STRATIGRAPHY AND TECTONIC DEVELOPMENT OF THE ALBUQUERQUE BASIN, CENTRAL RIO GRANDE RIFT

FIELD-TRIP GUIDEBOOK FOR THE GEOLOGICAL SOCIETY OF AMERICA
ROCKY MOUNTAIN-SOUTH CENTRAL SECTION MEETING, ALBUQUERQUE, NM
PRE-MEETINNG FIELD TRIP

GUIDEBOOK

FIRST DAY, SANTO DOMINGO SUB-BASIN: HAGAN EMBAYMENT AND NORTHERN FLANK OF THE SANDIA MOUNTAINS

SECOND DAY, CALABACILLAS SUB-BASIN: ZIA PUEBLO, RIO RANCHO, AND TIJERAS ARROYO

THIRD DAY, BELEN SUB-BASIN: BELEN, SEVILLETA NATIONAL WILDLIFE REFUGE, AND NORTHERN SOCORRO BASIN

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REVISIONS TO GUIDEBOOK AND MINI-PAPERS

This field-guide accompanied a pre-meeting field trip of the Geological Society of America Rocky Mountain and South-Central Section conference in Albuquerque, New Mexico. A limited quantity of guidebooks and mini-paper compilations were produced for participants of this field trip. A number of typographical, grammatical, and editorial errors were found in this first version of the guidebook, mainly because of logistical constraints during preparation for the field trip. In the revised version, *released on June 11, 2001*, many errors have been corrected. Many photographs, figures, and maps, shown during the field trip but not included in the first version, are included in this revision. Numerous minor editorial changes and corrections have also been made to the guidebook mini-papers.

The field-guide has been separated into two parts. Part A (open-file report 454A) contains the three-days of road logs and stop descriptions. Part B (open-file report 454B) contains a collection of mini-papers relevant to field-trip stops.

The contents of the road logs and mini-papers have been placed on open file in order to make them available to the public as soon as possible. Revision of these papers is likely because of the on-going nature of work in the region. The papers have not been edited or reviewed according to New Mexico Bureau of Mines and Mineral Resources standards. The contents of this report should not be considered final and complete until published by the New Mexico Bureau of Mines and Mineral Resources. Comments on papers in this open-file report are welcome and should be made to authors. The views and preliminary conclusions contained in this report are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the State of New Mexico or the U.S. Government.

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We thank the New Mexico Geological Society for granting permission to reprint three papers from their 1999 Guidebook 50 entitled *Albuquerque Geology* (F.J. Pazzaglia and S.G. Lucas, eds). We especially thank V.J.S. Grauch for agreeing to present summaries of recent regional geophysical surveys of the Albuquerque Basin.

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PRE-MEETINNG FIELD TRIP: STRATIGRAPHY AND TECTONIC DEVELOPMENT OF THE ALBUQUERQUE BASIN, CENTRAL RIO GRANDE RIFT

FIRST DAY ROAD LOG, APRIL 27, 2001
SANTO DOMINGO SUB-BASIN: HAGAN EMBAYMENT AND NORTHERN FLANK OF THE SANDIA MOUNTAINS

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The following road log through the Santo Domingo sub-basin has been summarized and modified from New Mexico Geological Society Guidebook 50 by Pazzaglia et al. (1999a) and Hawley and Galusha (1978). Road-log mileage not checked for accuracy.

Mileage	**Description**
0.0	Load vehicles at Sheraton Old Town hotel. Turn right (North) on Rio Grande Blvd. **0.3**
0.3	Cross under 1-40 overpass. **1.4**
1.7	Turn right (east) onto Candelaria Blvd. **1.8**
3.5	Cross drain at corner of 2nd Street and Candelaria. **0.2**
3.7	Cross Railroad tracks. **0.2**
3.9	Cross Edith Blvd. and begin ascending Holocene-latest Pleistocene valley border fans derived from the Sandia Mts. These alluvial deposits grade over, and interfinger with, floodplain and old channel deposits of the Rio Grande. **0.7**
4.6	Turn left onto North Frontage Rd. (Pan American Highway). Keep to your left and merge onto I-25 northbound to Santa Fe. The basalt flows and splatter cones to your left across the Rio Grande Valley are the Albuquerque volcanoes, which have been dated ($^{238}U/^{230}Th$ method) at 156±29 ka (Peate et al., 1996). These basalt flows interfinger with the upper part of am ancestral Rio Grande fluvial deposit of the Los Duranes Fm, which was originally defined by Lambert (1968). **1.6**
6.2	Pass under Montaño Blvd. (exit 228). **0.6**
6.8	Gravel quarries on your left are excavating aggregate from the Edith Fm, an extensive and important marker unit originally defined by Lambert (1968) for exposures along Edith Blvd. Many of the original exposures along Edith Blvd. are being covered or obscured by urban development. The Edith Fm locally yields fossil mammals of Rancholabrean age (~400-10 ka), including mammoth, bison, horse, and ground sloth (Lucas et al., 1988). On your left, north to exit 230 are a number of industrial/commercial tracts constructed on reclaimed aggregate quarries in the Edith Fm. On your right is the rugged western escarpment of the Sandia Mts. Rincon Ridge is between 1:00-2:00. Well-sorted axial-fluvial sand and gravel of the ancestral Rio Grande underlie locally derived piedmont deposits of the rift-bounding Sandia Mts. to the east. These fluvial deposits constitute the narrow axial-fluvial lithofacies of the ancestral Rio Grande, which represent some of the best aquifer units of the Santa Fe Group. Deposits of the ancestral Rio Grande basin fill are mostly between Eubank and Edith Blvds. **1.8**

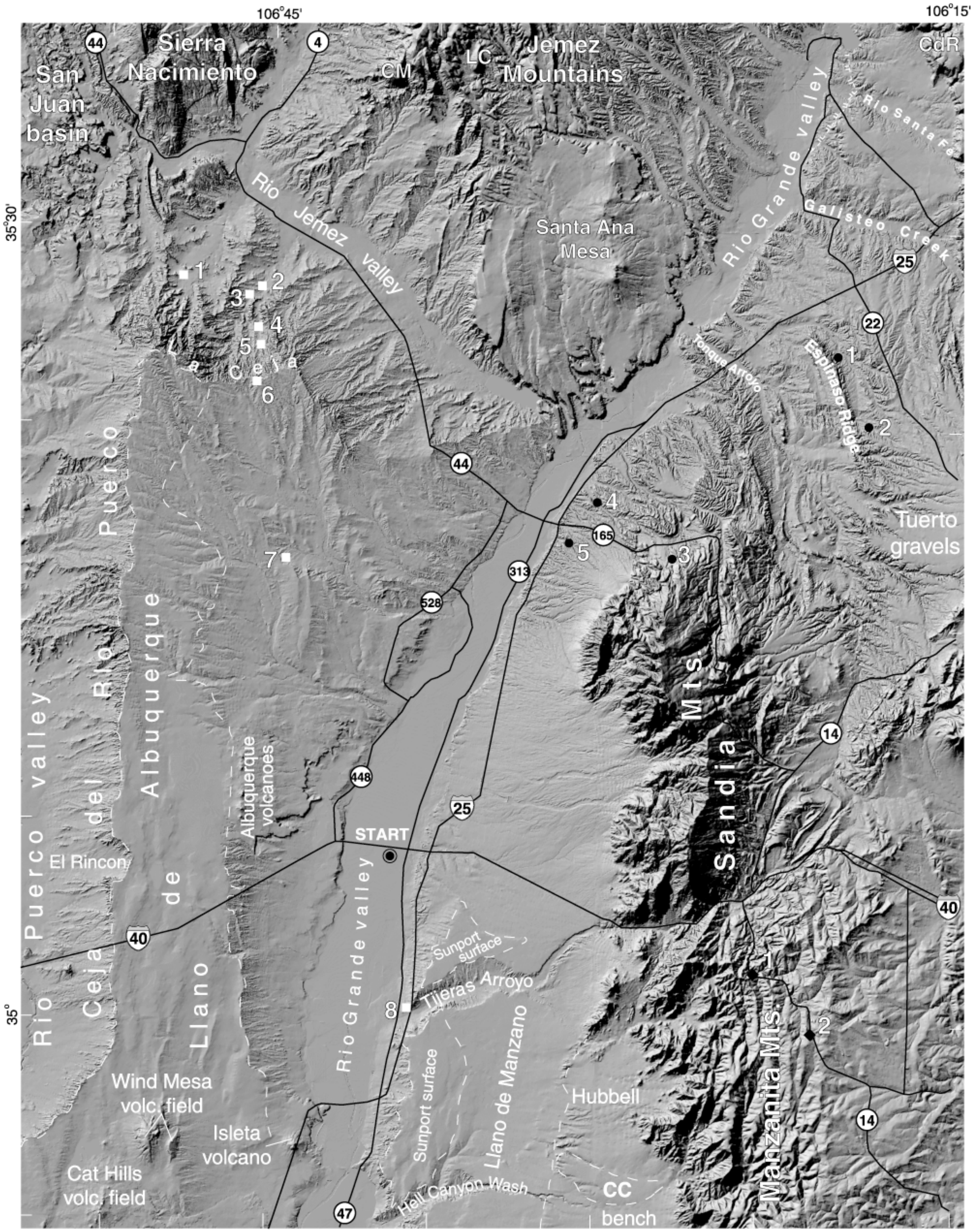

Figure 1-1. Shaded-relief map of the Albuquerque area, illustrating the locations of stops for day 1 (black circles), and day 2 (white squares). Base prepared by S.D. Connell for Pazzaglia et al. (1999b).

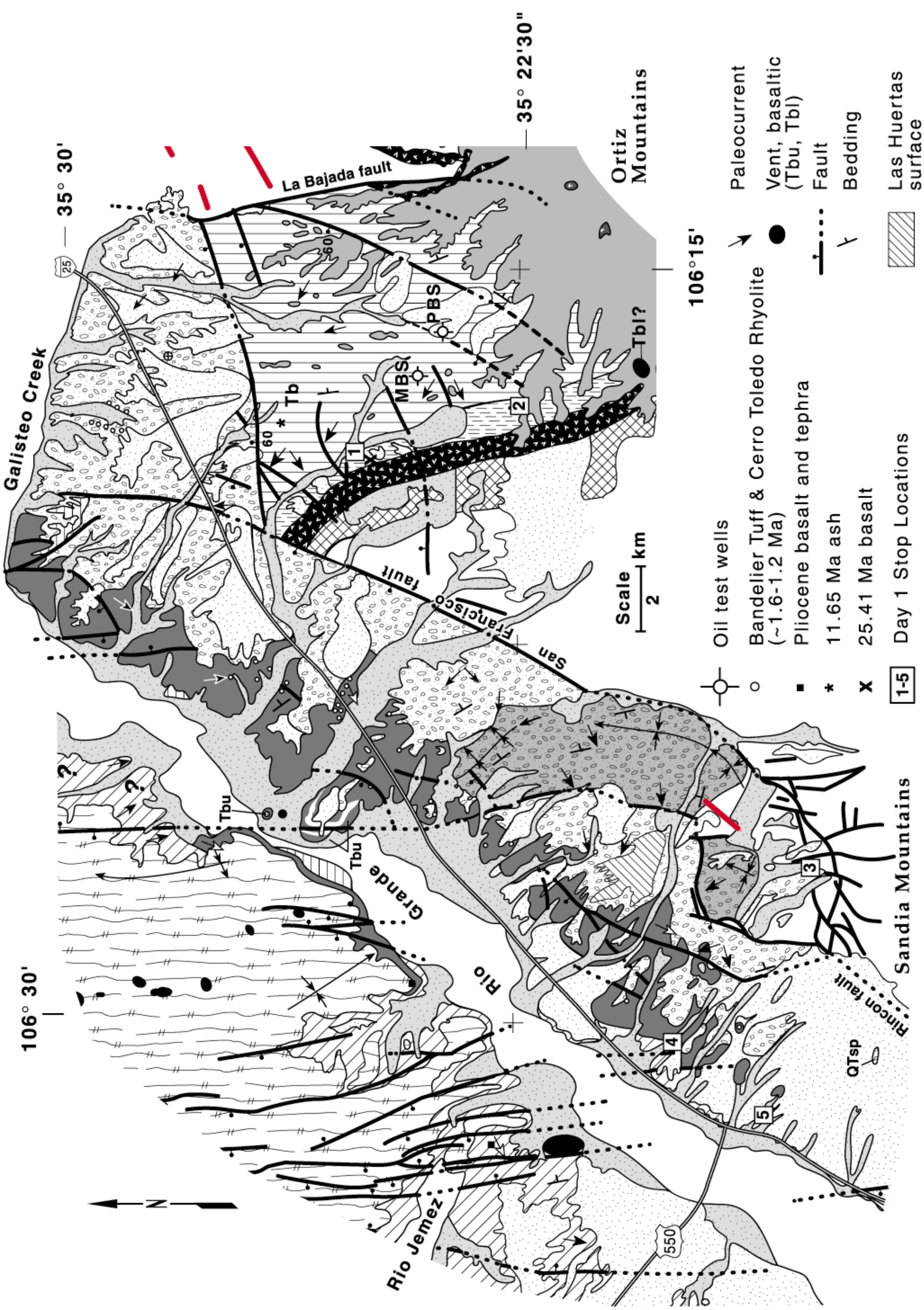
35° 30'
35° 22'30"
106° 30'
106°15'
La Bajada fault
Galisteo Creek
Ortiz Mountains
San Francisco fault
Rio Grande
Rio Jemez
Sandia Mountains
Rincon fault
PBS
MBS
Tb
Tbl?
Tbu
QTsp
25
550
Scale
2 km
N
Oil test wells
Bandelier Tuff & Cerro Toledo Rhyolite (~1.6-1.2 Ma)
Pliocene basalt and tephra
11.65 Ma ash
25.41 Ma basalt
Day 1 Stop Locations
Paleocurrent
Vent, basaltic (Tbu, Tbl)
Fault
Bedding
Las Huertas surface

Figure 1-2. Explanation and simplified geologic map of the southeastern Santo Domingo sub-basin (previous page), illustrating locations of Day 1 stop localities (compiled from Cather and Connell, 1998; Cather et al., 2000; Connell, 1998, Connell et al., 1995; unpublished mapping). Bandelier Tuff and Cerro Toledo Rhyolite are found as fallout ash and lapilli and, more commonly, as fluvially recycled pumice pebbles and cobbles.

