erosional surface at the base of Pennsylvanian beds. In Little Tesuque Creek Canyon, 0.3 mi upstream from Bishops Lodge, 26 ft of Espiritu Santo Formation sandstone and shaly limestone overlie Proterozoic granite gneiss and are disconformable beneath 26 ft of Tererro massive limestone. Basal Pennsylvanian sandstone fills depressions on truncated Tererro limestones. Upstream 0.8 mi, where Hyde Park Road enters the canyon, Pennsylvanian sandstones overlie decomposed granite gneiss.

The lower 50 to 75 ft of Pennsylvanian are "Sandia"-type sandstones, pebbly conglomerate lenses, shales, thin calcarenites and coal lenses. Above are intertongued limestones and light gray to pale red shales with some lenses of medium-grained sandstones, as much as 350 ft thick beneath the truncating Miocene Tesuque Formation. Sutherland and Harlow (1973) collected Morrowan and Atokan fossils from this outcrop, and assigned them to their La Pasada Formation. **0.8**

3.2 Roadcuts in Tesuque Formation along west side of road. **0.3**

3.5 Crest of hill leading down to Rio Tesuque drainage. View to the north across badlands eroded in Miocene Tesuque Formation in Española Basin, basalt-capped Black Mesa, and Tusas Mountains on skyline. On a clear day, in the very far distance at 12:00, San Antonio Mountain, a Taos plateau volcano on the Colorado–New Mexico border, is visible from here. Sangre de Cristo Mountains to the east. Strata in the Tesuque Formation badlands type area (Spiegel and Baldwin, 1963) dip 5–30° to the west with dips generally increasing to the east. Gently west-sloping surfaces on top of Tesuque outcrops, the Divide surface, is a Quaternary pediment surface with thin gravel veneers. Farther west, the Ancha Formation is unconformable on the Tesuque.

The Española Basin is an asymmetric west-tilted graben. The Sangre de Cristo Mountains rise above the east side of the basin, and Neogene volcanic rocks of the Jemez Mountains overlap the faulted western margin (Fig. 1.1). The north end of the Mississippian–Pennsylvanian block is about 1.5 mi to the northeast near Bishops Lodge. In the foothills, the basal Tesuque Formation overlies the Pennsylvanian, and then a short distance to the east and north, the Proterozoic rocks. Pennsylvanian shales once were quarried by State Penitentiary inmates to make bricks. Some of the lenticular coals in the northeastern part of Santa Fe, along with Pennsylvanian limestones, were utilized to make lime in a small kiln (destroyed by modern construction).

The type section of the Tesuque Fm (Spiegel and Baldwin, 1963) is along Tesuque Creek northeast of Bishops Lodge, where only the lower part of the unit is present; it thickens westward to more than 4000 ft at the east edge of Cerros del Rio. In this area it consists mainly of debris from Proterozoic rocks with some limestone fragments in lower beds. Near Bishops Lodge the lower 0–110 ft are of light gray to reddish brown conglomerate to siltstone with basal boulder conglomerate. It is overlain by the Bishops Lodge (mappable) Member, 50–530 ft of light gray volcanic sandstone and siltstone with weathered pebbles of porphyritic andesite and blocky massive tuff. Above are typical grayish orange, moderate reddish orange, and light brown, calcite-cemented sandstones and siltstones with conglomerate lenses near the foothills. Southeast of Bishops Lodge local, thin, olivine basalt flows and tuffaceous sandstones occur 140 ft above the Bishops Lodge Member. As Ingersoll et al. (1990) and Cather (1992) noted, the Bishops Lodge is a southeastern equivalent of the Abiquiu Formation. **1.8**

5.3 Several Quaternary pediment and strath surfaces cut on Tesuque Formation are visible between the highway and the Sangre de Cristo Mountains to the right and left. **0.5**

5.8 Entrance to Santa Fe Opera on left. **0.9**

6.7 Entering Tesuque Indian Reservation. Excellent view ahead of gently west-dipping pediment surface. The foreground is drained by the Rio Tesuque. Santa Fe ski area is located in the high-country bowl at 3:00. The High "Bull Lake" terrace is on the left, west side, of the highway, and the Middle "Pinedale" terrace is off on the right 0.2 mi. **0.9**

7.6 Crossing Rio Tesuque. High and Middle terraces ahead, west of the highway. Two lower terraces occur along the "Rio", and have been dated between A.D. 1880 and 2230 B.P. (Miller and Wendorf, 1958). **0.2**

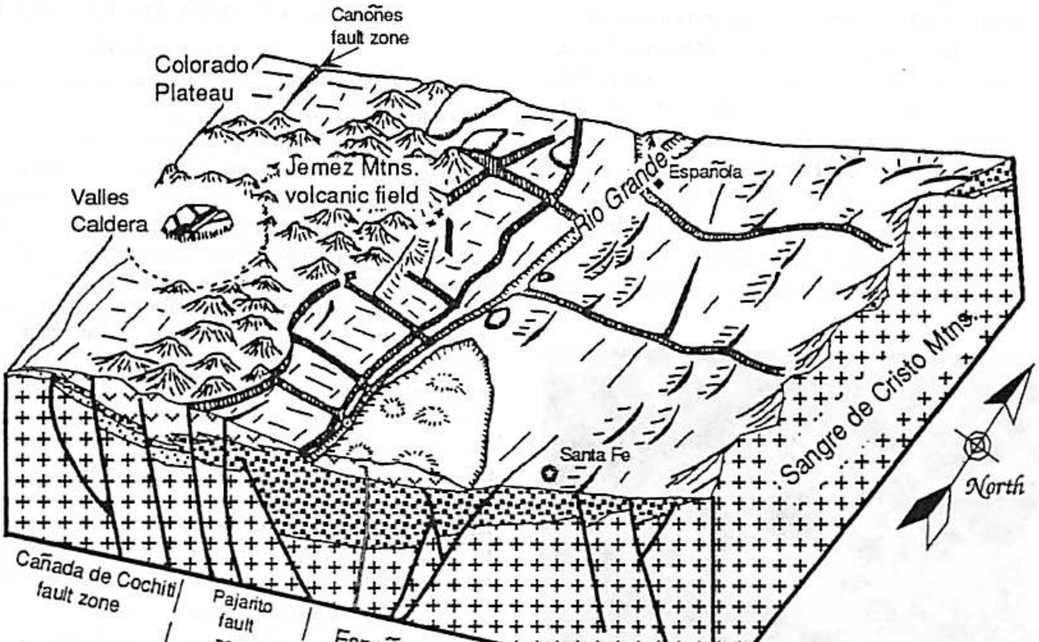

FIGURE 1.1. Block diagram illustrating the general structure and stratigraphy of the Española Basin (modified from Golombek et al., 1983).

7.8 Junction with county road 73 to Tesuque; continue north on US–84/285. View to the west of the Jemez Mountains and the prominent Pajarito Plateau, underlain by Pleistocene Bandelier Tuff and Pliocene Puye Formation extending eastward to the Rio Grande. **3.3**

11.1 Camel Rock on left. This erosional feature resembling a dromedary is sculpted in alluvial sediment of the Tesuque Formation (Fig. 1.2). Erosion has considerably modified the "camel" during the past 45 years; it may not be recognizable in 2040. Since 1924, several paleontologists from the American Museum of Natural History Frick Laboratory have collected and described the vertebrate fossils (including camels!) found in the Tesuque Formation. Two of these workers, Ted Galusha and John Blick (1971), also completed a thorough stratigraphic study of the Tesuque strata. They divided the Tesuque in this area into (in ascending order) the Nambé, Skull Ridge and Pojoaque Members. Based on fossil mammals, the Nambé Member is of late-early Miocene (late Hemingfordian) age; the Skull Ridge Member is of early-middle Miocene (early Barstovian) age; and the Pojoaque Member is of late-middle Miocene (late Barstovian) age. The mammals from these units are mostly camels, deer, antelope, rhinoceroses, horses, gomphotheres (primitive elephants) and carnivores. Together with magnetostratigraphy and radiometric ages, the fossil mammals provide a remarkably precise Neogene chronology in the Española Basin.

East of the road are excellent outcrops of the Skull Ridge Member of Galusha and Blick (1971). The prominent white tephra layer is white ash #2 of Galusha and Blick, repeated across north-south striking normal faults. The older white ash #1 is visible along the road a short distance to the north. These tephras, and others, are nearly continuously exposed for 12 mi to the north of here and serve as important stratigraphic markers in the Tesuque Formation. Izett and Naeser (1981) reported a zircon-fission-track age of 14.6±1.2 Ma for white ash #2, but vertebrate biostratigraphy and magnetostratigraphy suggest an age of about 16 Ma (Barghoorn, 1981; Tedford and Barghoorn, 1993). A more recent ^{40}Ar/^{39}Ar date of 15.42±0.06 Ma for sanidine in the younger white ash #4 (W. McIntosh and J. Quade, personal commun., 1995) support the magnetostratigraphic and vertebrate paleontology assessments of the age of these strata. The ashes are of biotite rhyolite composition and were possibly erupted in the Jemez Mountains, although sources in southern Arizona, Nevada and southern Idaho cannot be excluded. The oldest such rhyolites exposed at the surface in the Jemez Mountains (Canovas Canyon Rhyolite) are about 13.5 Ma (Gardner et al., 1986). The Tesuque ashes may be a record of Jemez volcanism that is older than what is presently exposed in the volcanic field. **0.5**


FIGURE 1.2. Camel Rock.

11.6 View at 12:00 in middle distance of the Pojoaque Bluffs, type area of the Pojoaque Member of the Tesuque Formation of Galusha and Blick (1971). The earliest Santa Fe Group fossil mammals were collected in this area in 1873 and 1874 by members of the Wheeler Survey (Lucas and Schoch, 1983). The famed paleontologist Edward Drinker Cope described these fossils (some of which he collected in 1874), first bringing to scientific attention the record of Neogene mammals preserved in this area. West of the Pojoaque Bluffs and across the Rio Grande are outcrops of mesa-capping gray strata of the Puye Formation (including the Totavi Formation of Waresback and Turbeville, 1990) overlying pink sediment of the upper Miocene Chamita Formation. **1.8**

13.4 Cross Arroyo Cuyamungue. Several miles west, along the Rio Grande, is the ghost town of Buckman, formerly a village and station on the D&RGW Railroad. It was founded about 1900 by H.F. Buckman, an Oregon lumberman who had sawmills and timber holdings on the Pajarito Plateau. Buckman was the location of the original bridge across the Rio Grande that led to the Los Alamos Ranch School (now the City of Los Alamos). **1.9**

BUCKMAN WELL FIELD

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The Buckman well field was developed by Public Service Company of New Mexico and put into operation in July 1972 to supply the city of Santa Fe. The field consists of seven wells drilled to depths of 1000–1400 ft below land surface. The well field is about 15 mi northwest of the city of Santa Fe, near the abandoned town of Buckman on the east side of the Rio Grande. Santa Fe currently has the capacity and water rights to divert 13,000 acre-ft per year (afy) from three sources: the Santa Fe River (up to 3300 afy), the Tesuque Formation aquifer in the vicinity of the city (up to 4340 afy), and from the Buckman well field (up to 5600 afy). In 1993, the total diversion by the city was near 12,000 afy, indicating the growing city will need to tap another source of water in the very near future. A likely source of water is the San Juan–Chama water that can be diverted directly from the Rio Grande. In the Buckman production wells, water levels have dropped up to 56 ft/yr over the past 10 years (R. Jorgenson, personal commun., 1994). The Buckman wells draw water from a confined production zone that is not replenished at a rate equal to the amount pumped. In Santa Fe city, production well levels have been declining at approximately 2.5 ft/yr during the past 40 years.

15.3 Enter Pojoaque Pueblo, located just southeast of the confluence of the Rio Tesuque and Rio Pojoaque. **1.0**

16.3 Intersection with NM–502 to Los Alamos. **Stay in right lane** and continue north on US–84/285. Pojoaque Bluffs visible to west. **0.5**

16.8 **Turn right (east) at traffic light onto NM–503**. Drive east along the Rio Pojoaque. **0.4**

17.2 Arroyo scarps on right expose west-dipping Tesuque Formation. **0.5**

17.7 Periodic bank erosion along the river has resulted in installation of a wire and riprap stabilization system. **1.0**

18.7 Village of Nambé. According to Pearce (1965), Nambé is Tewa, *nambay-ongwee*, for "people of the roundish earth." Sacred Heart Church on right. **0.9**

19.6 Prominent outcrops of white ash #1 in the Tesuque Formation to the right of the road (Fig. 1.3). **0.4**

20.0 Junction on right with road to Nambé Falls and Nambé Lake, which are described in Supplemental Road Log 2. Main roadlog continues north on NM–503. **0.8**

20.8 Southeastward view of angular unconformity between west-dipping Tesuque Formation and Quaternary pediment gravel on north side of east-trending ridge. **0.1**

20.9 Milepost 4. **0.2**

21.1 View at 10:00 of east-facing bluff with prominent exposure of white ash #2 within the Skull Ridge Member of the Tesuque Formation as defined by Galusha and Blick (1971). The ash rests just below a distinctive transition from pink siltstones below, to tan sandstones above. This vertical facies change is present at this stratigraphic position, as marked by the ash, over an area of at least 29 mi^2 within the basin. At 2:30, the high, angular peaks on the skyline are the Truchas Peaks. **1.3**

CONTRASTING MODES OF TEPHRA PRESERVATION IN THE SKULL RIDGE MEMBER OF THE TESUQUE FORMATION

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The ash beds of the Tesuque Formation, particularly the Skull Ridge Member, were first described by Galusha and Blick (1971) in their study of regional stratigraphy and vertebrate paleontology. Approximately 40 ash layers are recognized in the Skull Ridge Member. Of these, Galusha and Blick (1971) labeled the most conspicuous white ashes 1 through 4, and the gray ashes between white ashes #2 and #3, as 2a–2d. Utilizing magnetostratigraphy and vertebrate biostratigraphy, Barghoorn (1981) and Tedford and Barghoorn (1993) assigned an age of about 15.5 to 16.5 Ma to this stratigraphic interval, which is consistent with a new $^{40}Ar/^{39}Ar$ date of 15.42 ± 0.06 Ma for white ash #4 (W. McIntosh and J. Quade, personal commun., 1995). Sources for these tephras have not been identified. Although in close proximity to the Jemez Mountains, the Skull Ridge ashes are older than the 13 Ma rhyolites cited by Gardner et al. (1986) as marking initial Jemez volcanism. If the Skull Ridge ashes were derived from Jemez vents, those vents are buried beneath younger volcanic rocks. White ash #2 is located near an abrupt transition between red mudstone-dominated strata, below, to buff sandstone-dominated strata above. This stratigraphic transition has been traced over a 29 mi^2 area where the ash is almost continuously exposed. This change in depositional environment is illustrated in the Arroyo Seco area by the preservational style of white ash #1 and the gray ashes above white ash #2.

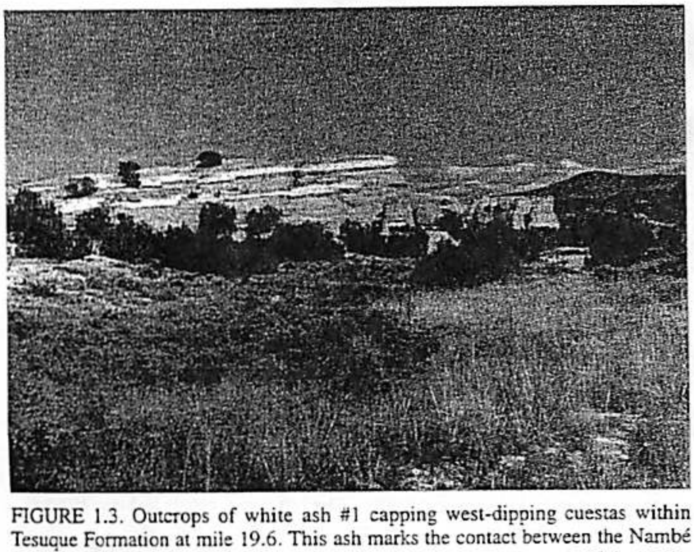

FIGURE 1.3. Outcrops of white ash #1 capping west-dipping cuestas within Tesuque Formation at mile 19.6. This ash marks the contact between the Nambé and Skull Ridge Members of the Tesuque Formation (Galusha and Blick, 1971). Sangre de Cristo Mountains form the eastern skyline.

White ash #1 has a continuous distribution over a strike distance of 3 km and exhibits a rather even thickness, ranging from 1.5 to 1.9 m. The slight variation in thickness is generally due to the original topography the ash was laid upon. The basal 1–2 cm is a bentonite that rests on micaceous siltstone (Fig. 1.4). Above the bentonitic layer is generally a 35–50-cm-thick layer of mixed ash and red mud. The remainder of the bed is composed of graded horizontal laminated and ripple-cross-laminated vitric ash mixed with variable amounts of fine- to medium-grained arkosic sand. Root traces and burrows are in the ash bed and it typically grades abruptly into arkosic sandy siltstone.