8.6 San Antonio Drive overpass (exit 231). Latest Pleistocene and Holocene piedmont deposits derived from Sandia Mts. form valley border fans that overlie the Edith Fm. Many of the larger buildings immediately east and west of I-25 in this area have been affected by structural damage attributed to hydrocollapsing soils associated with these young silty sands, which are typically less dense than the older piedmont deposits, have higher blow counts during percussion drilling, and consolidate when wetted. These soils are susceptible to compaction when they receive large amounts of moisture, typically associated with landscaping irrigation or leaking water or sewer pipes. **1.0**

9.6 Paseo del Norte Blvd. overpass (exit 232). **1.1**

10.7 To the left are computer chip production facilities run by Phillips and Sumitomo Sitix, which have cooperated with the City of Albuquerque on a joint water reclamation project to recycle water for use on the grounds of Balloon Fiesta Park. **0.8**

11.5 Southern boundary of Sandia Pueblo. **0.1**

11.6 Milepost 234. Tramway Blvd./Roy Avenue underpass. Sierra Nacimiento at 10:00, Jemez Mts. and basalts at Santa Ana Mesa (a.k.a. San Felipe Mesa) at 11:00, Sandia Mts. at 3:00. The cliffs consists of the 1.44 Ga Sandia granite, which intruded into the 1.7 Ga Rincon Ridge metamorphic complex. These crystalline rocks are nonconformably overlain by the Pennsylvanian Sandia and Madera fms. Late Pleistocene to Holocene valley border deposits are inset against the Edith Fm to the north, but overlie the Edith Fm to the south. The entrenchment of younger alluvium into the Edith Fm is attributed to broad deformation across the northwest-trending Alameda structural zone (Pazzaglia et al., 1999a). Quaternary deformation is interpreted here, primarily because the basal contact (strath) of the Edith Fm decreases in elevation by about 15 m across this inferred structural zone (Connell, 1998) and younger piedmont alluvium is inset against the Edith Fm to the north. To the west are abandoned and reclaimed quarries in the Edith Fm. Current quarry operations are to the north. **2.9**

14.5 Milepost 237. At about 9:00, west of the Rio Grande Valley is Loma Colorada del Abajo, a low hill underlain by Pliocene-aged light gray sandy gravel of the Ceja Mbr, which overlies reddish-brown sediments of the Loma Barbon Mbr (same formation, Pliocene). To your left is an unconformable contact between the Edith Fm and slightly east-tilted reddish-brown strata assigned to the Loma Barbon Mbr. **2.0**

16.5 Milepost 239. Edith Fm overlies east-tilted red sandstone of the Loma Barbon Mbr. **2.7**

19.2 On your right, reddish-brown Loma Barbon Mbr unconformably overlain by rounded quartzite-bearing gravel of the Edith Fm. **0.3**

19.5 Exit 242 to Rio Rancho and Placitas, highways NM-165 and US-550. **0.2**

19.7 Overpass of US-550 and NM-165. **0.8**

20.5 Milepost 243. Centex Gypsum wallboard production plant on the left at 9:00. This plant processes gypsum from local quarries developed in the Jurassic Todilto Fm, some of which is locally mined from exposures along the basin margin. **1.0**

21.5 Milepost 244. Maar of Canjilon (octopus) Hill at 9:00. This volcanic edifice was K/Ar dated at 2.6±0.1 Ma (Kelley and Kudo, 1977). Between 10:00 and 11:00, are the east-tilted and faulted basalts at Santa Ana Mesa. Recent $^{40}Ar/^{39}Ar$ dates along the southeastern margin indicate these flows were emplaced between 2.24-1.77 Ma (W.C. McIntosh, 1997, written commun.; Cather and Connell, 1998). **1.0**

22.5 Milepost 245. Ascending hill underlain by middle to late Pleistocene (post-Santa Fe Group) piedmont deposits overlying Edith Fm. **1.5**

24.0 Las Huertas Creek. **0.3**

24.3 Middle to late Pleistocene piedmont deposits overlying the Edith Fm. **0.4**

24.7 Between 9:00 and 10:00 are interbedded reddish brown sand of the Arroyo Ojito Fm and light-gray sand of the ancestral Rio Grande facies (Sierra Ladrones Fm) beneath the basalt flows at Santa Ana Mesa. **0.7**

25.4 Exit 248. Algodones overpass. **0.4**

25.8 On your left is the Plains Electric generation plant. The hummocky topography flanking the basalt flows at Santa Ana Mesa is formed by Pleistocene landslides that locally cover inset fluvial (fill-terrace) deposits of the ancestral Rio Grande (Cather and Connell, 1998). **0.6**

26.4 Milepost 249. To your left are moderately dipping cliffs of older piedmont deposits of the Santa Fe Group, exposed in Arroyo Maria Chavez. **0.6**

27.0 At 10:00, a basalt flow of the Santa Ana Mesa basalts is cut by the Escala fault, which is a prominent down-to-west fault that begins south at the northern flank of the Sandia Mts., near Placitas. The eastern margin of these basalt flows and vents are exposed on Santa Ana Mesa but descend eastward where they are interbedded with ancestral Rio Grande (fluvial) deposits of the Sierra Ladrones Fm (Fig. 1-3). **1.2**

28.2 On the right is a gravel quarry in the ancestral Rio Grande deposits of the Sierra Ladrones Fm (upper Santa Fe Group). **1.0**

29.2 On the left is a succession of sandy piedmont deposits of the Sierra Ladrones Fm that overlie ancestral Rio Grande deposits (ARG) of the same formation. These piedmont deposits interfinger with fluvial facies to the east. **0.6**

29.8 Exit 252. Overpass to San Felipe Pueblo. Crossing over Tonque Arroyo. **0.7**

Figure 1-3. Photo looking to the north near Milepost 249. Plio-Pleistocene ancestral Rio Grande deposits of the Sierra Ladrones Fm (ARG) interfinger with this Pliocene basalt.

30.5 On your left is a northeast-tilted, white ash bed. Along the south side of Tonque Arroyo, just east of the San Felipe Casino, this ash bed is at the contact between fluvial deposits of the ancestral Rio Grande and overlying piedmont deposits. This ash bed was dated using the $^{40}Ar/^{39}Ar$ method at 1.57±0.06 Ma (W.C. McIntosh, 1998, written commun.) and is chemically similar to the Cerro Toledo Rhyolite (N. Dunbar, 2000, written commun), a series of eruptions between the caldera collapse events of the lower and upper Bandelier Tuff in the Jemez Mts. **0.4**

30.9 To the north between 11:00 and 12:00 is the Cerros del Rio volcanic field, which is on the footwall of the La Bajada fault. Tetilla Peak is at 11:00. **0.8**

31.7 Crossing Arroyo de la Vega de los Tanos (Tanos Arroyo). On your right, Espinaso ridge is held up by upper Eocene and Oligocene volcaniclastic deposits of the Espinaso Fm, which conformably overlies the Eocene Galisteo Fm. The Ortiz Mts., at 3:00, are the source of detritus for the Espinaso Fm at Espinaso Ridge. The northern tip of Espinaso Ridge is cut by the San Francisco fault. This fault is another major down-to-west normal fault that begins at the northern flank of the Sandia Mts., near Placitas. **1.7**

33.4 On your left are the Jemez Mts. Between 9:00 and 10:00, Tent Rocks underlain by late Miocene Peralta Tuff Mbr of the Bearhead Rhyolite. Some of the oldest deposits of the ancestral Rio Grande are recognized in ~6.9 Ma beds of the Peralta Tuff at Tent Rocks (Smith and Kuhle, 1998). The Cerrillos Hills, another Oligocene-age intrusive and volcanic center, related to the Ortiz Mts., is between 10:00 and 1:00. **1.2**

34.6 Leave I-25 at Budaghers exit (exit 257). **0.3**

34.9 Turn right onto Budaghers Blvd. at stop sign at top of offramp. **0.1**

35.0 Make a sharp right onto east frontage road. The cliffs in the quarry to your left contain well cemented sandstone and travertine of the upper Santa Fe Group, on the footwall of the San Francisco fault. **0.4**

35.4 Cross cattleguard, pavement ends at Arroyo Vega Tanos Rd. Proceed on dirt road to the left. **0.4**

35.8 Low hills to the left are topographic scarps of the Budaghers fault. **0.4**

36.2 To your left, note well cemented piedmont pebbly sandstone of the Blackshare Fm. **0.1**

36.3 Cross through cattle gate **and make a sharp left. You must obtain permission from the Ball Ranch prior to passing this gate**, which is normally locked. **0.2**

36.5 Crossing Tanos Arroyo. **1.2**

37.7 Pass through cattle gate. **0.1**

37.8 Around you is mudstone and sandstone of the Tanos Fm, which is commonly overlain by gravelly Quaternary alluvium. **0.9**

38.7 **STOP 1:** Oligocene through middle Miocene deposits of the Lower Santa Fe Group at Arroyo de la Vega de los Tanos (Tanos Arroyo). *San Felipe Pueblo NE 7.5' quadrangle, GPS: NAD 83, UTM Zone 013 S, N: 3,920,012 m; E: 380,479 m.*

The purposes of this stop are to: 1) summarize the geology of Paleogene pre-rift rocks of the Espinaso, Galisteo, and Diamond Tail fms; 2) discuss the Oligocene hypabyssal intrusive and volcanic rocks of the Ortiz porphyry belt; 3) examine the oldest, dated, exposed section of lower Santa Fe Group in the Hagan embayment.

The Hagan embayment is a structural re-entrant formed between the San Francisco and La Bajada faults. The embayment marks the eastern boundary of the rift and contains a well exposed succession sedimentary rocks, encompassing much of the Pennsylvanian-Pleistocene geologic record. The discussion of pre-Espinaso Fm rocks is summarized from Pazzaglia et al. (1999a, b).

The Diamond Tail and Galisteo fms comprise upper Paleocene and Eocene sedimentary rocks that were deposited in the Galisteo basin, a Laramide basin developed in response to basement-cored uplifts in the current location of the Sangre de Cristo and Nacimiento Mts. Paleocurrent data indicate deposition in the Galisteo basin was by extensive river systems flowing to the south (Gorham and Ingersoll, 1979; Kautz, 1981; Smith, 1992). The thickness of the Diamond Tail and Galisteo fms is as much as 1300 m. Fossil mammals indicate deposition began in the early Eocene (~54 Ma) and continued through the latest Eocene (~37 Ma) (Lucas et al., 1997).

The Oligocene Espinaso Fm conformably overlies the Galisteo Fm, but marks a distinct change in deposition. The Espinaso Fm was defined by Stearns (1953a) for volcaniclastic detritus shed off of the Ortiz Mts., a lacolithic and volcanic complex, ~12-15 km east of this stop, emplaced between 27-36 Ma. The Espinaso Fm was deposited as volcanic and hypabyssal intrusive rocks were eroded off the Ortiz Mts. The Espinaso Fm is about 430 m here and contains a lower member composed of calc-alkaline rocks (hornblende+pyroxene) that are overlain by an upper alkaline (biotite+clinopyroxene) member (Erskine and Smith, 1993).

Deposits of the Santa Fe Group (Spiegel and Baldwin, 1963) are generally differentiated into two, and in some places three, informal sub-groups (Bryan and McCann, 1937, 1938; Lambert, 1968; Kelley, 1977; Hawley, 1978, 1996; Hawley et al., 1995). These sub-groups are divided into a number of formation- and member-rank units throughout much of the Española, Albuquerque, Socorro, and Palomas basins. The lower sub-group records deposition in internally drained basins (bolsons) where streams terminated at broad alluvial plains or ephemeral or intermittent playa lakes bounded by basin-margin piedmont deposits derived from emerging rift-flanking uplifts. The upper sub-group records deposition in externally drained basins where perennial streams and rivers associated with the ancestral Rio Grande fluvial system flowed toward southern New Mexico. Deposition ceased during Pleistocene time, when the Rio Grande began to incise into the earlier aggradational phase of the Santa Fe Group basin fill (Spiegel and Baldwin, 1963; Hawley, 1996; Hawley et al., 1969).

The northeastern flank of Espinaso Ridge exposes some of the oldest deposits of the Santa Fe Group in the Albuquerque Basin (*see mini-paper by Connell and Cather, this volume*). The Tanos Fm is the stratigraphically lowest preserved deposits of the Santa Fe Group exposed in the northern Albuquerque basin. The Tanos Fm rests disconformably upon Oligocene volcaniclastic conglomerate and sandstone of the Espinaso Fm (Fig. 1-4). The contact is sharp and stratal tilts do not change noticeably across this boundary; however, a continuous dip-meter log from a nearby oil test well indicates an angular relationship at this contact. The Tanos Fm is subdivided into three unmapped members: basal conglomeratic piedmont, middle mudstone and sandstone, and upper tabular sandstone. The basal member contains 25.41 Ma olivine basalt about 9 m above the base. The middle mudstone member represents a basin-floor playa-lake facies of the Tanos Fm (Fig. 1-5).

The Tanos Fm is conformably overlain by the Blackshare Fm, which contains conglomeratic sandstone, sandstone, and mudstone, commonly arranged in upward fining sequences bounded by weakly developed soils (Fig. 1-6). The basal contact of the Blackshare Fm interfingers with the Tanos Fm and is mostly covered by Quaternary alluvium in Tanos Arroyo. An 11.65 Ma ash is about 670-710 m (based on measured sections and estimated from geologic map of Cather et al., 2000) above the base.

Figure 1-4. Contact between white conglomeratic sandstone of the Espinaso Fm (left) and overlying conglomerate of the Tanos Fm (right).

Figure 1-5. Moderately northeast-dipping (to the right) basin-floor facies of the middle mudstone member of the Tanos Fm.

Composition, gravel size, and paleocurrent data indicate derivation from the Ortiz Mts. (Large and Ingersoll, 1997; Cather et al., 2000). The Espinaso, Tanos, and Blackshare fms contain abundant porphyritic hypabyssal intrusive and volcanic rocks derived from the neighboring Ortiz Mts., which are exposed on the footwall of the La Bajada fault. The upper Espinaso Fm contains alkalic rocks, as described by Erskine and Smith (1993). Overlying deposits of the Tanos Fm contain a more diverse assemblage of hypabyssal intrusive and volcanic gravels. Thermally metamorphosed Cretaceous shales and sandstones (hornfels) and fine rounded quartzite pebbles are very rare near the base, but they increase in abundance within the overlying Blackshare Fm. These hornfels are exposed near the flanks of the Ortiz Mts. and were metamorphosed during emplacement of the Ortiz porphyry at about 27-36 Ma (Maynard, 1995). Sandstones of the Espinaso Fm are quartz-poor lithic arkoses, whereas those of the overlying deposits of the Santa Fe Group are lithic arkose and feldspathic litharenite containing more quartz than in the underlying Espinaso Fm.

Figure 1-6. Blackshare Fm. Conglomerate facies (top), and upward-fining sequences of conglomeratic sandstone, sandstone, and mudstone (bottom).

	End of Stop 1. Proceed south-southeast along dirt road. **0.4**
39.1	Cross Tanos Arroyo. **0.3**
39.4	Cross under power lines. **0.1**
39.5	Blackshare Ranch is straight ahead. Pass through the cattle gate and take a sharp and immediate right. **0.5**
40.0	To your left is a north-trending normal fault with down-to-the-west movement. Pink beds in stream cut near arroyo terminate at the fault. Within about 100 m west of this fault is a topographic scarp of the major fault from which this fault is a splay. **0.2**
40.2	Cross tributary of Tanos Arroyo. **0.1**
40.3	Pass through cattle gate and cross small arroyo. **0.9**

41.2 Ruin to your right. Keep straight and cross over earthen dam. **0.4**

41.6 Make a hard right at the intersection of two dirt roads. **0.3**

41.9 Bear left. Ascend hill to broad alluvial surface of the Tuerto Fm. **1.0**

42.9 Cross arroyo. **0.8**

43.7 Windmill on your right. **0.1**

43.8 Turn right onto weakly developed two-track road. **0.1**

43.9 **STOP 2:** Plio-Pleistocene basin-margin gravels of the Tuerto Fm. *San Felipe Pueblo NE 7.5' quadrangle, GPS: NAD 83, UTM Zone 013 S, N: 3,915,540 m; E: 380,210 m.*

The purposes of this stop are to: 1) summarize the geology of Plio-Pleistocene basin-margin deposits of the Tuerto and Ancha fms; 2) discuss the development of the La Bajada fault zone.

Deposits of the Tuerto Fm (upper Santa Fe Group) overlying moderately tilted beds of the Tanos and Espinaso fms, just south of the Arroyo del Tuerto (Arroyo Pinovetito of Stearns, 1953a) section along Tanos Arroyo (Fig. 1-7). The purposes of this stop are to: 1) examine the Tuerto Fm and compare it to the Ancha Fm of the Santa Fe embayment; and 2) discuss the influence of basin-bordering faults, such as the La Bajada fault. The top and base of this unit have been considered part of the Ortiz surface (Stearns, 1979). We assign the upper constructional surface to the Ortiz, also recognizing the stratigraphic and structural importance of the underlying unconformity.