The gray ashes, 2a–2d, are also reworked and mixed with varying sized arkosic sand. These ashes vary in thickness from 2–50 cm. The gray ashes are not laterally continuous but are both truncated by, and overthickened within, channel-fill units 2–7.5 m wide. An example of one of the many channels associated with the gray ashes is shown in Figure 1.4B.

The depositional environment for gray ashes 2a–2d contrasts with that for white ash #1. We interpret white ash #1 to have been deposited on a broad, low-relief floodplain. This setting explains the tabular geometry, lack of channels, association with arkosic muds and fine sands, and presence of lower-flow-regime sedimentary structures, burrows and root traces. Because of the general similarities between white ash #1 and white ash #2, both were probably deposited in a similar environment. The gray ashes were deposited on a piedmont characterized by closely spaced, shallow channels. In this setting, the ashes were more poorly preserved because of erosion and redeposition in the channels. A simple Walther's law approach would suppose that the abrupt facies change above white ash #2 to be the consequence of lateral migration of consanguineous floodplain and channel facies. Presence of ash beds as time lines conclusively shows, however, that these two facies associations are nowhere time equivalent, but represent intervals of distinctly different depositional processes on the piedmont. Cavazza (1989) hypothesized that grain-size variations in Tesuque strata are somehow related to varying rates of subsidence in the Española Basin. Our observation of pond deposits below white ash #2 and abundant eolian sand above that ash suggest the possibility of a climatic influence.

All ash beds in the Skull Ridge Member have been reworked and mixed in varying degrees with arkosic sediment eroded from the Sangre de Cristo Mountains. Ashes redistributed on broad floodplains remain as laterally continuous stratigraphic markers. Those eroded and redeposited by channelized flows are less continuous and have more limited stratigraphy utility. The *original* fallout thickness for any of the tephras is unknown and cannot, therefore, be used to constrain the locations for the eruptive vents.

22.4 View straight ahead of west-dipping beds of the Tesuque Formation. The Tusas Mountains form the skyline at 10:00–11:00. Tesuque Formation also underlies the gently west-dipping Truchas surface (Manley, 1976) on the skyline. This high-level surface is cut on basin-fill within the topographically expressed Picuris embayment, which interrupts the continuity of Sangre de Cristo Proterozoic rocks to the north of the Rio Quemado. Hollywood westerns are occasionally filmed in these picturesque Santa Fe Group badlands. **1.5**

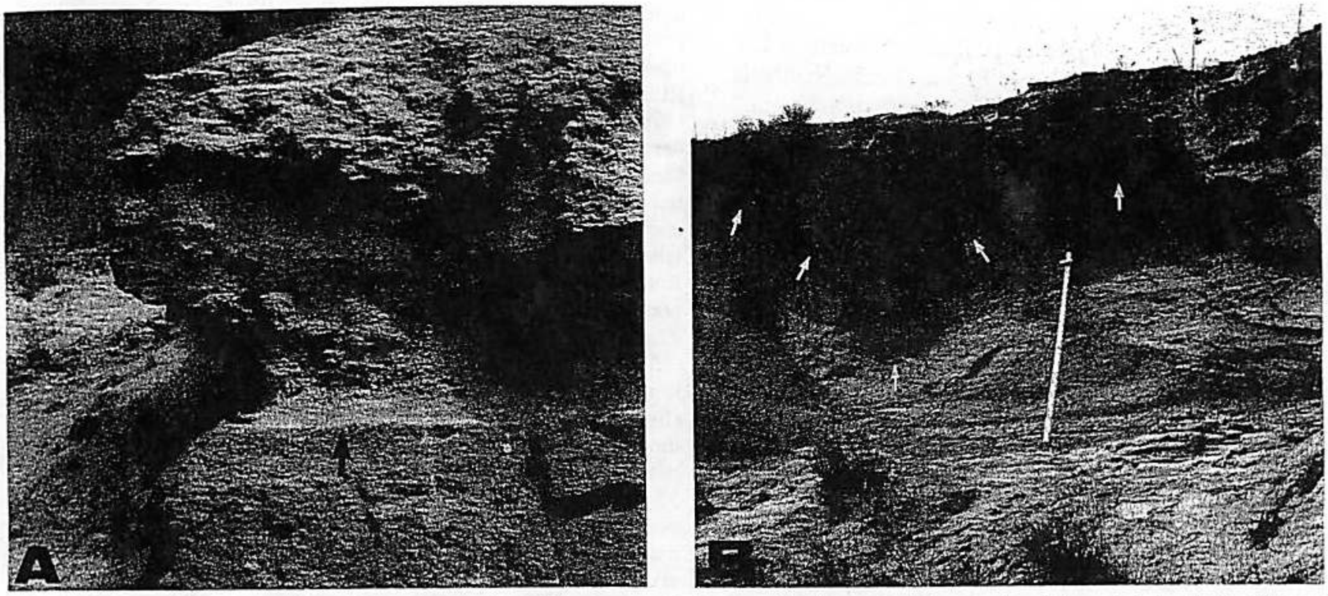

FIGURE 1.4. A, Typical outcrop of white ash #1 with the entire thickness exposed. Arrow marks the contact between ash and the underlying blocky siltstone. Note hammer for scale. B, Channel filled with dark gray ash 2b; base of the channel is indicated by arrows. Note the broad channel-form stratification and the underlying sandstone. Staff is 2.5 m long.

23.9 Milepost 7. Highway curves to right. View straight ahead of gently west-dipping pediment surface (Fig. 1.5) in Proterozoic granite leading up to the base of Sierra Mosca (11,765 ft) and The Dome (11,275 ft). **0.6**

THE PLIOCENE(?) BORREGO PEDIMENT SURFACE AND DEVELOPMENT OF THE WESTERN SANGRE DE CRISTO MOUNTAINS FRONT

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A forested upland surface covering about 105 mi^2 and sloping westward at 2-3° forms the flank of the Sangre de Cristo Mountains, west of the high peaks of the Santa Fe Range, from near Santa Fe to Truchas (Fig. 1.5). Cabot (1938) briefly described this feature as the oldest of many pediments in and adjacent to the Española Basin but, despite the large scale of this striking geomorphic feature, no significant further attention has been paid to it. We propose the name Borrego surface for this now-dissected pediment, which includes Mesa Borrego south of Truchas (Fig. 1.6A).

The Borrego surface truncates Proterozoic bedrock and projects under Cenozoic deposits of the Picuris embayment north of Truchas. Rounded pediment lag gravels are sparsely preserved on the Borrego surface, but no stratified deposits or soils whose characteristics might be used to directly estimate the age of the pediment remain. In the vicinity of Truchas, Manley (1976) identified three major "pediment" surfaces cut across Miocene Tesuque Formation basin fill. From oldest to youngest, these surfaces were named the Osa, Entranas and Truchas. Recent reconnaissance suggests that these "pediments" are probably alluvial fills now occupying the high interfluves of a landscape that has undergone significant topographic inversion. Late Cenozoic gravel underlying the Truchas surface of Manley (1976) unconformably overlies the Tesuque Formation in the Picuris embayment and projects south where it locally unconformably overlies Proterozoic rocks of the Borrego surface south

FIGURE 1.5. Eastward view of the Sangre de Cristo Mountains from a point about 3 mi west of mile 23.9. Light-colored outcrops of the Miocene Tesuque Formation in the foreground. Arrows point to a nearly flat, ponderosa-covered, pediment surface cut on Proterozoic rocks in front of the prominent peaks of the Sangre de Cristo Mountains on the skyline (from left, The Dome, 11,275'; Sierra Mosca, 11,765'; Santa Fe Baldy, 12,622'; Lake Peak, 12,409'). The left arrow points to Mesa Borrega, which forms part of this pediment. Deep canyons have been incised into this surface, the most obvious of which are those occupied by the Rio Frijoles (visible in front of Sierra Mosca) and Rio Nambé (between Santa Fe Baldy and Lake Peak). The middle-ground escarpment between the dark Proterozoic rocks and lighter Tesuque Formation has been interpreted as an exhumed depositional contact or as a fault escarpment by various workers.