Stearns (1953a) informally named the Tuerto Fm for a broad alluvial gravel associated with streams draining the Ortiz Mts. and Cerrillos Hills. The Tuerto Fm generally ranges from about 10 to 21 m in thickness and is readily distinguished by its angular basal contact with tilted beds of the Espinaso, Tanos, and Blackshare fms, and by a marked increase in maximum gravel size (cobbles and boulders are locally common) and increase in the proportion of hornfels gravel. The Tuerto Fm forms an areally extensive alluvial apron. It unconformably overlies the Espinaso, Tanos, and Blackshare fms. The Espinaso Fm and cemented conglomerates of the Blackshare Fm typically form low hills inset by the Tuerto Fm.

A thin, unnamed limestone-bearing deposit is recognized south of the main belt of Tuerto Fm outcrops, just south of San Pedro Creek. These limestone-bearing deposits constitute a lithologically differentiable unit that is coeval with the Tuerto Fm that has not yet been differentiated.

Spiegel and Baldwin (1963) defined the Ancha Fm as the uppermost part of the Santa Fe Group. They defined this deposit for exposures along Canada Ancha, where an interbedded ash was recently dated at 8.48±0.14 Ma using the $^{40}Ar/^{39}Ar$ method (*see mini-paper by Koning et al., this volume*), which suggests that this unit is probably too old to be correlative to the Ancha Fm. Much of this section is lithologically similar to the Pojoaque Mbr of the Tesuque Fm. Therefore, we consider most of the type Ancha section to be correlative to the underlying Tesuque Fm. The Ancha Fm was mapped as a granite-bearing gravel and sand derived from the southwestern front of the Sangre de Cristo Mts. in the Santa Fe embayment, near Santa Fe, New Mexico. Exposures extend from just north of the Santa Fe River, to Galisteo Creek. Although the type section of this unit was mis-correlated by Spiegel and Baldwin (1963), it has been mapped in a consistent manner throughout the Santa Fe embayment and, thus is a stratigraphically useful term. Therefore, we propose replacing the Cañada Ancha section with a new type section near Lamy, New Mexico.

Figure 1-7. View to south of angular unconformity between northeast-tilted beds of the Espinaso Fm (white) and overlying sub-horizontally bedded Tuerto Fm. Sandia Mts. in background.

The Ancha Fm contains abundant granite with less amounts of gneiss and schist. The Ancha Fm is compositionally distinct from the Tuerto Fm, which contains porphyrytic andesite and monzanite and hornfels derived from the Ortiz Mts. The Tuerto Fm locally overlies the Ancha Fm along the southern margin of Galisteo Creek, indicating that these two formations are coeval in part. The Tuerto and Ancha fms are locally overlain by Pliocene basalt flows of the Cerros del Rio field, which were mostly emplaced between 2.3 and 2.8 Ma (*cf.* Woldegabriel et al., 1996). The age of the Ancha Fm is constrained by the presence of tephra Ar/Ar dated at 1.48 Ma, which is temporally correlative to the Cerro Toledo Rhyolite, from the Jemez Mts. This ash, and another dated at 1.61 Ma, lie near the top of the Ancha Fm (Read et al., 2000). In Bonanza Wash, just east of the Cerro Bonanza in the Cerrillos Hills, an ash containing 1.26 Ma tephra is recognized in deposits associated with Bonanza Creek (*Koning et al., this volume*). This ash-bearing deposit is interpreted to be inset against the Ancha Fm. Thus, the entrenchment of the Ancha Fm, near Bonanza Creek, began between 1.5 and 1.2 Ma. This entrenchment of the Ancha constructional surface, called the Plains surface by Spiegel and

Baldwin (1963), was probably not synchronous. The Ancha Fm is thin and contains fallout tephra of the lower Bandelier Tuff (Read et al., 2000) near the mouth of Arroyo Hondo, suggesting that the Ancha Fm was deposits during early Pleistocene time along that segment of the mountain front. Along the southern flank of the Sangre de Cristo Mts., granitic deposits containing preserved constructional deposit tops have only weakly developed soils, commonly exhibiting Stage I to II carbonate morphology. These deposits are nearly indistinguishable from the underlying Ancha Fm and are not differentiated on maps. This weak soil development suggests that deposition of the Ancha Fm deposition continued into the middle Pleistocene along parts of the front of the southern Sangre de Cristo Mts., especially near Seton Village, New Mexico. Similar soil-geomorphic relationships are recognized in the Tuerto Fm along the flanks of the Ortiz Mts.

These three units are relatively thin, unconformably overlie older rocks with distinct angularity, and are recognized along the rift margin where they are associated with mountainous drainages. These deposits locally contain an unmapped, well cemented lower member that is overlain by poorly exposed, weakly cemented upper members that contain remnants of soils exhibiting Stage II to III+ carbonate morphology. The well cemented units contain abundance fine- to medium-grained sparry calcite, suggesting prolonged saturation of these deposits by groundwater. Younger inset alluvial and fluvial deposits typically do not contain such well cemented intervals, presumably because they were deposited during long-term dissection of tributary drainages. These deposits would constitute members of a formation, however, they all contain locally differentiable sub-units, thus rendering a member rank for these units problematic. These units comprise a group of relatively thin strata associated with faulted basin-margin flanks that record a slightly different geologic history compared to nearly continuous deposition within sub-basin depocenters.

North of NM-22, the Tuerto Fm is cut by the La Bajada fault, however, displacements significantly decrease to the south and probably bury the southern tip of the La Bajada fault..

End of Stop 2. Turn vehicles around and retrace steps to dirt road. **2.0**

45.9 Bear right. **0.4**

46.3 At intersection, go straight. **0.4**

46.7 Take a sharp left. **0.5**

47.2 Gravel on top of ridge may be remnants of Tuerto Fm. **0.6**

47.8 Pass through cattle gate. Keep right. Metal pole near road to your left is the Marion Oil Co. Blackshare No. 2 oil test well, which ended in the Morrison Fm at 2079 m (6820 ft) below land surface. **0.8**

48.6 Bear right. **0.1**

48.7 Merge right. **0.6**

49.3 Pass through cattle gate. Turn left onto dirt road (NM-22). To your right is the La Bajada fault capped by Pliocene basalts of the Cerros del Rio volcanic field. To the north are the Cerrillos Hills. **2.0**

51.3 Descend northeast-trending scarp of Budagher fault, which has down-to-the-northwest normal movement. The Budagher fault is mapped between the San Francisco and La Bajada faults and probably represents a hard-linked relay fault between these rift-border structures. **1.6**

52.9 Left onto I-25 southbound onramp. **1.6**

54.5 East tilted mudstone and sandstone of Sierra Ladrones Fm piedmont deposits on your left. **0.5**

55.0 Driving over approximate location of trace of the San Francisco fault, which is buried here by Quaternary sediments. **2.6**

57.6 Gray sands at the bottom of arroyo face contain Bandelier Tuff. White beds along I-25 are correlated to a 1.57 Ma ash of one of the Cerro Toledo events (*see notes for mileage 30.5*). **0.9**

58.5 Cuestas at 9:00 are Dakota Sandstone. Underlying white deposits are Todilto Fm gypsum beds exposed at a quarry. **0.5**

59.0 White ash of 1.57 Ma Cerro Toledo Rhyolite at 10:00 (*see notes for mileage 30.5*). **0.5**

59.5 Tonque Arroyo overpass. To the right, the eastern edge of the upper Pliocene basalts at Santa Ana Mesa are interbedded with ancestral Rio Grande deposits of the Sierra Ladrones Fm. **1.2**

60.7 To your left are brownish-yellow stained fluvial Sierra Ladrones deposits. This zone of staining is along a north-trending zone that is the northern extension of a north-trending fault mapped to the south. **1.5**

62.2 This stretch of the highway contains a number of irregular dips associated with hydrocollapsible soils of latest Pleistocene-Holocene valley border fan deposits derived from sandy deposits of the upper Santa Fe Group to the east. **5.8**

68.0 Water tanks to the left sit on a middle Pleistocene piedmont gravel that unconformably overlies reddish-brown sandstone of the Loma Barbon Mbr of the Arroyo Ojito Fm. Assignment of these reddish-brown sediments to the Arroyo Ojito Fm is ambiguous, primarily because of the paucity of gravel. This assignment is made primarily based on comparisons to similar strata exposed west of the Rio Grande valley. **1.5**

69.5 Bear right and leave I-25 at Placitas and Bernalillo offramp (exit 242). **0.2**

69.7 Turn left at the stop sign at the top of the offramp. **0.7**

70.4 Ascend hill and travel on middle Pleistocene piedmont deposits derived from the northern Sandia Mts. **0.9**

71.3 The arroyo to the left, beyond house in floodplain, exposes rounded quartzite and brown, cliff-forming sandstone and conglomerate of the ancestral Rio Grande and piedmont deposits, respectively, of the Sierra Ladrones Fm. Piedmont deposits contain limestone, granite, and sandstone derived from the Sandia Mountains. To the east and stratigraphically above this fluvial gravel in the arroyo are lenses of ancestral Rio Grande deposits containing fluvially recycled pumice cobbles (not visible from road). One of these cobbles has been dated at 1.61±0.02 Ma (Connell et al., 1995) and is temporally correlative to the lower Bandelier Tuff, which was derived from the Jemez Mts. **0.8**

72.1 Homestead Village strip mall to your left. Between 10:00 and 12:00 the northwest-trending escarpment marks the Valley View fault, which terminates to the south near the Rincon fault (Connell et al., 1998). Within the next mile is the eastern projection of ancestral Rio Grande facies of the Sierra Ladrones Fm, which is overlain by piedmont deposits here. **0.5**

72.6 Rincon ridge is your right. **0.3**

72.9 Milepost 3. Hills in the foreground are post-Santa Fe Group middle Pleistocene gravels that overlie stream-flow dominated piedmont sandstone and conglomerate of the Sierra Ladrones Fm. **0.5**

73.4 Las Placitas site marker. Low angle fault is part of Ranchos fault zone, which juxtaposes Santa Fe Group deposits against Cretaceous sandstone, shale, and coal. You have just crossed the border of the rift and are on the northern flank of the Sandia Mts. **1.3**

74.7 Pass intersection with Puesta del Sol Rd. **0.1**

74.8 Turn right onto Tunnel Springs Rd. and begin to ascend the Las Huertas surface. Deposits underlying this constructional piedmont surface unconformably overlie older tilted rocks and are inset against undivided lower Santa Fe Group piedmont conglomerate and sandstone. The basal contact of these deposits has a slightly unconformable relationship with underlying upper Santa Fe Group beds of the piedmont facies of the Sierra Ladrones Fm to the north, across the Escala fault; however, these deposits are conformable further into the basin. This relationship suggests that the La Huertas geomorphic surface marks a local top of the upper Santa Fe Group on the hanging wall of the Escala fault (Connell and Wells, 1999). **0.2**

75.0 Intersection with Quail Meadow Rd. Tunnel Springs is visible at 11:00. It is the area that is marked by dense cottonwood vegetation, which contrasts with the surrounding Piñon-Juniper woodland. **1.3**

76.3 **STOP 3:** Tunnel Springs. *Placitas 7.5' quadrangle, GPS: NAD 83, UTM Zone 013 S, N: 3,906,400 m; E: 369,080 m.*

This is an overview stop of some stunning views of the northern flank of the Sandia Mts. and northern Albuquerque basin. Tunnel Springs emanates from the Placitas fault zone.

The purposes of this stop are to: 1) discuss the stratigraphy of the lower Santa Fe Group strata exposed in the Placitas area; 2) discuss the tectonic development of the northern flank of the Sandia Mts. and Santo Domingo sub-basin; and 3) discuss previous models of development of the basin, including the existence of the postulated Rio Grande fault.

The northern flank of the Sandia Mts. is a north-plunging structural ramp created by a 6.5-km wide eastward step in the rift-bounding Rincon and San Francisco faults. A complicated zone of steep faults called the Placitas fault zone accommodates this step. The origin of this step has created much controversy. Kelley (1977, 1982) considered this feature to be a relay ramp associated with left-oblique movement along the San Francisco and Rincon faults; however, there is no strong evidence for transpression in this step over, which would be the likely result of a right step on a left-oblique fault system. Karlstrom et al. (1999), proposed that the Placitas fault zone represented an older, steeply dipping, northeast-trending strike-slip fault of Laramide age that was reactivated during the Neogene. Paleomagnetic studies of a single 30.9 Ma mafic dike in the Placitas area (Connell et al., 1995) indicates that much of the deformation post-dates emplacement of the dike (Lundahl and Geissman, 1999). It is likely that the northern Sandia Mts. represents a breached relay ramp or transfer zone that formed during development of the Rincon and San Francisco faults.

The Santa Fe Group in the Placitas area contains a record of early unroofing of the Sandia Mts. Along Overlook Rd. on the southern flank of Lomos Altos, the Santa Fe Group is well cemented with sparry calcite and rests with angular unconformity on Cretaceous sandstone and shale. This section is conglomeratic. The base contains abundant Permian sandstone and minor limestone, most likely derived from the Glorieta and San Andres fms. Upsection the gravel is predominantly reddish-brown sandstone of the Abo Fm. Near the top of the exposed section, gravel is predominantly limestone and cherty limestone derived from the Pennsylvanian Madera Fm. At the southern tip of the Cuchilla de Escala, the composition of the Santa Fe Group gravel contains abundant rounded cobbles and pebbles of porphyryitic intrusive rocks derived from the Ortiz Mts. This gives way upsection to a mixture of sandstone, limestone and Ortiz-derived rocks.

The juxtaposition of these differing source areas indicates that during early development of the rift, sediment was being derived from both an emerging Sandia Mts., and a degrading (eroding) Ortiz Mts. The location of Ortiz-derived gravel also indicates that the Cuchilla de San Francisco had not been uplifted enough to affect the composition of the gravel, at least not initially.

Another interesting unroofing sequence was recognized in the post-Santa Fe Group inset stratigraphy, where the topographically highest inset gravels are composed almost exclusively of limestone. On progressively inset deposits, the composition becomes more heterolithic, and granite and metamorphic rocks become more common in the late Pleistocene and Holocene deposits associated with the modern valley floors that head into the northern flank of the Sandia Mts. This Plio-Pleistocene unroofing sequence is recorded in a deeply dissected geomorphic region, or domain, that is structurally defined by the Ranchos, Lomos, Escala and Placitas faults (Connell and Wells, 1999). This geomorphic domain records progressive dissection along the northern flank of the Sandia Mts. that occurred in response to migration of the locus of faulting from the Placitas and southern San Francisco faults basinward to the Lomos, Escala, and Valley View faults, which probably started during late Pliocene time, prior to deposition of the gravel of Lomos Altos.

The Placitas area was interpreted to represent the surface expression of major listric faults that define the eastern basin margin. Woodward (1977) first proposed listric geometries for faults of the basin. These are recognized on seismic data (deVoogd et al., 1988; Russell and Snelson, 1994) and are suggested by increasing tilts of basin-margin fault blocks. This listric geometry is expressed on seismic profiles along the southern margin of the basin. Russell and Snelson (1994) propose that the Albuquerque Basin narrowed significantly between the late Miocene and Pliocene and that the range-bounding master faults of the Sandia Mts. were cut by a younger intrabasinal listric-normal fault having up to about 6 km of displacement of Cenozoic strata. They proposed that offset along this major intrabasinal structure, which they named the Rio Grande fault, began when the range-front master fault migrated basinward about 15-20 km to the west.

Significant displacement of Cenozoic strata is recognized in seismic-reflection lines and deep oil-test data near Isleta Pueblo (Russell and Snelson, 1994; May and Russell, 1994). Subsurface studies in the Albuquerque area indicate that much of the Santa Fe Group strata thicken and tilt to the northeast (Connell et al., 1998a) and are not displaced across the projected trace of the Rio Grande fault of Russell and Snelson (1994). Geomorphic and stratigraphic studies along the northern flank do not support the presence of such a young and large magnitude structure (Connell and Wells, 1999). Late Quaternary movement of range-bounding faults of the Sandia Mts. indicates that faults along the eastern structural margin of the Calabacillas sub-basin were active during Pleistocene time, at least locally (Connell, 1996).