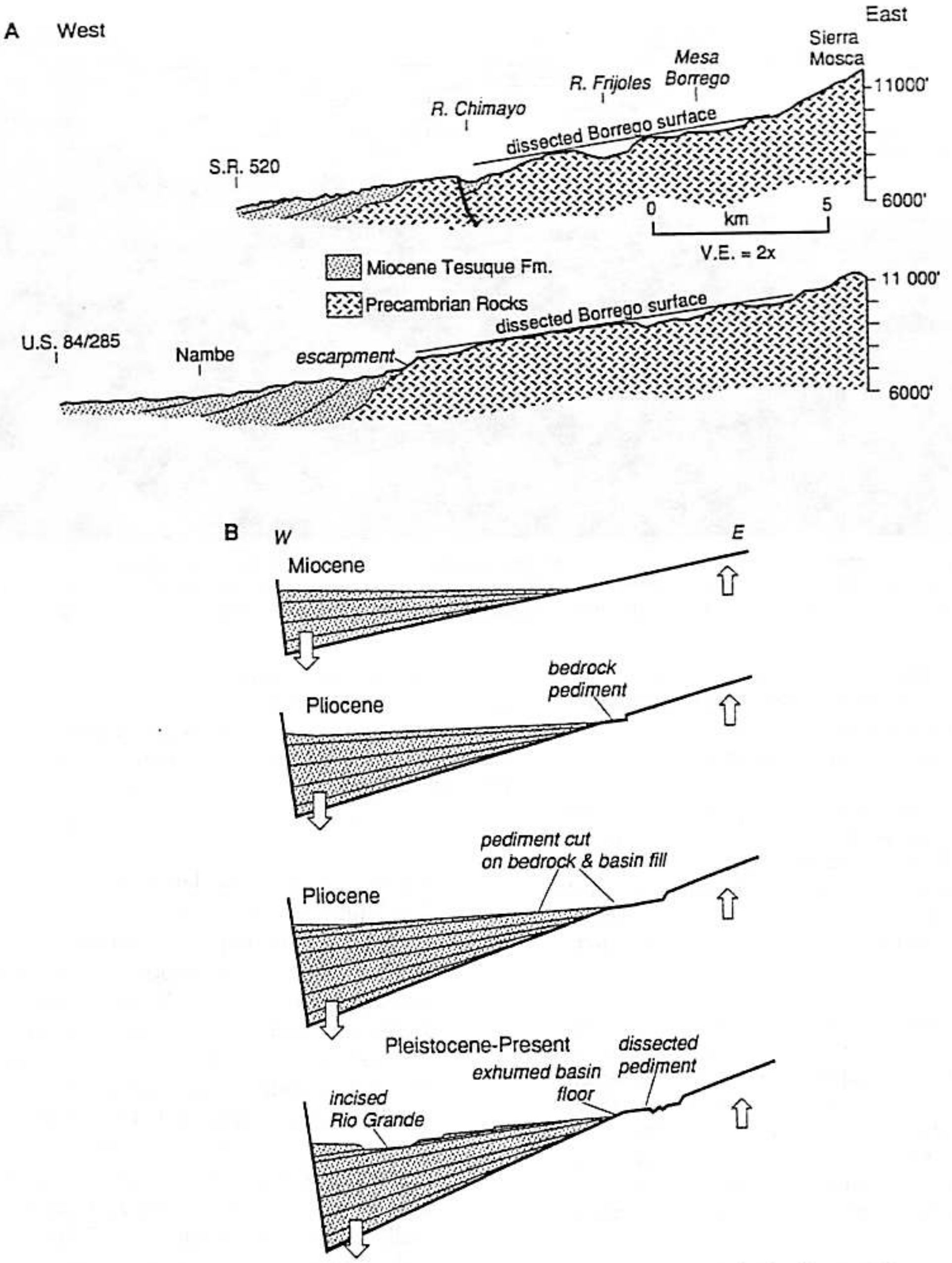


FIGURE 1.6. A, East-west geologic profiles near the latitudes of Santa Cruz Lake (top) and Nambé (bottom) showing the dissected Borrego pediment surface. Form lines in the Tesuque Formation indicate stratal dips (from Kelley, 1978, and Smith, unpubl.) adjusted for the illustrated vertical exaggeration. B, Schematic diagrams showing possible development of pediments on the eastern side of the Española Basin concurrent with deposition in the western part of the basin (e.g., Pliocene Puye Formation). Following incision of the Rio Grande, these eastern pediments were dissected and softer basin fill was preferentially excavated to exhume the original basin floor. The escarpment between the basin-fill badlands and the dissected bedrock pediment, also labeled in the lower profile of Figure 1.6a, may not, therefore, be of tectonic origin.

of Truchas (Kelley, 1978). A younger alluvial fill inset below the Truchas surface contains tephra correlated to the Guaje Pumice of the Bandelier Tuff (Manley, 1976), which has been mostly recently dated at 1.51 +0.03 Ma (Spell et al., 1990). Because the Truchas surface is, therefore, older than about 1.5 Ma and the Borrego surface is contemporaneous with or older than the gravels underlying the Truchas surface it is likely that the Borrego surface is Pliocene age or older (i.e., >1.64 Ma). It is conceivable that the Borrego surface is a complex, polygenetic surface, not strictly correlative to the sub-Truchas surface in the Picuris embayment, but rather the equivalent of all three of the high surfaces identified by Manley (1976) in the northern Española Basin.

Pediments are thought to represent a long period of base-level stability when hillslopes and river profiles have sufficient time to reduce relief to their base level of erosion (e.g., Ritter et al., 1994, p. 258-263). We propose that the Borrego pediment, and older erosion surfaces in the Picuris embayment, formed at the same time as deposition was occurring in the western Española Basin and partly or wholly before incision of the Rio Grande in the latest Pliocene or early Pleistocene. The timing of regional incision is constrained by a 1.7±0.1 Ma age on tephra (Turbeville, 1991) in the upper Puye Formation, which underlies the Pajarito Plateau on the western side of the basin. Initial incision of the Rio Grande had ensued by the early Pleistocene because the Puye Formation underwent dissection before eruption of the Bandelier Tuff at 1.51 Ma.

Formation of the Borrego pediment during basin subsidence is illustrated in Figure 1.6B. Neogene, down-to-the-west tilting of the Sangre de Cristo block exposed Proterozoic bedrock on the east side of the Española Basin. Concurrent deposition of basin-fill sediment occurred at a rate equal to basin subsidence, such that streams draining the hanging-wall block were able to attain and maintain a graded profile over a

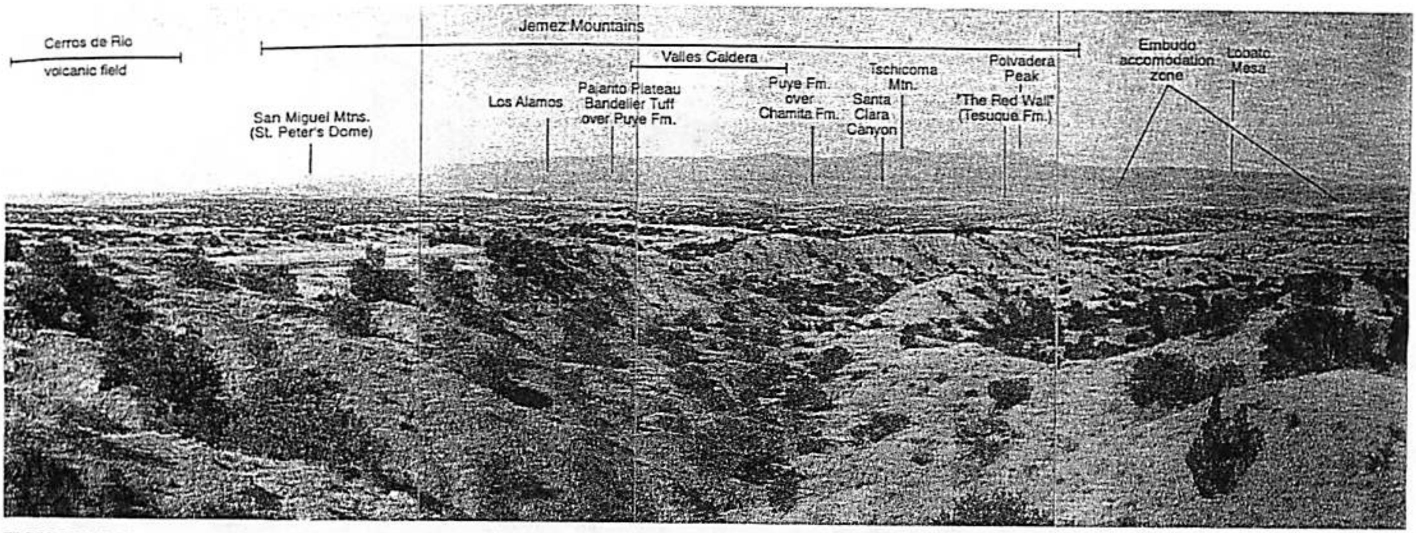


FIGURE 1.7. View westward at Stop 1. Foreground and middle ground outcrops are west-dipping beds of the Nambé and Skull Ridge Members of the Tesuque Formation. Arroyo Seco trends obliquely from the right edge of the photo to the center. The Red Wall is at the extreme right edge, capped by a white ash layer. The Jemez Mountains form the skyline. The highest peaks, Tschicoma Mountain (center, 11,561') and Polvadera Peak (right, 11,232') are upper Miocene or lower Pliocene composite volcanoes