Gravity data indicates that the basin-margin is marked by a 2-3 km wide zone of normal faults that extend about 3-6 km west of the front of the Sandia Mts. (Cordell, 1979; Grauch et al., 1999; Connell et al., 1998a). The gravity data also suggest that Russell and Snelson's Rio Grande fault may be correlative with an older northwest-trending feature, rather than a younger north-trending fault (Maldonado et al., 1999). This northwest-trending zone is called the Mountainview fault to avoid confusion with Russell and Snelson's postulated Rio Grande fault. The Mountainview fault coincides with a northwest-trending gravity ridge (Grauch et al., 1999, *this volume*) and likely marks the part of the structural boundary between the Calabacillas and Belen sub-basins (Maldonado et al., 1999). Thus, the low-angle fault shown described by Russell and Snelson (1994) may the result of apparent dip of the northwest trending Mountainview fault, rather than a true dip of a low-angle fault.

The projected trace of the Rio Grande fault is buried by Plio-Pleistocene sediments and is west of a prominent inflection in the isostatic gravity field (Cordell, 1979; Grauch et al. 1999). Geomorphic and stratigraphic evidence (Connell and Wells, 1999; Connell et al., 1998a) also indicate that the Rio Grande fault is not a young intrabasinal normal fault. Basin narrowing is recognized throughout the basin (Russell and Snelson, 1994), but is commonly restricted to prominent steps or re-entrants in the basin margin (Connell and Wells, 1999; Connell, 1996). At the northern flank of the Sandia Mts. is an excellent example of such a step-over fault. The Placitas fault zone accommodates slip across the Rincon and San Francisco faults, and forms an east-stepping ramp (Connell and Wells, 1999; Connell et al., 1995). Using the down-plunge method of cross section construction, several workers (Woodward and Menne; 1995; Russell and Snelson; 1994; May et al., 1994) suggested that the trace of the Placitas fault zone (northern structural boundary of the Sandia Mts.) is curved in map view. They interpreted apparent curvature as indicative of a listric fault plane at depth; however, the trace of the Placitas fault zone is rather straight (Connell et al., 1995), suggesting a steep dip. Furthermore, the down-plunge method may have been misapplied, principally because the southward direction of projection is nearly perpendicular to the Placitas fault zone. Instead, the Placitas fault zone probably acts as a transfer zone between the frontal faults of the Sandia Mts. and the San Francisco fault (Karlstrom et al., 1999).

In summary, the Rio Grande fault concept of Russell and Snelson (1994) is not supported for the following reasons:

1) Geomorphic evidence does not support the presence of a long, discrete intrabasinal fault having a large magnitude of post-Miocene displacement (Connell and Wells, 1999);
2) Regional geophysical surveys (principally isostatic residual gravity, and aeromagenetic surveys) do not support the presence of a north-trending intrabasinal fault zone (Grauch et al., 1999; Grauch, 1999);
3) Studies of borehole geophysics and cuttings from numerous wells in the Albuquerque area identify marker units that are not displaced across the projected trace of the Rio Grande fault (Connell et al., 1998a); and
4) Stratigraphic data are inconsistent with the development of this structure (Connell and Wells, 1999; Maldonado et al., 1999).

End of Stop 3. Retrace route to NM-165. **1.4**

77.7 Turn left at stop sign onto NM-165. **2.2**

79.9 At 3:00 in the hills covered by numerous houses on the footwall of the Valley View fault, notice interfingering of light-gray sand of the ancestral Rio Grande sands and light-brown piedmont deposits. You are near the eastern limit of the ancestral Rio Grande, as projected onto NM-165 (Connell et al., 1995). **2.6**

82.5 Turn right on north frontage road. **0.2**

82.7 Reddish-brown sandstone of the Loma Barbon Mbr unconformably overlain by Edith Fm. **0.2**

82.9 Turn right onto Yearsley Ave. Note the road cut on the adjacent road to the north (La Mesa Rd). Here red east-tilted Loma Barbon deposits are interbedded with gray Rio Grande sand and unconformably overlain by quartzite gravels of the Edith Fm. **0.3**

83.2 Normal fault with down-to-the-east movement to your left. **0.4**

83.6 **STOP 4:** LaFarge gravel pit operation. *Bernalillo 7.5' quadrangle, GPS: NAD 83, UTM Zone 013 S, N: 3,910,800 m, 362,837 m.*

Deposits of the ancestral Rio Grande and interfingering piedmont deposits derived from the northern Sandia Mts. (upper Santa Fe Group). The purposes of this stop are to: 1) examine ancestral Rio Grande and piedmont members (or facies) of the Sierra Ladrones Fm; 2) discuss ongoing studies of deposit provenance and lithologic differentiation of the Sierra Ladrones and Arroyo Ojito fms in the northern Albuquerque Basin; and 3) discuss evidence of continuous aggradation of upper Santa Fe Group deposits through late Pliocene-early Pleistocene time.

At this stop we will examine exposures of Plio-Pleistocene fluvial deposits of the ancestral Rio Grande system and interfingering piedmont deposits. Ancestral Rio Grande deposits are gravelly with scattered rip-up clasts of mudstone (Fig. 1-8). The ancestral Rio Grande fluvial system is documented to be at least 6.9 Ma, based on the presence of quartzite-bearing fluvial conglomeratic sandstone that was affected by the emplacement of the late Miocene Peralta Tuff, near Tent Rocks and Cochiti, New Mexico (Smith and Kuhle, 1998; Smith et al., 2001). Between Bernalillo and Tonque Arroyo, three facies tracts can be seen: the western fluvial facies of the Arroyo Ojito Fm (Connell et al., 1999); the central axial-river facies of the ancestral Rio Grande, and streamflow-dominated piedmont deposits derived from rift-margin uplifts, such as the Sandia Mts. Geologic mapping indicates that the ancestral Rio Grande member of the Sierra Ladrones Fm interfingers with the piedmont member.

Figure 1-8. Photograph of ancestral Rio Grande gravels in the La Farge gravel pit at Placitas (Bernalillo quadrangle). Note the mudstone rip-up clasts. The upper part of the outcrop is dumped fill from quarry operations.

These major, mappable lithofacies assemblages in the SE Santo Domingo and Calabacillas sub-basins are the: western-margin facies, central ancestral Rio Grande facies, and the eastern-margin piedmont facies. The western margin facies is the Arroyo Ojito Fm, which represents the fluvial facies of the ancestral Rio Puerco, Rio Jemez/Guadalupe, and Rio San Jose. Sediments were probably derived from the Sierra Nacimiento, San Juan Basin, and Colorado Plateau to the west and northwest of the Albuquerque basin. The ancestral Rio Grande lithofacies is part of the Sierra Ladrones Fm and represents deposits of the through-flowing axial-river system of the Rio Grande. The eastern piedmont facies is part of the Sierra Ladrones Fm and contains detritus shed from rift-flanking uplifts, such as the Sandia Mountains.

Large and Ingersoll (1997), in a study of sand petrography in the northern part of the Albuquerque Basin, concluded that deposits of the Santa Fe Group were not petrographically differentiable. A current study of gravel and sand composition (Derrick and Connell, 2001) indicates that these mapped facies are indeed differentiable, as discussed below.

Preliminary results of point counts of pebbles and cobbles in the northern Albuquerque Basin (Fig. 1-9) indicate that the Arroyo Ojito Fm contains abundant volcanic tuffs and fine- to medium-grained red granites with lesser amounts of Pedernal chert, basalt, sandstone, and white quartzite. The ancestral Rio Grande member of the Sierra Ladrones Fm commonly contains rounded, bedded quartzites of various colors and diverse volcanic and intrusive rocks, including tan and gray tuffs, diabase, and granite. Sedimentary rocks are rare. The eastern piedmont deposits contain abundant limestone, sandstone, coarse-grained pink granite, and sparse igneous rocks.

Sand composition from point counts of 400 grains per sample show that these mapped facies are not as easily differentiable as the gravel counterparts. The sand is quartz rich (46-85% quartz) and facies exhibit considerable compositional overlap when plotted using the modified Gazzi-Dickinson method. Compositional trends are observed when proportions of chert, granite, and volcanic grains are compared (Fig. 1-10).

There is a stronger correlation among the lithofacies using gravel. Possible explanations for this correlation include the shorter transport distance of gravel from the source area, similar source areas for the ancestral Rio Puerco and the ancestral Rio Grande, or greater sediment recycling and transport of the finer-grained sand fraction.

Near this stop, a series of stratigraphic sections were measured on San Felipe Pueblo that document the interaction of these facies from late Pliocene through early Pleistocene time. In the Santo Domingo sub-basin, the Santa Fe Group experienced continuous deposition prior to 2.2 Ma to younger than 1.6 Ma. Deposition of the system ceased as the Rio Grande began to incise into the basin fill. A fluvial terrace deposit containing the middle Pleistocene Lava Creek B ash is inset against the basin fill, indicating that incision was underway prior to *ca*. 0.66 Ma.

Paleocurrent data measured from gravel imbrications, channel orientations, and cross beds for deposits in the southeastern Santo Domingo sub-basin and Calabacillas sub-basin (Cather and Connell, 1998; Cather et al., 1997, 2000; Connell, 1998; Connell et al., 1995, 1998, 1999; Derrick, unpubl. data) indicate that coarse-grained sediments of the Arroyo Ojito Fm flowed to the S-SE (Fig. 1-11a), ancestral Rio Grande deposits of the Sierra Ladrones Fm flowed to the S-SW (Fig. 1-11b), and eastern-margin piedmont deposits of the Sierra Ladrones Fm flowed to the west (Fig. 1-11c, d).

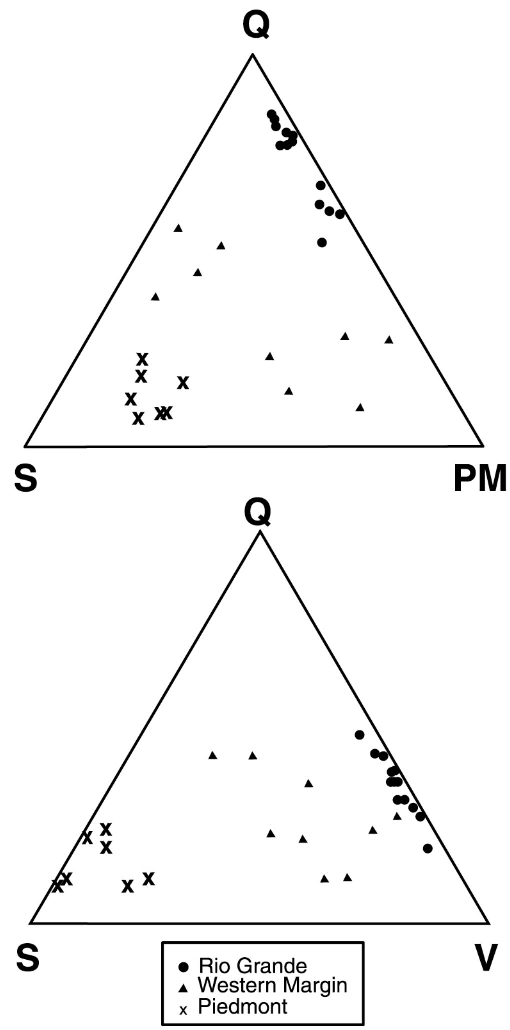

Figure 1-9. Preliminary gravel petrography from selected localities in the SE Santo Domingo sub-basin and Calabacillas sub-basin (N. Derrick, unpubl. data). Rio Grande and piedmont samples are from the Sierra Ladrones Fm; western margin denotes samples from the Arroyo Ojito Fm. Abbreviations include quartz, quartzite, and chert (Q), sedimentary (S), volcanics (V), and plutonic-metamorphic (PM) gravels.

End of Stop 4. Retrace route to frontage road at entrance to gravel pit. **0.7**

84.3 At stop sign turn to your left, getting back out onto the frontage road heading south. **1.4**

85.7 At the intersection of the frontage road and NM-165, go straight, remaining on the frontage road heading south. **0.3**

86.0 Light-brown middle Pleistocene sand and gravel overlie rounded quartzite-dominated gravel of the Edith Fm. **0.2**

86.2 Entrance gate to reclaimed aggregate mine. Must get permission from owner to enter. Turn left. **0.3**

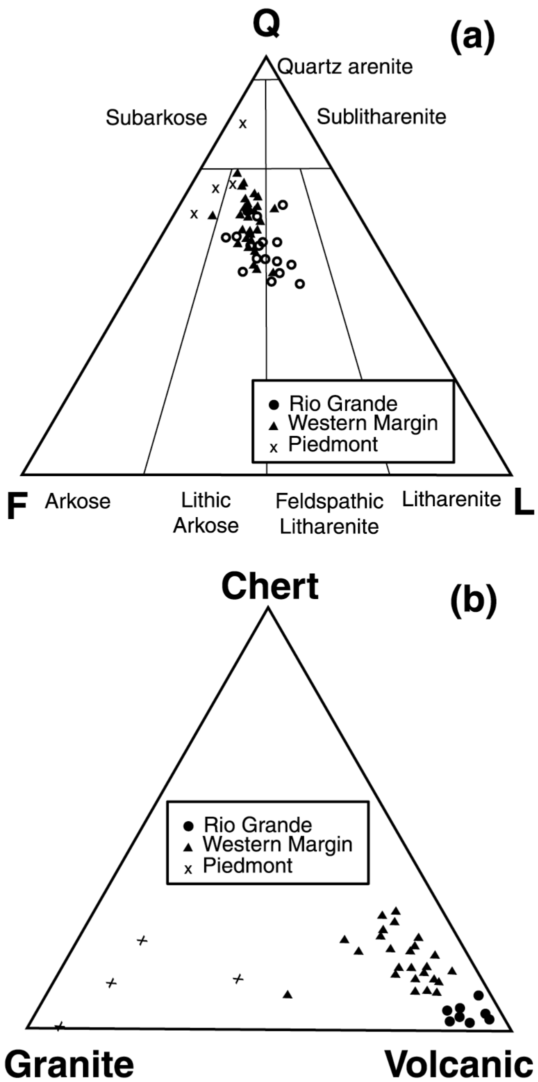

Figure 1-10. Preliminary sand petrography from selected localities in the SE Santo Domingo sub-basin and Calabacillas sub-basin (N. Derrick, unpubl. data). See Figure 1-9 for description of sample symbols. Plot of sand using modified Gazzi-Dickinson method (a); plot of major sand constituents (b).

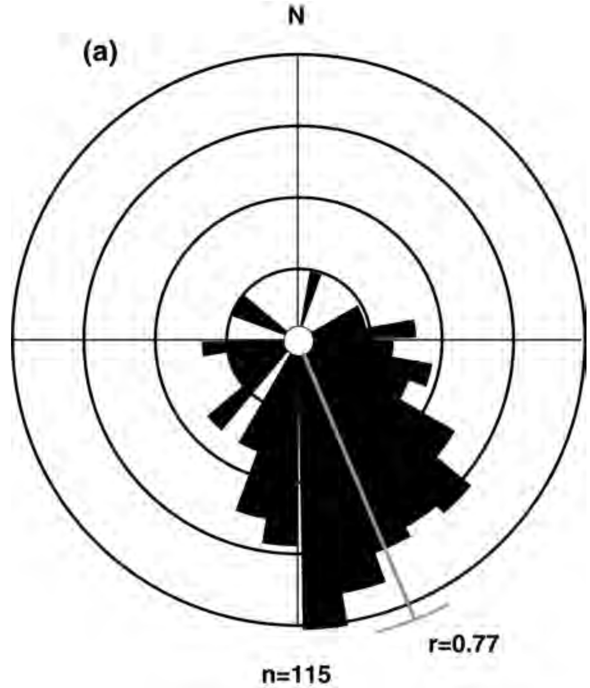

Figure 1-11a. Paleocurrent rose for Arroyo Ojito Fm (western margin) deposits (at 10° intervals), including correlation coefficient (r). Data from Cather et al. (1997), Connell et al. (1999), Koning (unpubl.), and Derrick (unpubl.).

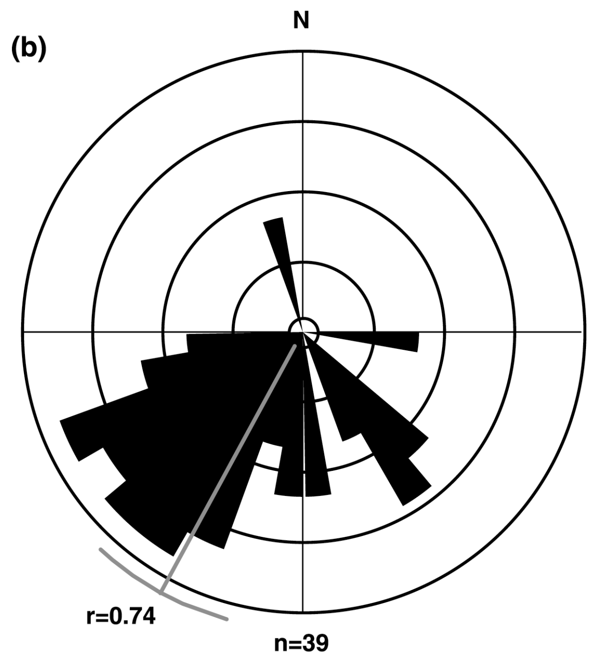

Figure 1-11b. Paleocurrent rose for ancestral Rio Grande deposits (at 10° intervals), including correlation coefficient (r). Data from Cather and Connell (1998), Cather et al. (2000), Connell (1998), Connell et al. (1995), and Derrick (unpubl.).

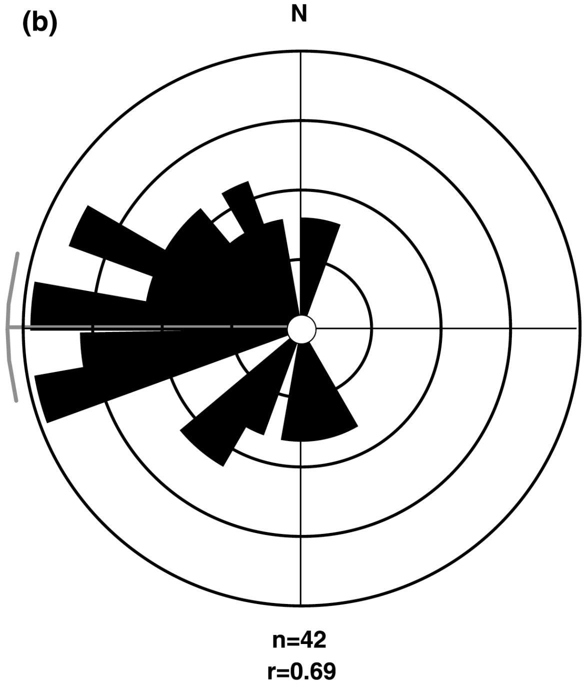

Figure 1-11c. Paleocurrent rose for younger eastern-margin piedmont deposits (Sierra Ladrones Fm, at 10° intervals), including correlation coefficient (r). Data from Cather and Connell (1998), Connell et al. (1995), and Derrick (unpubl.).

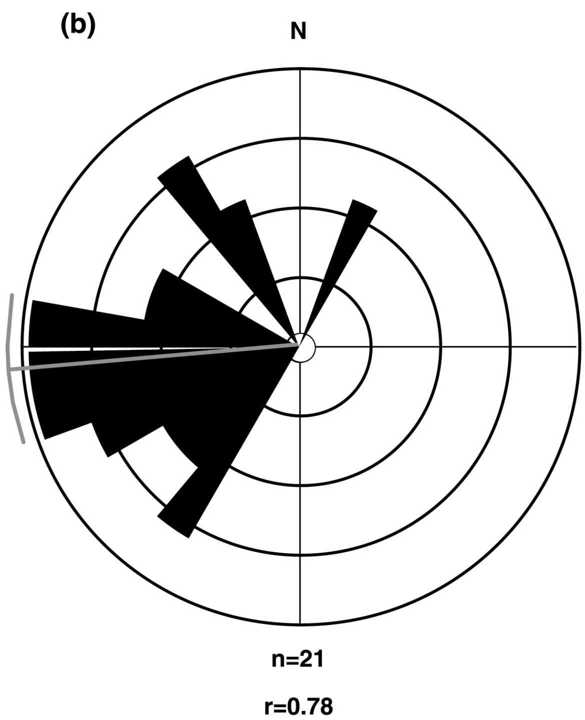

Figure 1-11d. Paleocurrent rose for older eastern-margin piedmont deposits (Santa Fe Group, at 10° intervals), including correlation coefficient (r). Data from Connell et al. (1995).

86.5 **STOP 5:** *Bernalillo 7.5' quadrangle, GPS: NAD 83, UTM Zone 013 S, N: 3,908,060 m; E: 360,720 m.*

Inset stratigraphic relationships between aggradation of the Santa Fe Group and post-Santa Fe Group entrenchment (*see mini paper by Connell and Love, this volume*), including a buttress unconformity between the Edith Fm and piedmont deposits, with the Sierra Ladrones Fm. We will hike eastward, up an unnamed arroyo to examine the inset stratigraphic relationship of a middle Pleistocene fluvial deposit of the ancestral Rio Grande called the Edith Fm. The purposes of this stop are to: 1) examine the Edith Fm and its basal strath with underlying upper Santa Fe Group strata; 2) examine a buttress unconformity between the Edith Fm and the Santa Fe Group; and 3) discuss the timing of entrenchment of the basin fill and development of the Rio Grande Valley.

The gravel quarry is surface mining the quartzite-bearing cobble and pebble gravel of the base of the Edith Fm. This coarse gravel commonly lies on fluvial deposits of the Sierra Ladrones Fm or Arroyo Ojito Fm with slight angularity. The gravel fines up into sand, which commonly forms an upward fining sequence with a locally preserved weakly developed soil. The Edith Fm is overlain by middle to late Pleistocene gravel and sand derived from the Sandia Mts. As we travel upstream, the Edith Fm is buried. About 1 km to the east is a buried paleobluff cut by the Edith Fm. The piedmont deposits formed a valley border fan that eventually buried this bluff. The rounded gravels in the tilted Santa Fe Group are thin beds of ancestral Rio Grande deposits, which extend ~2.4 km to the east, where it occupied a proximal position to the mountain front until early Pleistocene time.

Retrace route back to NM-165. End of first-day road log.

GEOLOGICAL SOCIETY OF AMERICA, ROCKY MOUNTAIN-SOUTH CENTRAL SECTION MEETING, ALBUQUERQUE, NEW MEXICO

PRE-MEETING FIELD TRIP: STRATIGRAPHY AND TECTONIC DEVELOPMENT OF THE ALBUQUERQUE BASIN, CENTRAL Rio Grande RIFT

SECOND-DAY ROAD LOG, APRIL 28, 2001
CALABACILLAS SUB-BASIN: ZIA PUEBLO, RIO RANCHO, AND TIJERAS ARROYO

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The following road log through parts of the Calabacillas sub-basin (Figs. 2-1, 2-2) has been summarized from New Mexico Geological Society Guidebook 50 (Pazzaglia et al., 1999a) and from Hawley and Galusha (1978). Road-log mileage not checked for accuracy.

Mileage	**Description**
	Start, parking lot of Sheraton Hotel. Road log follows Day 1 log to Bernalillo.
0.0	Leave I-25 at exit 242 to US-550 and NM-165.
0.3	Turn left at stop light and proceed towards Bernalillo. **0.3**
0.6	Railroad crossing cut into alluvial fan that overlies valley-floor alluvium of the Rio Grande valley, which are ~25 m thick (Connell, 1998). **0.3**
0.9	Intersection with Camino del Pueblo. **0.7**
1.6	East bank of the Rio Grande. Cross the Rio Grande and riparian bosque in the floodplain. Gravel along the west bank of the Rio Grande, overlying reddish-brown sandstone and mudstone of the Arroyo Ojito Fm, are correlated to the Los Duranes Fm (Connell, 1998). **0.7**
2.3	Santa Ana Casino on your right. Road to Jemez Canyon Dam to your right. Ascend terrace riser between Los Duranes and Lomatas Negras fms. The Lomatas Negras Fm is a high-level terrace gravel approximately 70-80 m above the Rio Grande (Connell, 1998). The geomorphic term tercero alto is an informal term applied by Machette (1985) to these gravels. Connell and Love (2000; *and this volume*) suggested the Lomatas Negras Fm as a lithologic (rather than geomorphic) term for these deposits, which are inset against the constructional basin-floor surface of the Llano de Albuquerque (Machette, 1985) represents an abandoned constructional surface that marks the highest level of basin aggradation in the Santa Fe Group west of the Rio Grande, and represents a local top of the Santa Fe Group.

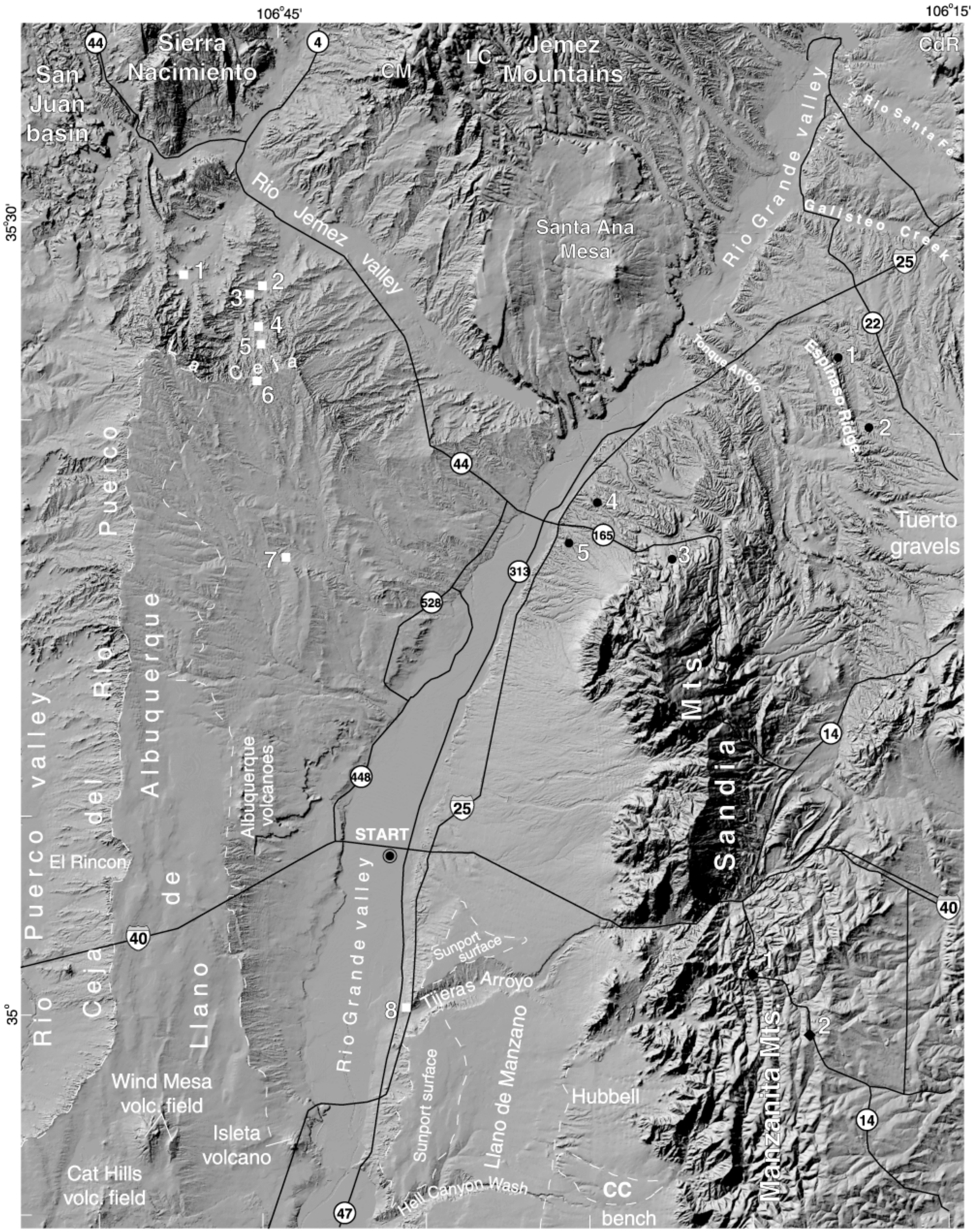

Figure 2-1. Shaded-relief map of the Albuquerque area, illustrating the locations of stops for day 1 (black circles), and day 2 (white squares). Base prepared by S.D. Connell for Pazzaglia et al. (1999b).

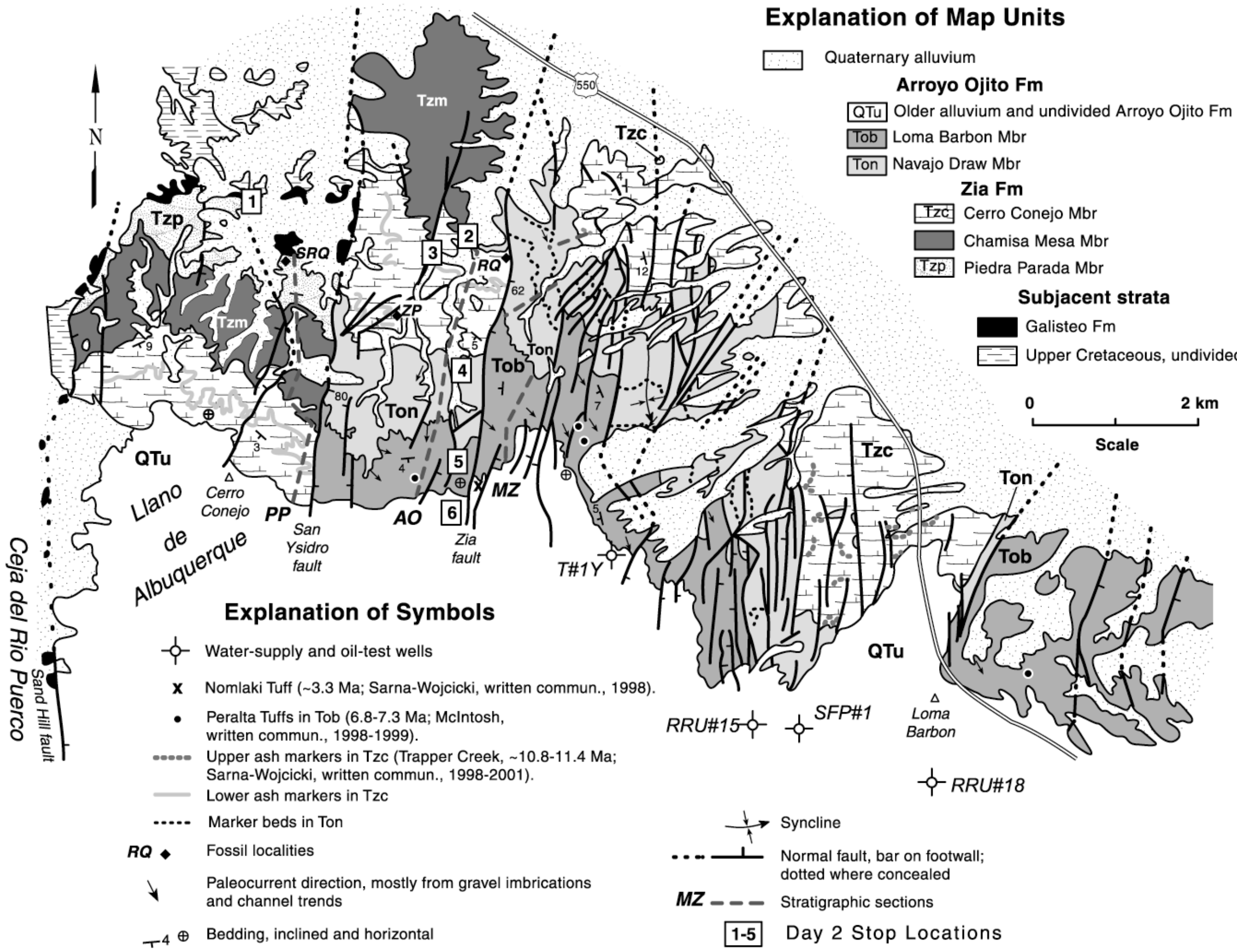

Figure 2-2. Simplified geologic map of the NW margin of the Calabacillas sub-basin, illustrating the approximate location of stops 1-6.