protracted period of time. Minor base-level changes were rather rapidly expressed in the soft strata of the Tesuque Formation, but the hard Proterozoic rocks provided a more resistant buffer to fluvial erosion. In this manner, the Española Basin sediments could experience several cut-fill cycles, now expressed by the Osa, Entranas, and Truchas fills with a common bedrock counterpart in the Borrego surface. Widespread incision in the Española Basin and abandonment of the Borrego surface is coincident with major latest Pliocene or earliest Pleistocene base-level drop of the Rio Grande and a climatic transformation to more seasonal, Quaternary-type high-magnitude, low-frequency storm events. During the Quaternary, the basin-fill sediments have been dissected into intricate badlands while the Borrego surface was stripped of most of its thin alluvial cover and incised by canyons up to 820 ft deep.

Quaternary erosion in the Española Basin has preferentially removed the poorly consolidated basin-fill sediment so that depositional contacts between the Tesuque Formation and underlying Proterozoic basement are widely exposed near the Sangre de Cristo Mountains front (Galusha and Blick, 1971). The exhumed basin floor is shown schematically in the lowest diagram in Figure 1.6B. As shown in the lower profile of Figure 1.6A, the resulting steep topographic step at the contact between the Tesuque Formation and the basement rocks is a significant escarpment.

The structural significance of this escarpment has been very controversial. Cabot (1938) showed clear evidence for faulting along segments of the escarpment, but the magnitude of displacement along these faults is unclear and is possibly less than 100 m (Vernon and Riecker, 1989). These faults displacing the Tesuque Formation against Proterozoic rocks along the eastern side of the basin are not demonstrably more significant than the myriad of other modest-displacement faults with surface expression entirely within the Tesuque Formation that are present across the entire width of the basin (Galusha and Blick, 1971; Kelley, 1978). Spiegel and Baldwin (1963), Kelley (1978), Cordell (1979) and Vernon and Riecker (1989) interpreted the topographic escarpment at the mountain front to represent a zone of faults (Santa Fe fault zone of Kelley, 1978) that mark the eastern boundary of the Española Basin. Manley (1976, 1979a) interpreted field relationships and gravity data to be most consistent with the lack of a significant border fault. Her interpretation is most consistent with the mapping of Galusha and Blick (1971) near Santa Cruz Lake, which shows depositional contacts between the basement rocks and the basin-fill sediment. A similar contact is shown in the lower profile in Figure 1.6A, although Kelley (1978) inferred the presence of a fault here; note that the slope of the basement surface on the escarpment is nearly coincident with the dip of the overlying Tesuque strata that are interpreted to have been deposited upon it during early stages of basin tilting. Although structural processes cannot be wholly discounted, the presence of the escarpment may be largely or entirely the result of erosional planation of basement and basin-fill rocks prior to and after initiation of Rio Grande incision, followed by preferential erosion of softer basin fill to expose the original basin floor, inclined moderately steeply from the upland Borrego pediment surface.

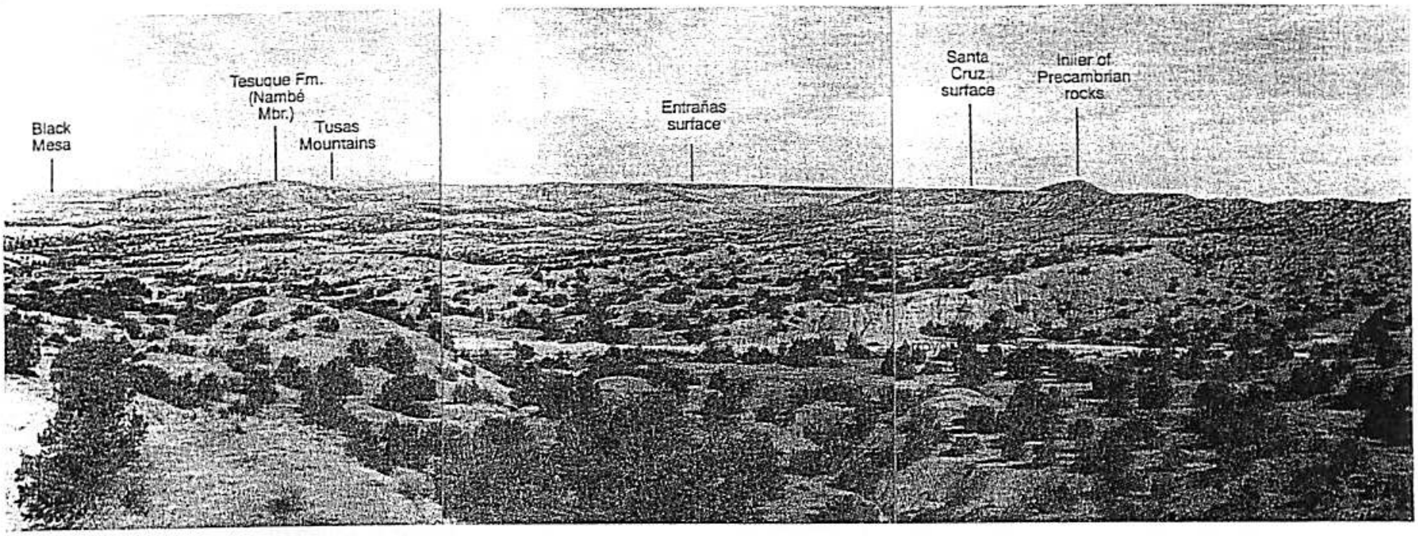
24.5 Junction with NM–520 to Chimayo; continue east on NM–503. **0.3**

24.8 **STOP 1. Pull out on left** (north) side of road at milepost 8 in Highway Dept. storage area.

Overview of Española Basin. This roadside pullout provides an excellent opportunity to view the large-scale geologic features of the Española Basin and adjacent regions. The Sangre de Cristo Mountains rise abruptly to the east. A variety of Proterozoic metavolcanic and granitic rocks underlie this part of the range (Miller et al., 1963). Sierra Mosca and The Dome rise above Mesa Borrego and equivalent high plateaus that define a dissected high-level erosion surface (Fig. 1.5). Southeast of Truchas, gravel rests on this surface; elsewhere it is generally devoid of sediment cover. This is the highest of several geomorphic surfaces in this part of the Española Basin and is probably Pliocene in age (see above).

To the north are views of the Tesuque Formation truncated by the Santa Cruz surface (foreground, to east of NM–520) and the higher Truchas surface (in background). The prominent knob projecting above the Santa Cruz surface directly to the north is an exhumed paleo-hill of Proterozoic rock surrounded by the Tesuque Formation. The contact between Proterozoic rocks and the Tesuque Formation is largely depositional in this area. The mountain front is largely unfaulted (Galusha and Blick, 1971; Kelley, 1978) and its steep relief is a consequence of erosion of the Tesuque Formation away from the original nonconformable surface, which now dips 35–45° to the west.

The view to the northwest is over west-dipping beds of Tesuque Formation. Black Mesa, capped by Sevilleta basalt that flowed south from the Taos Plateau volcanic field, looms above the confluence of the Rio Ojo Caliente (beyond) and the Rio Chama (left) west of the Rio Grande. The Tusas Mountains, a Laramide uplift of Proterozoic rocks frosted with distal volcanic and volcaniclastic rocks



that are the namesakes of the Tschicoma Formation and the Polvadera Group volcanic rocks. The dissected mesas at the base of the Jemez Mountains form the Pajarito Plateau. Volcaniclastic sedimentary strata of the Puye Formation, eroded from the large composite cones, underlie the plateau on the right. To the rear and left, the Puye Formation is overlain by lighter colored Pleistocene Bandelier Tuff.

derived from the San Juan Mountains volcanic field in southern Colorado and Latir volcanic field near Taos, forms the skyline beyond Black Mesa. The Rio Chama flows through the Abiquiu embayment, a structural platform in the western Rio Grande rift between the Colorado Plateau, visible on the skyline to the left of Black Mesa, and the deeper Española Basin in the foreground (Baldridge et al., 1994).