To the south, correlative deposits contain the middle Pleistocene Lava Creek B ash (*ca*. 0.66 Ma; N. Dunbar, 2000, written commun., A. Sarna-Wojciki, 2001, written commun.). The maximum vertical extent of incision by the Rio Grande during the Pleistocene is approximately 100-200 m. **0.3**

2.6 Intersection with NM-528. **0.5**

3.1 Milepost 3. Ascend terrace riser between Los Duranes and Lomatas Negras fms. **1.0**

4.1 Milepost 4. **0.4**

4.5 Loma Barbon Mbr offset down-to-the-east by the Luce fault of Kelley (1977) in road cut to your right. **2.1**

6.6 Badlands at 9:00 expose the Loma Barbon Mbr of the Arroyo Ojito Fm, which are capped by conglomeratic sand of the Ceja Mbr of the Arroyo Ojito Fm beneath the Llano de Albuquerque. Loma Barbon is low hill between 9-10:00. A volcanic ash exposed on a ridge less than 2 km to the northeast yields a $^{40}Ar/^{39}Ar$ date (on sanidine) of 6.82±0.04 Ma (Connell, 1998) and is geochemically correlative to the Peralta Tuff Mbr of the Bearhead Rhyolite, exposed at Tent Rocks and Peralta Canyon in the western Santo Domingo sub-basin (N. Dunbar, oral commun., 2001). A number of lapilli and ash fall deposits in similar stratigraphic positions are exposed along the southern margin of the Rio Jemez valley. These tephra are dated between 6.8-7.4 Ma (W.C. McIntosh, 1998-2000, written commun.). Similar-aged fall deposits have not been recognized to the south in the Arroyo Ojito Fm, suggesting that these exposures may be near the southern limit of fallout from the Bearhead vents. **0.5**

7.1 Milepost 7. Sierra Nacimiento at 11:00 and the eastern flank of the Ziana structure between 9:00 and 10:00. The Ziana structure is interpreted to be a horst by Personius et al. (2000, see cross section), or an anticlinal accommodation zone (Stewart et al., 1998) that marks the boundary between the Calabacillas and Santo Domingo sub-basins. The southern flank of the Jemez Mts at 1:00-3:00. An angular unconformity between Quaternary alluvial deposits and dipping sediments of the Arroyo Ojito and Zia fms are visible. **0.5**

7.6 Santa Ana Pueblo reservation boundary. Volcanic rocks and Santa Fe Group sediments are exposed at the southern flank of the Jemez Mts between 1-3:00. From left to right is Chamisa Mesa, capped by the 10.4±0.5 Ma basalt at Chamisa Mesa (K/Ar date in Luedke and Smith, 1978). The Chamisa Mesa basalt (Paliza Cyn Fm) overlies the Cerro Conejo and Chamisa Mesa Mbrs of the Zia Fm. Other late Miocene basaltic features of the Paliza Cyn Fm include Borrego Mesa, Pico Butte, and Bodega Butte. **1.1**

8.7 White bed to your left is an ash correlated to one of the Trapper Creek tephra. **0.4**

9.1 Cross valley incised into the Cerro Conejo Mbr with at least two prominent white ashes exposed between 9:00 and 10:00. The thicker ash bed has been geochemically correlated (A. Sarna-Wojcicki, written commun., 1999, 2001) to Snake River Plain/Yellowstone tephra from the Trapper Creek section of southern Idaho. Age estimate of the best match is 11.2±0.1 Ma and a weaker match to a higher tephra in the same section was correlated to tephra dated at 10.94±0.03 Ma by Perkins et al. (1998). The ~11 Ma age of this ash agrees well with the presence of the Clarendonian canid *Epicyon*, which was obtained near here (Lucas and Morgan, this volume; R.H. Tedford, 1999, oral commun.). **0.8**

9.9 To your right, note outcrop of ledgy, cemented sandstone beds in the Cerro Conejo Mbr of the Zia Fm with oriented concretions (see Mozley and Davis, 1996; Beckner and Mozley, 1998). **1.2**

11.1 Milepost 11. **2.2**

13.3 Zia Pueblo reservation boundary. **2.2**

17.9 Entrance to Zia Pueblo at 3:00. The Pueblo sits atop a middle Pleistocene terrace tread (Qt4 of Formento-Trigilio and Pazzaglia, 1998) north of the Rio Jemez. The western flank of the Rio Grande rift, eastern margin of the Colorado Plateau, and southern tip of the southern Rocky Mts. are between 11:00 and 3:00. The high peak at 2:00 is Pajarito Peak of the Sierra Nacimiento. Rio Jemez valley incised through an ignimbrite sheet of the upper Bandelier Tuff (*ca*. 1.2 Ma) and Permian sandstone at 3:00. The white cliffs between 12:00 and 1:00 are underlain by gypsum of the Todilto Fm, which is being quarried here. **1.0**

18.9 Low hills to left are underlain by Chamisa Mesa Mbr of Zia Fm. **1.1**

20.0 Approaching western boundary of the rift. Jurassic and Cretaceous rocks ahead. Jemez valley at 3:00. **1.0**

21.0 Turn left onto Cabezon Rd. and stay straight, passing onto Zia Pueblo land. The following stop is on Zia Pueblo land. **You must obtain permission to travel on Zia tribal lands from the Pueblo administration**. **1.1**

21.1 Bear right, stay on Cabezon Rd. Traveling on pre-rift rocks of the Colorado Plateau and San Juan Basin. Road traverses Jurassic strata of the Summerville and Todilto Fms to your right, and Brushy Basin Mbr of the Morrison Fm to your left. Cross north-striking, down-to-the-east San Ysidro fault (Woodward and Ruetschilling, 1976). To the north, it places Precambrian rocks against Neogene basin fill. To the south, it places Zia Fm against the Arroyo Ojito Fm. This fault shows evidence of Pliocene and possible early Quaternary displacement exposed along La Ceja, the southern margin of the Rio Puerco valley and northern limit of the Llano de Albuquerque. **1.4**

22.5 Pass narrows through the Salt Wash Mbr of the Morrison Fm **1.5**

24.0 Turn left on unmarked dirt road. **0.9**

24.9 Gray cliffs on your left are Piedra Parada Mbr deposits of the Zia Fm overlying the Galisteo (Eocene) and Menefee (Cretaceous) fms. On your right is Cretaceous Mancos Shale. **1.1**

26.0 Bear right. **0.5**

26.5 Pull off road into field and park. Hike up hill to outcrop. **STOP 1. The Zia Fm and base of syn-rift sediments.** *Cerro Conejo (formerly Sky Village NE) 7.5' quadrangle, GPS: NAD 83, UTM Zone 013 S, N: 3,926,640 m; E: 334,515 m.*

The purpose of this stop is to observe the contact between pre- and syn-rift rocks and discuss the sedimentology, paleo-environmental, and structural setting of the Zia Fm.

We will examine exposures of the type Piedra Parada Mbr of the Zia Fm, which rests upon upper Galisteo Fm mudstone and conglomerate. The basal 0.5-3 m of the Zia section in Arroyo Piedra Parada contains fluviatile gravel composed mostly of rounded chert pebbles derived from Mesozoic rocks of the Colorado Plateau. Scattered within the gravel are cobbles of rounded, intermediate volcanic rocks (Fig. 2-2). Elsewhere, these cobbles form a discontinuous stone pavement, where many of the volcanic clasts have been sculpted by the wind into ventifacts (Tedford and Barghoorn, 1999; Gawne, 1981). Three volcanic clasts have been $^{40}Ar/^{39}Ar$ dated between 32 to 33 Ma (31.8±1.8 Ma, 33.03±0.22 Ma, 33.24±0.24 Ma, S.M. Cather, W.C. McIntosh, unpubl. data), indicating that they were once part of the middle Tertiary volcaniclastic succession. The dates alone are not sufficient to established correlation to possible Oligocene sources, such as the San Juan volcanic field, Mogollon-Datil volcanic field, or the Ortiz porphyry belt. The clasts could be derived from the now buried unit of Isleta #2 of Lozinsky (1994), which approaches 2.2 km thickness in oil-test wells about 25-30 km to the south.

GEOLOGICAL SOCIETY OF AMERICA, ROCKY MOUNTAIN-SOUTH CENTRAL SECTION MEETING

PRE-MEETING FIELD TRIP: STRATIGRAPHY AND TECTONIC DEVELOPMENT OF THE ALBUQUERQUE BASIN, CENTRAL RIO GRANDE RIFT

THIRD-DAY ROAD LOG, APRIL 29, 2001
BELEN SUB-BASIN: BELEN, SEVILLETA NATIONAL WILDLIFE REFUGE, AND NORTHERN SOCORRO BASIN

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The following road log is summarized and modified from Hawley (1978). Road-log mileage not checked for accuracy.

Mileage Description

0.0 Load vehicles in front of Sheraton Old Town. Turn left onto Bellamah Road (north of hotel) and reset odometer at intersection of Bellamah and Rio Grande Blvd. Turn south (left) on Rio Grande Blvd. **0.2**

0.2 Turn east on Central Ave. **0.3**

0.5 Turn left on Lomas Blvd. **1.5**

2.0 Cross Broadway and begin ascent of Holocene to latest Pleistocene valley border fan surfaces. **0.1**

2.1 Cross Edith Blvd. **0.3**

2.4 Turn right on south Frontage Road. **0.4**

2.8 Cross Martin Luther King Blvd. **0.2**

3.0 Cross Central Ave. and ascend onramp to southbound I-25. **1.6**

4.6 Gibson Blvd. overpass. Albuquerque International Airport on high surface to your left. The airport is constructed on a nearly flat constructional surface that locally marks the top of the upper Santa Fe Group. This surface was called the Sunport surface by Lambert (1968) for the airport. To the left are pinkish-orange arkosic sediments that are derived from the ancestral Tijeras Creek and upper Santa Fe Group strata along the eastern margin of the Rio Grande valley. **2.6**

7.2 Rio Bravo Blvd. overpass (exit 220). Exposures to left are light-brown sand and gravel of the Arroyo Ojito Fm, overlain by light-gray sand and gravel of the ancestral Rio Grande facies of the Sierra Ladrones Fm, which contains abundant pumice gravel derived from the Cerro Toledo Rhyolite and Bandelier Tuff from the Jemez Mts. **0.8**

8.0 Overpass of abandoned railroad and location of **Day 2, Stop 5**. Descending into Tijeras Arroyo, which drains an area of Proterozoic, Paleozoic, and Mesozoic rocks within and east of the Sandia and Manzanita Mts. The arroyo's course through the mountains is in a deep canyon that follows the Tijeras fault in places. The Arroyo Ojito Fm underlies hills bordering both sides of the mouth of Tijeras Arroyo. Kelley (1977) proposed the term Ceja Mbr (Santa Fe Fm) to designate the upper, gravelly part of the upper buff member of Bryan and McCann (1937) and Lambert (1968). However recent mapping has differentiated the Arroyo Ojito Fm from an overlying ancestral Rio Grande facies of the Sierra Ladrones Fm (Connell et al., 1998b). Lambert (1968) and Lucas et al. (1993) reported early Pleistocene (early Irvingtonian) vertebrates (*e.*g., camel and horse) from the ancestral Rio Grande sediments near the top of the exposures along the margins of Tijeras Arroyo. The top of the erosional scarp on the south side of Tijeras Arroyo east of I-25 is a remarkably flat and weakly dissected surface that is a northward extension of the piedmont plain west of the Manzano Mts. (Llano de Manzano of Machette, 1985). **0.4**

8.4 Milepost 219. Bridge over Tijeras Arroyo. Begin ascent out of Tijeras Arroyo. Exposures along I-25 are underlain by Arroyo Ojito Fm sand and gravel and partially covered by alluvial deposits derived from the overlying Rio Grande deposits east of the abandoned landfills along the southern margin of Tijeras Arroyo and near the crest of the hills east of I-25 for the next mile. **4.1**

ELEVATIONS OF GEOLOGIC FEATURES, PAJARITO GRANT, LOS PADILLAS, AND MESA DEL SOL, BETWEEN I-25 MILE POSTS 216 AND 217

Elevations are in feet above mean sea level as measured from USGS 7.5-minute topographic maps. Arrows point to described features and elevations to your left (east) and right (west) in decreasing order of elevation.

EAST **WEST**

← 5490 base of Hubbell Spring fault scarp, Sandia National Labs/Kirtland AFB
east edge of Llano de Albuquerque (Pajarito) 5410 →
top of Isleta volcano (3 km south) 5387 →
← 5331 Top of Mesa del Sol
← 5325 Top of Rio Grande gravel with Upper Bandelier Tuff boulders
← 5305 Surface at top of 1650-foot Mesa del Sol well
← 5290 Base of Rio Grande gravelly sand capping Mesa del Sol
← 5170 Pliocene pumice (chemically correlated to NW and SW) under Mesa del Sol
← 5160 Pliocene Hawaiite tephra in section
top of Rio Grande upper terrace gravel 5160 →
Lava Creek B ash in gravel terrace ~ 5050 →
top of Black Mesa lava flow 5060 (west) to 5029 (east) →
base of Black Mesa lava flow 5050 (west) to 4990 (east) →
base of upper gravel terrace complex 5030 →
base of Rio Grande lower gravel terrace 4980 →
← 4910 base of Pliocene exposures of Arroyo Ojito Fm
← 4895-4905 Rio Grande flood plain →
← 4900 Rio Grande floodway channel →
← 4825 base of Rio Grande paleovalley →

12.5 Exit 215, NM-47 (South Broadway). Road descends Holocene alluvial-fan apron to river floodplain and exposures of a down-to-the-east fault zone in the underlying Santa Fe Group. The Arroyo Ojito Fm underlies scarp east of the floodplain. **0.1**

12.6 Bridge over Burlington Northern-Santa Fe Railroad. **0.3**

12.9 East abutment of I-25 bridge over Rio Grande. Rio Grande channel ahead. **0.4**

13.3 Milepost 214. West bridge abutment. **0.5**

13.8 Crossing Isleta Blvd. **0.3**

14.1 Entering Isleta Pueblo. Overpass of drain and location of Isleta-Black Mesa piezometer, which encountered 73 ft (22 m) of sandy fluvial deposits underlying the Rio Grande floodplain (Los Padillas Fm of Connell and Love, *this volume*). Deposits are associated with the last incision/aggradation episode of the Rio Grande. Incision probably occurred during latest-Pleistocene time, and entrenched 100 m below the highest inset terrace deposit of the Lomatas Negras Fm. **0.6**

14.7 Crossing bridge over Old Coors Road, which follows a former course of the Rio Grande cut through the lava flow of Black Mesa. Roadcut to right shows the edge of the 2.68±0.04 Ma ($^{40}Ar/^{39}Ar$, Maldonado et al., 1999) Black Mesa flow overlying cross-bedded pebbly sands of the Arroyo Ojito Fm and base-surge deposits from Isleta volcano. The tholeiitic Black Mesa flow has no outcrop connection with, and is slightly younger than, Isleta volcano, which forms the dark, rounded hill ahead and to the right of the highway. A buried vent for the Black Mesa flow is suspected in the floodplain area to the northeast (Kelley et al., 1976; Kelley and Kudo, 1978). **0.3**

ELEVATIONS OF GEOLOGIC FEATURES, WIND MESA, ISLETA, MESA DEL SOL (SOUTH), BETWEEN I-25 MILE POSTS 212 AND 210

Elevations are in feet above mean sea level as measured from USGS 7.5-minute topographic maps

Arrows point to described features and elevations to your left (east) and right (west) in decreasing order of elevation.