Looking directly westward, Miocene rift-filling sediment of the Tesuque Formation dominates the foreground (Figs. 1.7–1.9). The prominent wash leading westward through the basin fill is Arroyo Seco. A distinctive red hued cliff with white-ash stripes to the north of Arroyo Seco is the Red Wall locality of Galusha and Blick (1971). The area around the Red Wall provides superb exposures of the stratigraphic relationships between the Skull Ridge and Nambé Members of the Tesuque Formation, as defined by Galusha and Blick. The prominent ash that is visible about two-thirds of the way up the Red Wall is white ash #2, seen previously to the south.

The Jemez Mountains dominate the western skyline. Most high peaks visible from this point are upper Miocene and Pliocene volcanic centers of the Tschicoma Formation. Alluvial fans derived from erosion of the centers deposited the Puye Formation, which is the gray rock underlying the Pajarito Plateau extending eastward from the Jemez Mountains to the Rio Grande. To the south, orange cliff-forming Pleistocene Bandelier Tuff overlies the gray Puye Formation. The Bandelier Tuff was erupted in two caldera-forming episodes in the central Jemez Mountains at about 1.4 and 1.1 Ma. The abrupt topographic step from the Tschicoma highlands to the Pajarito Plateau marks the position of the Pajarito fault, which forms the western boundary of the Española Basin.

The view to the south is largely obscured by adjacent high ridges. To the southwest, however, can be seen the approximately 60 cinder cones of the Pliocene Cerros del Rio volcanic field (Aubele, 1978), which flanks the southeastern Jemez Mountains. The Sandia Mountains form the skyline.

ESTIMATED RATES OF QUATERNARY CRUSTAL EXTENSION IN THE RIO GRANDE RIFT, NORTHERN NEW MEXICO

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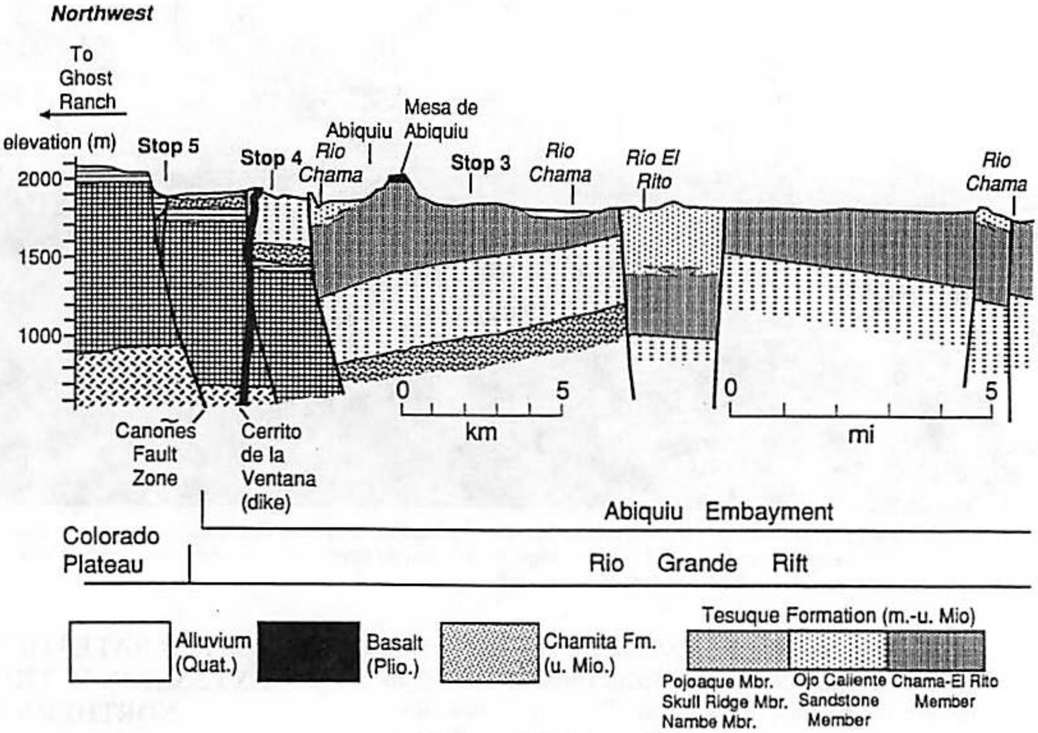
This study assesses Quaternary rates of horizontal E–W extension in the northern Rio Grande rift, based on slip rates of primary faults bordering and within the major rift basins. The Rio Grande rift in northern New Mexico consists of several north-trending asymmetric basins, including the San Luis, Española and Santo Domingo Basins (Fig. 1.10). The polarities of these half grabens change across accommodation zones that traverse the rift at high angles. The amount of Neogene extension within each rift basin decreases northward, with at least 28% extension in the southern Albuquerque Basin, at least 17% in the northern Albuquerque Basin, and about 8 to 12% in the San Luis Basin (Keller and Cather, 1994; Kluth and Schaftenaar, 1994; Russell and Snelson, 1994). On a regional scale, the present least principal stress direction is horizontal and trends roughly WNW (Sanford et al., 1991; Zoback and Zoback, 1989). In this analysis, we use estimated Quaternary slip rates on individual faults to assess cumulative rates of E–W extension along three regional transects across the northern Rio Grande rift.

The San Luis Basin is an east-tilted half graben with several kilometers of west-down displacement on the Sangre de Cristo fault along its eastern margin, and a gentle homocline along its western margin (Chapin and Cather, 1994). Compared with other major basins of the Rio Grande rift, the San Luis Basin is structurally uncomplicated, with few major intrabasin faults (Kluth and Schaftenaar, 1994).

The Española Basin, in contrast, is a west-tilted half graben that contains several intrabasin faults. The east-down Pajarito fault forms the western margin of the basin, and has had about 1.5 km of late Cenozoic displacement (Gardner and Goff, 1984). The eastern margin of the Española Basin lacks a well-defined, continuous fault, and has had little or no discrete west-down displacement (Baltz, 1978). Discontinuous intrabasin faults exhibit east-down and west-down displacements and likely accommodate distributed strain related to westward tilting of the basin (Biehler et al., 1991).

The Santo Domingo Basin is located between the Española and northern Albuquerque Basins (Fig. 1.10). The basin is an east-tilted half graben bordered on the east by the La Bajada fault (Stearns, 1953b; Kelley, 1978) and on the west by a distributed zone of faulting and flexuring grouped herein as the San Felipe fault zone (Smith et al., 1970; Baltz, 1978). Intersections between the La Bajada and Pajarito faults at the



northern end of the basin and between the San Felipe fault zone and Sandia-Rio Grande fault (Wong et al., 1995) suggest that the Santo Domingo Basin itself may transfer extensional strain between the Española and northern Albuquerque Basins.

Considerable data exist on the rate of vertical movement along major rift-border and intrabasin faults in the northern Rio Grande rift (Table 1). Extension in the southern San Luis Basin is accommodated primarily by the rift-margin Sangre de Cristo fault and the intrabasin Los Cordovas fault zone (Personius and Machette, 1984). For the Sangre de Cristo fault, Menges (1988, 1990) reported a post-Pliocene vertical slip rate of 0.15 to 0.25 mm/yr, and we assume a median value of 0.20 mm/yr (Table 1). The Los Cordovas fault zone has displaced a middle Pleistocene geomorphic surface about 15 m (Kelson, 1986), thus yielding an estimated average long-term vertical slip rate of 0.02 mm/yr (Table 1).

Seven primary faults are identified in the Española Basin (Fig. 1.10). The Pajarito fault exhibits 81 m of displacement of the 1.2 Ma upper Bandelier Tuff, averaged along the fault trace (Wong et al., 1995). These data yield an average vertical slip rate of 0.07 mm/yr. At the latitude of the Española transect (Fig. 1.10) the Rendija Canyon Guaje Mountain faults displace the upper Bandelier Tuff about 25 and 20 m, respectively (Wong et al., 1995), both of which yield a vertical slip rate of 0.02 mm/yr. The east-down Sawyer Canyon fault exhibits about 25 m of displacement of the upper Bandelier Tuff (K.E. Carter, personal commun., 1994), suggesting an average vertical slip rate of about 0.02 mm/yr. The Puye fault zone consists of several east-down faults that exhibit evidence of multiple Pleistocene ruptures (LaForge and Anderson, 1988). There is 9 m of displacement of a Pleistocene surface that may be as young as 350 ka (Dethier et al., 1988) across a primary strand of the fault zone, suggesting an estimated vertical slip rate of 0.03 mm/yr (Wong et al., 1995).

There are little or no data on the rates or amounts of displacement across the Pojoaque and Nambé fault zones. The Pojoaque fault likely is part of distributed brittle deformation within the western part of the Española Basin, which has subsided about 60 m in the past 3 Ma (the Velarde graben of Manley, 1979a). We estimate an upper bound for the long-term average vertical slip rate on the fault of 0.02 mm/yr (Table 1), based on the assumption that a 1-2-m-high fault scarp could survive at most only 100,000 to 150,000 years in the climatic and geologic environment of the northern Rio Grande rift (M.N. Machette, written commun., 1994). The presence and continuity of the Nambé fault zone are debatable: field mapping shows a series of discontinuous faults (Cabot, 1938; Spiegel and Baldwin, 1963; Galusha and Blick, 1971; Baltz, 1978), whereas air-photo interpretations suggest a more continuous structure (Vernon and Riecker, 1989). As with the Pojoaque fault zone, we estimate an upper bound for the long-term average vertical slip rate on the fault of 0.02 mm/yr (Table 1).

Along the Santo Domingo transect to the south of the Española Basin, we consider the Jemez-San Ysidro fault zone, which likely borders the northwestern margin of the Albuquerque Basin, and three faults bordering the Santo Domingo Basin (Fig. 1.10). The Jemez-San Ysidro fault zone used herein includes the Jemez fault of Goff and Shevenell (1987) and the San Ysidro fault of Hawley and Galusha (1978). Goff and Shevenell (1987) noted 50 m of displacement of the 1.2 Ma upper Bandelier Tuff across the Jemez fault, which yields an estimated long-term vertical slip rate of 0.05 mm/yr (Table 1). The San Felipe fault zone as used herein includes the Santa Ana, Luce, Algodones and associated faults, which overall border the north-trending San Felipe graben (Smith

FIGURE 1.9. Oblique aerial view looking WNW across the Tesuque Formation badlands west of Stop 1. Prominent white bands are white ash #2 of Galusha and Blick (1971) structurally repeated across numerous north-striking, down-to-the-east normal faults. Valley of the Santa Cruz River downstream from Chimayo is visible in the upper right.

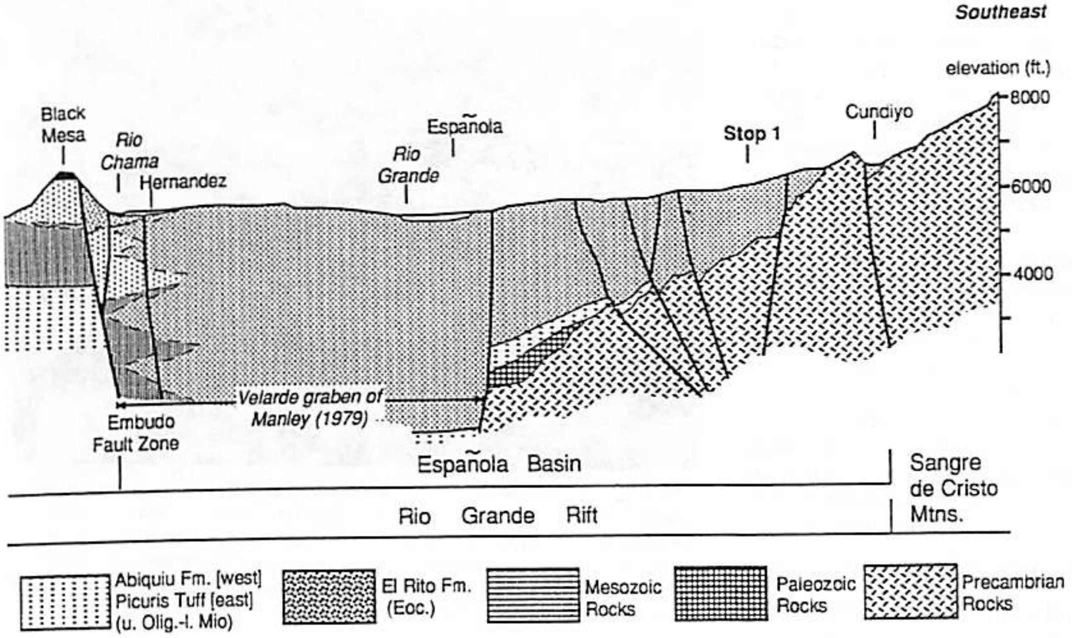


FIGURE 1.8. Generalized geologic cross section across the northern Española Basin and Abiquiu embayment showing locations of Stops 1,3,4 and 5 in relation to rift structure and stratigraphy. Cross section is based mostly on the map of Kelley (1978) and the geophysical interpretations of Golombek et al. (1983) and Baldridge et al. (1994).

et al., 1970; Kelley, 1977; Hawley and Galusha, 1978). The faults displace 2.5 Ma basalt of Santa Ana Mesa (Bachman and Mehnert, 1978), and are associated with topographic scarps developed in basalt as much as 50 m high. We assume the presence of two primary fault strands bordering the San Felipe graben, and, based on these data, conservatively estimate a long-term vertical slip rate of 0.04 mm/yr for the entire zone (Table 1). There are no available data on the Quaternary slip rate of the San Francisco fault; we assume a value equal to that on the La Bajada fault based on comparable geomorphic expression and probably similar tectonic role in the rift (Wong et al., 1995). The La Bajada fault is located at the base of a 160-m-high escarpment developed in 2.5 Ma basalt (Aubele, 1978; Bachman and Mehnert, 1978), which yields an estimated vertical slip rate of 0.06 mm/yr (Table 1).

Rates of regional crustal extension can be estimated assuming that all of the extension is accommodated by brittle deformation on identified faults; the faults dip 60° through the seismogenic crust; and the direction

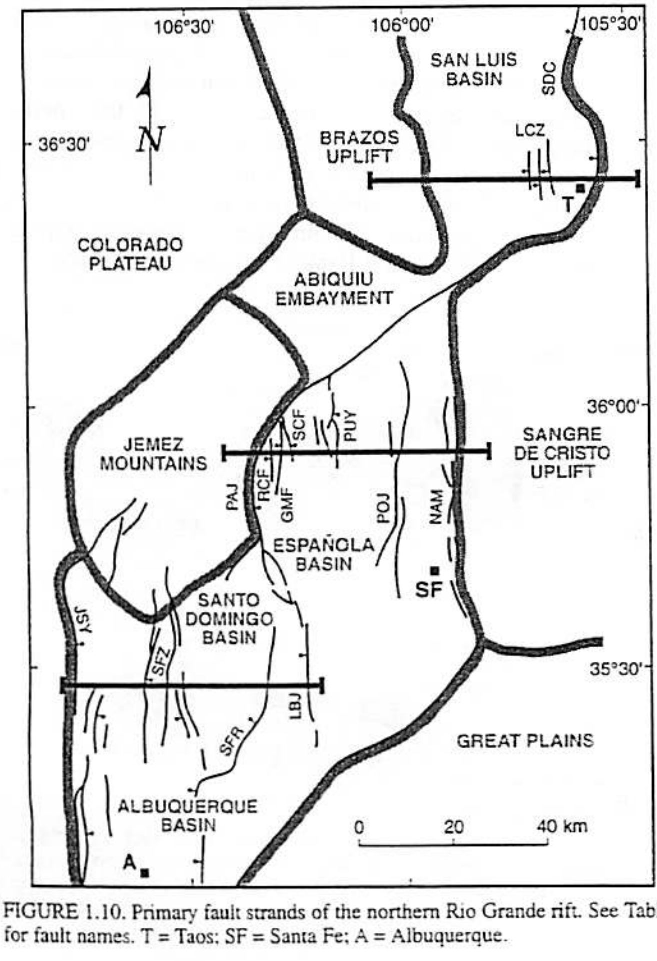


FIGURE 1.10. Primary fault strands of the northern Rio Grande rift. See Table 1 for fault names. T = Taos; SF = Santa Fe; A = Albuquerque.