EAST **WEST**

top of east horst of Wind Mesa 5730→
"bath-tub ring" of gravel, east side of Wind Mesa 5500 →
top of Isleta volcano 5387 →
← 5340 base of Western Hubbell Spring fault scarp
← 5240 top of Mesa del Sol
east edge of Llano de Albuquerque (down-faulted block) 5240 →
← 5230 top of gravel with Bandelier boulders
← 5210 base of Rio Grande gravelly sand capping Mesa del Sol
← 5205 tilted Arroyo Ojito Fm under Mesa del Sol containing Pliocene pumice
← 5195 Pliocene Isleta (?) basaltic tephra in Arroyo Ojito Fm
← 5130 local top of Pliocene thick reddish-brown sandy clay of Arroyo Ojito Fm
top of upper terrrace gravel west of Isleta volcano 5100 →
← 5050 base of thick reddish-brown clay (Pliocene) of the Arroyo Ojito Fm
upper edge of lava lake within tuff ring 5050 →
top of Los Duranes Fm 5020 →
← 4960 Pliocene pumice gravel
top of Rio Grande terrace inset against Isleta volcano 5000 →
basaltic edifice southeast of Isleta volcano with strath terrace at top 4910-4970 →
base of Rio Grande terrace inset against Isleta volcano 4910 →
← 4910 Pliocene pumice gravel
Base of lava flow east of Highway 85, 4900 →
← 4885 Isleta (?) tephra 4895 →
← 4892 Pliocene pumice gravel
← 4890 Rio Grande flood plain→
← 4885 Rio Grande floodway channel →
← 4805 base of Rio Grande paleovalley →

15.0 Base-surge deposits of tuff cone associated with emplacement of Isleta volcano in outcrops on both sides of route. **0.5**

15.5 Change in primary dip direction of base-surge deposits at crest of tuff ring on right. Overlying alkali-olivine basalt flows fill tuff ring and extend southeast beyond Isleta volcano. Radioisotopic dates ($^{40}Ar/^{39}Ar$ method) indicate that oldest flow is 2.75±0.03 Ma and the second is 2.78±0.06 Ma (Maldonado et al., 1999). Basaltic cinders correlated to the Isleta volcano flows are recognized in the Arroyo Ojito Fm exposed along the eastern margin of the Rio Grande valley. These cinder-bearing deposits are about 75-100 m (estimated) stratigraphically below exposures of Pleistocene, Bandelier-Tuff bearing sand and gravel of the ancestral Rio Grande facies of the Sierra Ladrones Fm. This stratigraphic relationship indicates that deposition of the Arroyo Ojito Fm continued after 2.72-2.78 Ma, thereby constraining the age of the mesa capping Llano de Albuquerque to between 2.7 to 1.6 Ma or 1.2 Ma. Based on local stratigraphy on both sides of the present valley, it is likely that the Llano de Albuquerque was abandoned as an active fluvial fan prior to deposition of Lower Bandelier ash and pumice gravel at *ca*. 1.6 Ma. Locally, the cinder deposits on the east side of the valley have experienced over 100 m of uplift with consequent erosion of the overlying units before final deposition by the Rio Grande to form the Sunport Surface. Because early Pleistocene terraces of the Rio Grande pass west of Isleta volcano at high levels, the volcanic edifice probably was exhumed during middle and late Pleistocene time (*see mini-paper by Love et al., this volume*). **0.1**

15.6 Entering cut exposing basalt flow of Isleta volcano over tuff unit. Shell Isleta #2 well is about 1 mi. to the west, where it reached a depth of 6482 m and ended in Eocene rocks. Lozinsky (1994) reports that the Santa Fe Group is 4407 m thick at the Isleta #2 well and is underlain by 1787 m of the Eocene-Oligocene unit of Isleta #2, which overlies more than 288 m of sediments correlated with the Eocene Baca or Galisteo fms. **1.8**

ELEVATIONS OF GEOLOGIC FEATURES, SAN CLEMENTE TO LOWER HELL CANYON, BETWEEN I-25 MILE POSTS 205 AND 206

Elevations are in feet above mean sea level as measured from USGS 7.5-minute topographic maps
Arrows point to described features and elevations to your left (east) and right (west) in decreasing order of elevation.

EAST **WEST**

base of 100,000-year-old basalt flow 1 of Cat Mesa resting on top of San Clemente graben fill 5315 →
← 5310 top of eastern piedmont aggradation, footwall of western Hubbell Spring fault
Lower (?) Bandelier pumice in cross-bedded sand, San Clemente graben 5300 →
← 5280 Lower Bandelier pumice in ancestral Rio Grande unit, footwall of western Hubbell Spring fault
encroaching piedmont from Los Lunas volcano on graben-fill (1.1 km south) 5280 →
Los Lunas volcano tephra (<1.2 Ma) at top of San Clemente section (2.2 km SE) 5260 →
← 5260 top of ancestral Rio Grande deposits bearing Upper Bandelier boulders, north side of Hell Canyon
Blancan fossil camel bones in section tilted 6 degrees SW, east of San Clemente graben 5240 →
thick soil at base of San Clemente graben section 5220 →
pumice similar to 3 Ma pumice in tilted section, east of San Clemente graben 5215 →
← 5140 top of Rio Grande gravel east of Palace-Pipeline fault, south of Hell Canyon
← 5100 top of Rio Grande gravel west of Palace-Pipeline fault
← 5065 top of Hell Canyon gravel and soil, mouth of Hell Canyon
← 5060 top of Rio Grande gravel in section at mouth of Hell Canyon
← 5000 Cerro Toledo (c.a. 1.5 Ma) ash in Janet Slate section , mouth of Hell Canyon
top of Los Duranes Fm 4985 →

←4915 base of exposures of ancestral Rio Grande with pre-Bandelier pumice and ash
← 4865 Rio Grande floodplain →
← 4863 Rio Grande floodway channel →

17.4 Exit 209 overpass to Isleta Pueblo. Road now on upper constructional surface of the Los Duranes Fm, a middle to upper(?) Pleistocene inset fluvial deposit of the ancestral Rio Grande named by Lambert (1968) for exposures in NW Albuquerque. The Los Duranes Fm is inset against middle Pleistocene fluvial deposits correlated to the Lomatas Negras Fm, which contains an ash that was geochemically correlated to the 0.60-0.66 Ma Lava Creek B ash, from the Yellowstone area in Wyoming (N. Dunbar, 2000, written commun,; A. Sarna-Wojcicki, 2001, written commun.). At 3:00 is a low dark hill of the 4.01±0.16 Ma Wind Mesa volcano (Maldonado et al., 1999). The late Pleistocene Cat Hill volcanoes between 2:00-3:00. Hell Canyon Wash is at 9:00 on the eastern margin of the Rio Grande Valley. **1.1**

18.5 Railroad overpass. A soil described in exposures of the uppermost Los Duranes Fm indicate that soils are weakly developed with Stage I and II+ pedogenic carbonate morphology (S.D. Connell, and D.W. Love, unpubl. data). **0.8**

19.3 Milepost 208. Between 1:00-2:00 is the rift-bounding uplift of Mesa Lucero, which is about 30 km west of here. **0.6**

19.9 Valencia County Line. **0.4**

20.3 Milepost 207. Late Pleistocene basalt flow of the Cat Hills volcanic field overlies the Los Duranes Fm at 3:00. This flow is the oldest of the Cat Hills seven flows and yielded two $^{40}Ar/^{39}Ar$ dates of 98±20 ka and 110±30 ka (Maldonado et al., 1999). The Albuquerque volcanoes (dated using $^{238}U/^{230}Th$ method at 156±29 ka, Peate et al., 1996) overlie the Lomatas Negras Fm and locally interfinger with the top of the Los Duranes Fm in NW Albuquerque. These dates constrain the upper limit of deposition of this extensive terrace deposit to between 98-156 ka, which spans the boundary of marine oxygen isotope stages (MOIS) 5 and 6 (Morrison, 1991). These dates and stratigraphic constraints indicate that much of the deposition of the Los Duranes Fm occurred prior to the interglacial MOIS 5. **1.0**

21.3 Milepost 206. Descend possible fault scarp in Los Duranes Fm. Beneath rim of Cat Hills lava flows about 6 km (4 mi.) west of here is the San Clemente graben. It extends northward from near Los Lunas volcano to a graben that splits Wind Mesa (Maldonado et al., 1999). The Arroyo Ojito beds and thick stage III soil beneath the graben-fill near San Clemente are deformed into a flat-floored syncline. At least 37 m of fine sand, silt, and clay with a few coarser pebbly sand units accumulated in this graben where we found a bed of fluvially recycled pumice pebbles about 29 m above the base of the graben-fill section. A pumice pebble has been geochemically correlated to the Bandelier Tuff (probably lower BT based on stratigraphic relationships at Los Lunas volcano). Farther south, near NM-6, tephra from Los Lunas volcano (*ca*. 1.2 Ma) overlies correlative graben-fill sediments, which lie only a few meters above a stage III soil that is interpreted to mark a break in deposition of the Arroyo Ojito Fm along the easternmost edge of the Llano de Albuquerque. **1.1**

22.4 Southern boundary of Isleta Reservation. El Cerro de Los Lunas between 1:00-2:00. Northwest of the volcano, northwest-tilted beds of the Arroyo Ojito Fm contain multiple layers of pumice pebbles. A pumice pebble collected in the middle of the section of the Arroyo Ojito Fm here has been geochemically correlated to a pumice unit which was $^{40}Ar/^{39}Ar$ dated at 3.12±0.10 Ma in the Arroyo Ojito Fm exposed beneath the Llano de Albuquerque in the valley of the Rio Puerco on the Dalies NW quadrangle (Maldonado et al, 1999). This pumice has been geochemically correlated to a pumice pebble at Day 1, Stop 7 in Rio Rancho. **0.7**

23.1 Borrow pit to right exposes weakly developed soil in Los Duranes Fm. **0.8**

23.9 Overpass of NM-6 to Los Lunas exit (Exit 203). El Cerro de Los Lunas consists of several eruptive centers of trachyandesite to dacite. The earliest eruption consisted of andesitic and dacitic vent breccias and lava flows that have an $^{40}Ar/^{39}Ar$ age of 3.88±0.01 Ma (Panter et al., 1999). The north edifice with the “LL” on it is a trachyandesite with an $^{40}Ar/^{39}Ar$ age of 1.22±0.01 Ma (Panter et al., 1999). A separate, undated vent at the top of the mountain produced red and gray scoraceous tephra that extended for several km^2 to the north, east and southeast of the volcano. The underlying flow and scoria were then cut by several north-south faults. The scoria vent, underlying flow, and Santa Fe Group strata were tilted and uplifted more than 100 m above the surrounding landscape and rapidly eroded, forming a piedmont apron to the west and northwest. An eroded fault scarp on the east side of the peak has dip-separation of 43 m on the 1.2 Ma flow. The next set of eruptions issued along the fault scarp and buried talus from the scarp. Between eruptions, minor amounts of talus and eolian sand buried the lava flows. The final vent produced at least three lava flows that descended eastward toward the valley. V. Grauch (personal commun., 1999) suggests that the magnetic polarity of these flows is reversed, indicating that they predate the Brunhes chron (older than 780 ka). **1.3**

25.2 Milepost 202. At 3:00, north-south faults cut flows and are overlain by more flows of Los Lunas volcano. **1.0**

26.2 Milepost 201. Older flows of Los Lunas volcano at 3:00-4:00. El Cerro Tomé across valley at 11:00-12:00 is small andesitic volcanic center. Bachman and Mehnert (1978) report a K/Ar age of 3.4±0.4 Ma from a plug from this center.

ELEVATIONS OF GEOLOGIC FEATURES, DALIES, LOS LUNAS VOLCANO, LOS LUNAS, AND MEADOW LAKE, BETWEEN I-25 MILE POSTS 202 AND 203

Elevations are in feet above mean sea level as measured from USGS 7.5-minute topographic maps

Arrows point to described features and elevations to your left (east) and right (west) in decreasing order of elevation.

EAST **WEST**

top of Los Lunas Volcano main edifice 5955 →
base of 1.2 Ma flow west of edifice fault ~5760 →
begin piedmont slope to west and northwest for 4.4 km to 5280 near Sandia siding 5740 →
base of 1.2 Ma flow east of edifice fault 5620 →
tilted 3.1 Ma pumice in section beneath uplifted volcano 5510 →
1.2 Ma Tschirege ash in paleovalley with boulders of 1.2 Ma lava, base of piedmont 5500 →
Dalies railroad junction resting on Llano de Albuquerque soil 5305 →
base of Los Lunas tephra in syncline, base of volcanic piedmont 5290 →
base of 1.2 Ma flow beneath falls, northeast edge ~5140 →
← 5110 top of Rio Grande deposits at western edge of Meadow Lake
base of southeast flow lobes 5100 →
←5050 faulted (?) bench at top of Rio Grande deposits east of Los Lunas
base of younger flow, straight bluff below round eastern lobe 5050 →
top of Los Duranes Fm 4950 →
← 4845 Rio Grande floodplain →
← 4840 modern channel of Rio Grande, southern Los Lunas →
← 4770 base of Rio Grande paleovalley →

The northern Manzano Mts. (Reiche, 1949) form the skyline between 9:00-12:00. Magdalena Mts. at 12:00-1:00, and the Ladron Mts. are at 1:00. The north-south-trending break in slope from midway up the Llano de Manzano to the Manzano Mts. is the scarp of the Hubbell Spring fault zone (Maldonado et al., 1999), which marks the western edge of the Joyita-Hubbell bench of Kelley (1977). This structural bench is up-thrown on the east and is formed on pre-rift Permian, Triassic, and mid-Tertiary rocks. The bench is down-faulted to the west along the range-bounding Manzano fault. Basin-fill thickness increases abruptly west of the scarp. Kelley (1977) inferred some movement along the 135-ft (40-m) high scarp in Holocene time; however, Machette et al. (1998) summarize investigations and conclude that the latest movement on the Hubbell Spring fault zone is late Pleistocene in age. About 1 mi. east of this point is the Harlan and others #1 exploratory well. Kelley (1977) reports that the base of the Santa Fe in this 4223-ft (1287-m) test hole is 2835 ft (864 m) below the floodplain of the Rio Grande valley. **2.2**

28.4 Rounded hill on left is probably a remnant of the Los Duranes Fm. The low, arcuate area to the west is probably a meander loop of the ancestral Rio Grande that was inset into the Los Duranes Fm during late Pleistocene time. **0.7**

29.1 Milepost 198. Cliff exposures of Arroyo Ojito Fm to west. The discontinuous white soil at the top of the slope is a strongly developed calcic soil of the Llano de Albuquerque. This soil exhibits Stage III+ to local Stage IV carbonate morphology in typically sandy parent material. The north Belen interchange is ahead at exit 195. **2.0**

31.1 Railroad overpass. **2.0**

33.1 Milepost 194. Spur of Arroyo Ojito Fm strata extending east from escarpment on right. **0.7**

33.8 Milepost 192. Water tank and Belen sanitary landfill on right. Titus (1963) described a 200-ft (60-m) section of upper Santa Fe beds that crop out in the escarpment badlands area at 3:00. The section is mainly sand and gravelly sand (including cemented sandstone and conglomeratic sandstone lenses) with several prominent zones of interbedded clay, silt, and fine sand interpreted to be part of the Arroyo Ojito Fm. Units are in upward-fining (channel sand and gravel to overbank silt and clay) sequences. No angular unconformities are noted in the section. Preliminary studies of gravel character and sedimentary structures indicate that these units may have been deposited on the distal part of a broad piedmont-slope/alluvial plain sloping gently eastward toward the aggrading fluvial plain of the ancestral river. The log of a Belen municipal water-supply well drilled near this base of the described section indicates that, for at least 500 ft (150 m), the gross lithologic character of the basin fill is similar to that of the bluff outcrop (Titus, 1963) and is likely correlative to the Arroyo Ojito Fm; however, lenses of ancestral Rio Grande strata may also be present in the subsurface. A study of drillhole cuttings would be required to confirm this interpretation. **1.0**

34.8 **Exit I-25 to Camino del Llano** (exit 191). **0.1**

34.9 Turn right at stop sign onto Camino del Llano and ascend hill. **1.1**

36.0 Turn around at top of Llano de Albuquerque and descend to parking area. **0.1**

36.1 Pull off road.
Stop 1. *Belen 7.5' quadrangle, GPS: NAD 83, UTM Zone 013 S, N: 3,835,765 m; E: 334, 235 m*.

Ancestral Rio San Jose facies of the Arroyo Ojito Fm. Walk about 200 m down abandoned, gullied, dirt road on south side of Camino del Llano to flat pad cut into upper Santa Fe Group deposits (Fig. 3-1). *See mini-paper by Lucas and Morgan (this volume) for a discussion of the stratigraphy and biostratigraphy of this stop.*

Figure 3-1. Photograph looking SE of Arroyo Ojito Fm outcrops south of Camino del Llano, west of Belen, NM. Dave Love for scale in lower left corner.