TABLE 1. Estimated Quaternary vertical slip rates and calculated extension rates, northern Rio Grande rift.

Fault	Best Estimate Quaternary Vertical Slip Rate (mm/yr)	East-West Quaternary Extension Rate (mm/yr)
San Luis Transect		
Sangre de Cristo fault (SDC)	0.20	0.12
Los Cordovas fault zone (LCZ)	0.02	0.01
		Total: **0.13**
Espanola Transect		
Pajarito fault (PAJ)	0.07	0.04
Rendija Canyon fault (RCF)	0.02	0.01
Guaje Mountain fault (GMF)	0.02	0.01
Sawyer Canyon fault (SCF)	0.02	0.01
Puye fault zone (PUY)	0.03	0.02
Pojoaque fault zone (POJ)	0.02	0.01
Nambe fault zone (NAM)	0.02	0.01
		Total: **0.11**
Santo Domingo Transect		
Jemez-San Ysidro fault (JSY)	0.05	0.03
San Felipe fault zone (SFZ)	0.04	0.02
San Francisco fault (SFR)	0.06	0.03
La Bajada fault (LBJ)	0.06	0.03
		Total: **0.11**

of extension is orthogonal to fault strike. We acknowledge that many, if not all, of the faults compiled herein may be listric in nature, and may have shallower dips at depth. Based on these assumptions and available vertical slip rates, we provide a first approximation of Quaternary extension rates across the rift. As shown on Table 1, the rate of extension along the San Luis, Española, and Santo Domingo transects ranges from 0.11 to 0.13 mm/yr. This range is surprisingly narrow considering that the number of faults crossed by each transect ranges from two to seven. This analysis does not account for ranges in slip rate values, and therefore provides no information on the uncertainty in the regional extension rates. Undoubtedly, some of the rates used are too low, and probably some are too high. Overall, however, this analysis supports an interpretation that the rate of regional Quaternary extension across the northern Rio Grande rift is about 0.1 mm/yr. The calculated extension rates given above do not show a northward decrease, as might be expected from the amounts of Neogene extension given by Chapin and Cather (1994). The discrepancy may be related, in part, to the poor constraints on estimated fault slip rates. Alternatively, if the rates of Quaternary extension are comparable among rift basins, the greater cumulative amounts of Neogene extension in the south suggest a northward progression of rifting.

Return to highway and continue eastward to Cundiyo. 0.5

25.3 Ledge-forming conglomeratic sandstones of the Nambé Member of the Tesuque Formation exposed to the left of the road. **0.3**

25.6 Junction with road to overlook of Santa Cruz Lake. Continue east on NM–503. **0.1**

25.7 Roadcut in Nambé Member of the Tesuque Formation. **0.3**

26.0 Milepost 9. View down valley to left (north) illustrates depositional contact between Tesuque Formation, on west, with dark Proterozoic amphibolite cut by granite sills, on east (Fig. 1.11). The map by Miller et al. (1963) is nearly devoid of faults in this area. In contrast, Kelley's (1978) map of the Española Basin shows numerous large-displacement, north-striking, normal faults through here. Galusha and Blick (1971; Fig. 1.12) sketched several examples of the depositional contact in this area to emphasize the lack of faulting along this part of the Sangre de Cristo mountain front. Even though large faults do not separate Proterozoic from Tertiary here, the Proterozoic rocks are extensively fractured and contain numerous minor faults. A moderately SE-dipping fault in the streamcut ahead contains oblique fault striae that plunge 30°S. **0.1**

26.1 Road nearly coincides with contact between Tesuque Formation, on right side of road, and Proterozoic granitic rocks, across wash on left side of road. Miller et al. (1963) mapped the enormous granitic terrane along the western Sangre de Cristo Mountains as Embudo Granite, a general term originally used in the Picuris Mountains. Subsequent more detailed mapping has shown that the Embudo Granite is a complicated plutonic complex that probably spans more than 200 Ma. **0.4**

26.5 Roadcut in granite on left. Most of the Proterozoic rocks here are metaintrusive rocks of some sort. The predominant lithology is reddish-orange, equigranular, ± tectonically foliated, fine-grained granite with abundant pods and stringers of pegmatite and quartz. Pegmatites range in thickness from a few centimeters to a few meters, and many show considerable range in grain size. Other common rock types are mafic schist, amphibolite and gneiss, all of which contain a moderately SE-dipping foliation. Tight folds in the gneisses and schists are common, as are gently to moderately SE-plunging extension lineations. **0.1**

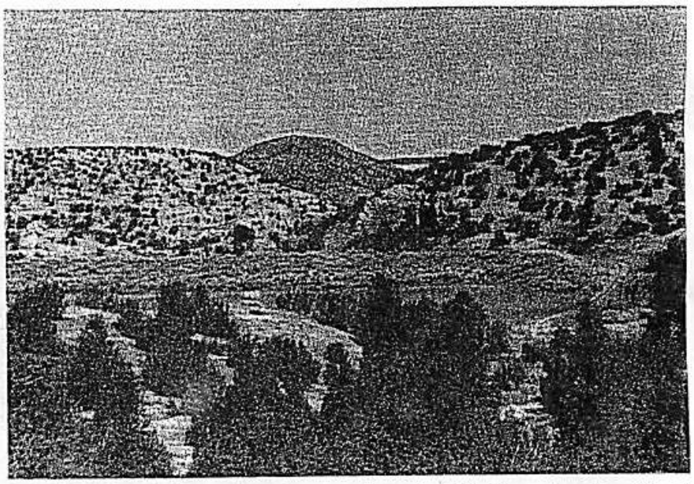


FIGURE 1.11. Northward view from road at mile 26.0, illustrating depositional contact (at tip of arrow) between west-dipping Tesuque Formation (left) and Proterozoic metamorphic and plutonic rocks (right); also see Fig. 1.12A. Prominent pinyon and juniper studded hill in center is a knob of Proterozoic rocks that has been exhumed from beneath the Tesuque Formation along the south side of Santa Cruz Lake (also see Fig. 1.12B).

26.6 Roadcut to left shows a variety of Proterozoic rocks. Granite, with screens and xenoliths of amphibolite and mafic schist, is present along the western part of the exposure and grades through a zone of foliation-parallel granitic intrusions into amphibolite with steep, E-dipping foliation. In one spot is a spectacular example of cuspate-lobate folding between granite and schist. The schist has been preferentially eroded, leaving the fold mullion surface fully exposed. The outcrop also contains delta porphyroclasts whose asymmetrical tails suggest top-to-the-north (reverse) ductile shearing. Asymmetrical minor folds show both reverse and normal sense-of-shear. Toward the central and western part of the roadcut recumbently folded compositional layering and foliation are cross-cut by a sub-horizontal, lenticular, complexly zoned, 6-ft-thick, garnet-bearing, granitic pegmatite (Fig. 1.13). The pegmatite contains an axial, fine-grained phase, that is symmetrically flanked by coarse, outward-radiat-

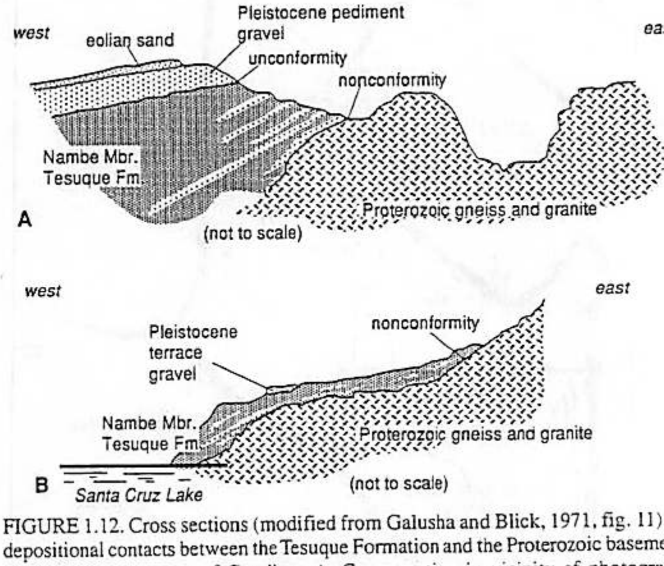


FIGURE 1.12. Cross sections (modified from Galusha and Blick, 1971, fig. 11) of depositional contacts between the Tesuque Formation and the Proterozoic basement rocks in the area west of Cundiyo. A, Cross section in vicinity of photograph shown in Figure 1.11. B, Cross section along western margin of Santa Cruz Lake.