Exposures along the bluffs of the western margin of the Rio Grande valley, near Belen, New Mexico, contain cross-stratified sand and pebbly sand correlated to the Arroyo Ojito Fm. At this stop, these deposits contain abundant sandstone and chert with lesser amounts of limestone, granite, and quartzite, with sparse scattered, disarticulated *Pycnodonte* and/or *Exogyra* valves and rounded obsidian pebbles derived from the 2.8-3.3 Ma East Grants Ridge vent, near Mount Taylor on the eastern Colorado Plateau, in the Rio San Jose watershed (Love and Young, 1983; Young, 1982). The limestone and bivalves are from Cretaceous strata, probably from the Dakota Fm-Mancos Shale (Greenhorn Limestone) interval, exposed in the Rio San Jose drainage basin in the adjacent Colorado Plateau. The deposits exposed at this stop generally have S-SE paleoflow directions, as measured from gravel imbrications. These deposits are associated with the ancestral Rio San Jose, a major tributary to the Rio Puerco. Based on preliminary comparisons of gravel composition of upper Santa Fe Group deposits in the Albuquerque Basin, we provisionally differentiate a western-margin, axial-fluvial, and an eastern-margin piedmont lithofacies that can be used to delineate the distribution of sediment in the Albuquerque Basin during Pliocene time (Fig. 3-2). The Rio Grande forms a rather narrow axial-fluvial systems tract that interfingers with the broader, more extensive western-margin fluvial facies of the Arroyo Ojito Fm. Ancestral Rio Grande deposits interfinger with piedmont deposits (mostly stream-flow dominated conglomerate and sandstone) that form narrow bands on the footwalls of basin-margin uplifts of the Sandia, Manzano, Los Pinos, and Ladron Mts.

The white horizontal band at the top of the section is a petrocalcic soil of the Llano de Albuquerque surface (Machette, 1985), which represents a local constructional top of the Arroyo Ojito Fm. The age of the Llano de Albuquerque surface was originally estimated at 0.5 Ma using soil-geomorphic and stratigraphic constraints (Machette, 1985). Additional stratigraphic constraints on the age of this surface indicate that the Llano de Albuquerque surface was formed prior to 1.6 Ma and likely formed much earlier (Connell et al., 2000; Maldonado et al., 1999), perhaps as early as 2.7 Ma (*see discussion on mile 15.*5). Deposition of less than 20 m of Arroyo Ojito Fm sediments continued after about 3.00 Ma ($^{40}Ar/^{39}Ar$ date on interbedded Cat Mesa basalt flow, Maldonado et al., 1999; Connell et al., 2000) on the footwall of the Cat Mesa fault. Between 75-100 m of deposits correlated to the Arroyo Ojito Fm overlie cinders of the 2.7 Ma Isleta volcano. Fluvially recycled pumice pebbles correlated to the early Pleistocene Bandelier Tuff and Cerro Toledo Rhyolite overlie these western-margin derived deposits. Other geomorphic constraints on the age of the Llano de Albuquerque are from the Rio San Jose drainages, which contains a suite of well dated Plio-Pleistocene basaltic flows near Grants, New Mexico. Entrenchment of the Rio San Jose and Rio Puerco, on the Colorado Plateau, was underway since 4 Ma (Love, 1989; Hallett, 1994; Baldridge et al., 1987; Maldonado et al., 1999), even as the basin was still filling. Significant entrenchment of the Rio San Jose was underway by 2-2.4 Ma (Fig. 3-3). This later period of entrenchment might signal the entrenchment of the Rio Puerco valley in the Albuquerque Basin.

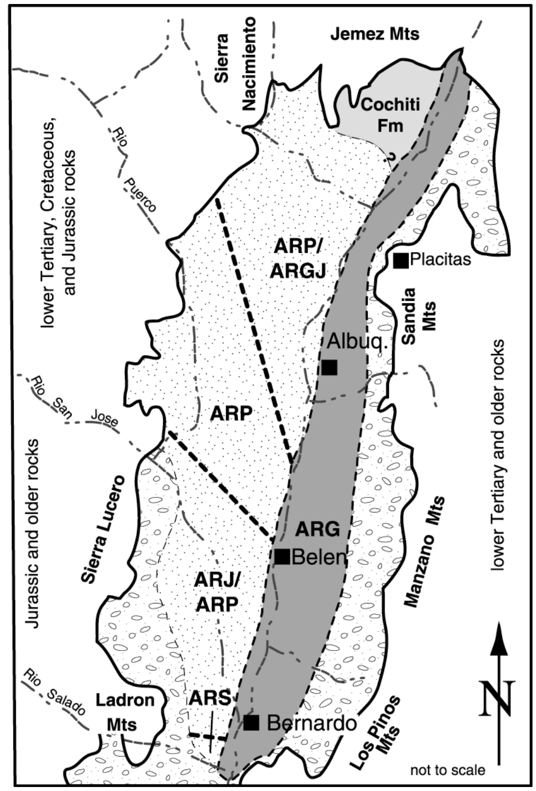

Figure 3-2. Schematic map showing the approximate areal distribution of major lithofacies in Pliocene sediments of the upper Santa Fe Group (modified from Connell et al., 1999). The south-flowing ancestral Rio Grande (ARG) is the axial-fluvial facies (moderate gray shading). The Arroyo Ojito Fm (stippled pattern) comprises a series of major, S-SE-flowing tributary drainages originating on the Colorado Plateau, San Juan Basin, and Sierra Nacimiento, and include the ancestral Rio Puerco (ARP), ancestral Rio Guadalupe/Rio Jemez (ARGJ), ancestral Rio San Jose (ARJ), and ancestral Rio Salado (ARS). These fluvial deposits merge into a single axial-fluvial system at the southern margin of the basin. The conlgomeratic pattern delineates locally derived deposits from rift-margin uplifts. The Cochiti Fm is a piedmont deposit developed along the SE flank of the Jemez Mts (*see* Smith and Lavine, 1996).

As you drive east along Camino del Llano towards I-25, note the embayment in the Manzano Mts., along the eastern margin of the Albuquerque basin, is less than 25-30 km to the east. Trigo Canyon is at the southern edge of this embayment, which rests on the footwall of the Hubbell Springs fault zone. **0.8**

36.9 Turn right onto southbound I-25. About 7 mi. east of this point on the Llano de Manzano is the Grober-Fuqua #1 oil test, drilled between 1937 and 1946. This 6300-ft (1920-m) hole penetrated 4550 ft (1387m) of Santa Fe Group. The Santa Fe overlies an unknown thickness of beds tentatively correlated with the Baca Fm (Foster, 1978). According to other interpretations of well data (Reiche, 1949, p. 1204; Lozinsky, 1987), the section below 4550 ft comprised 1750 ft (535 m) of upper Cretaceous and probably Triassic rocks. **0.9**

37.8 Milepost 191. **4.7**

42.5 Crossing irrigation canal with drop structures to right. The upper third of cliff exposures to your right contain obsidian derived from East Grants Ridge (Young, 1982). **0.8**

43.7 Milepost 185.

In the late 1980s and early 1990s a group of geology and hydrology students from New Mexico Institute of Mining and Technology, funded by grants to Drs. Phillips, Wilson, Gutjahr and Love, mapped nearly continuously exposed units about 40 m thick along a belt more than 1.2 km long. The goal of the study was to develop geostatistical methods to describe and predict permeabilities and hydrological heterogeneity in adjacent units based on limited drill-hole data. Davis et al. (1997) developed a portable air mini-permeameter that could be applied to the uncemented sandy bluffs to measure permeability *in situ* on the outcrop. Each measurement was located by theodolite survey. The overall permeability structure trends to the southeast, along channels mapped in outcrop (Fig. 3-4; Davis et al., 1993; Davis et al., 1997). These correlations are remarkably similar to the regional paleocurrent directions, as measured from channel geometry, gravel, imbrication, and cross-stratification, which suggests that paleocurrent directional data can be used to infer paleogroundwater flow. Mapping of calcium-carbonate concretion orientations by Mozley, Davis, and their students show similar trends (Mozley and Davis, 1996).

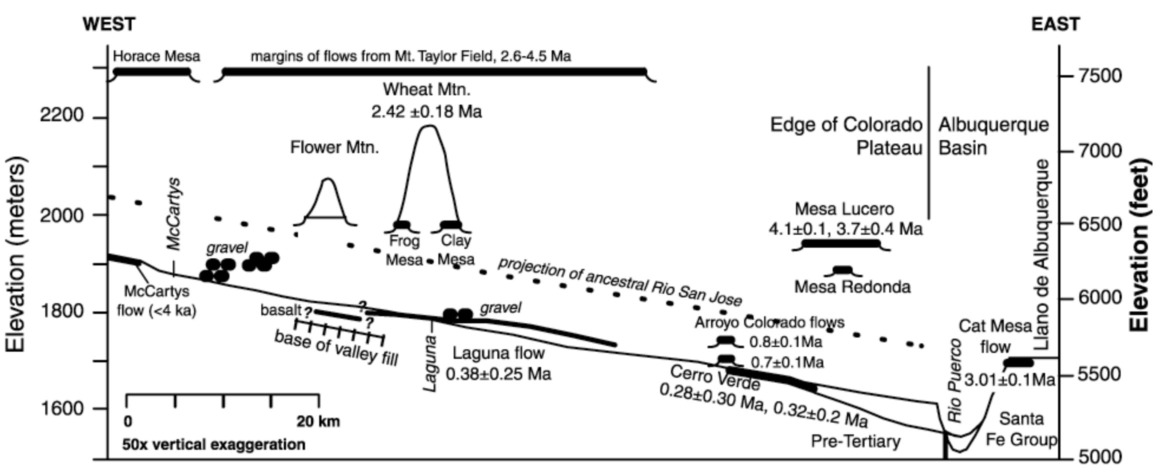

Figure 3-3. Longitudinal profile of the Rio San Jose from the distal end of McCartys flow to the confluence with the Rio Puerco and western edge of the Llano de Albuquerque surface (modified from Love, 1989 with date of Cat Mesa flow from Maldonado et al., 1999). Stratigraphic data indicate that the Llano de Albuquerque is younger than 3.0-2.7 Ma and older than 1.2 Ma. Major incision of the Rio San Jose after about 2.4 Ma suggests that the Llano de Albuquerque surface may have formed somewhat later, perhaps by 2.4-2.0 Ma.

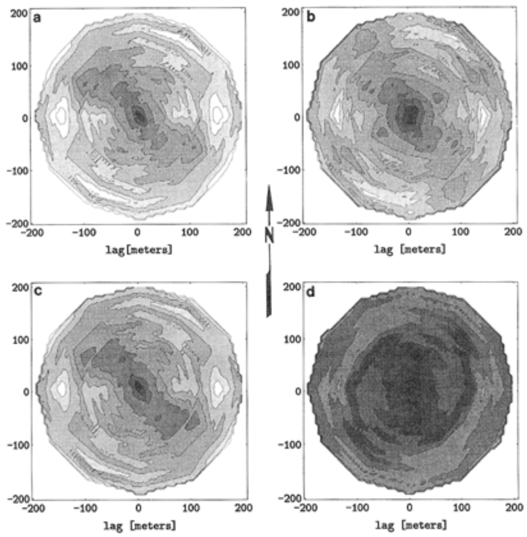

Figure 3-4. Azimuthal horizontal variograms constructed by combining horizontal variograms estimates of N0E, N30E, N90E, N30W, and N60W. (a) Log-permeability data set; (b) CH-II element indicator data set. (c) OF element indicator data set. (d) P_s element indicator data set. Contours are in units of dimensionless log-permeability square. Contour ranges and intervals (range, interval) are (a) (0-10, 1), (b) (b-d) (0-2.5, 0.025). Element indicators shown in Figure 3-5. From Davis et al. (1993).

Individual facies within the 40-m section were lumped into six architectural elements and traced laterally (Fig. 3-5). Two elements were traceable over broad areas—the thick, coarse-pebble conglomerates that formed the base and top of the studied units (CH-I), and eolian sand and soils. Medium-sized channels scoured, back-filled with sand, and overtopped the former landscape within the larger package of sand-to-clay units (CH-II).

Besides these six elements, a raised channel was found buried within the basin fill (Love et al., 1999). This channel is similar to some found in the Mimbres valley (Love and Seager, 1996). The overall architecture of coarse- and fine-grained units and the raised channel suggest that this area was built up as part of a larger fluvial fan-eolian plain (Mack et al., 1997). The gravels reflect episodes of high discharge connected to gravelly headwaters alternating with episodes of lower (perhaps local) discharge (arroyo-like channels) and with episodes of eolian sheet sands and soils. It is debatable whether the large and small channels are part of autocyclic processes on a large fluvial fan or whether they are related to large, episodic climatic shifts during the Pliocene. **0.9**

44.6 Socorro County line. To west is a stratigraphic section measured by Lozinsky (1988). **1.0**

45.6 Milepost 183. Sabinal Vinyards to your left. Los Pinos Mts. and Black Butte (Turututu) between 10:00-11:00. **1.3**

46.9 Rift-bounding Los Pinos Mts. at 10:00. The basin margin trends towards the Joyita Hills, where the Albuquerque basin narrows to less than 10 km in width between the villages of La Joya and San Acacia, known as the Socorro constriction (Kelley, 1977). The low-lying dark-colored hill is Black Butte, or Turututu, a small horst, which is capped by a basaltic andesite K/Ar dated at about 24 Ma (Bachman and Mehnert, 1978; correlative to the La Jara Peak basaltic andesite). It overlies Oligocene La Jencia ashflow tuff (Osburn, 1983; Osburn and Chapin, 1983). **1.7**

48.6 Milepost 180. Dairy feedlot in foreground and Los Pinos Mts. in background at 9:00. Northwest sloping cuestas are Pennsylvanian and Permian strata in the northern Sierra de las Cañas. Between 12:00-1:00 is the Lemitar-Socorro Range, which marks the western boundary of the present Socorro basin. The Sabinal fault cuts the Llano de Albuquerque surface to the west and descends toward the windmill in the foreground. This fault has repeatedly moved in Pleistocene time (Machette et al, 1998; Love 2000). The Central New Mexico Livingstone #1 was drilled in 1939 on the Llano de Albuquerque, about 1.7 mi. (2.8 km). to the west (elevation 5074 ft, 1547 mi.), where it penetrated about 2100 ft (640 m) of Santa Fe Group strata and bottomed in possible Cretaceous strata at 2978 ft (908 m). **4.8**

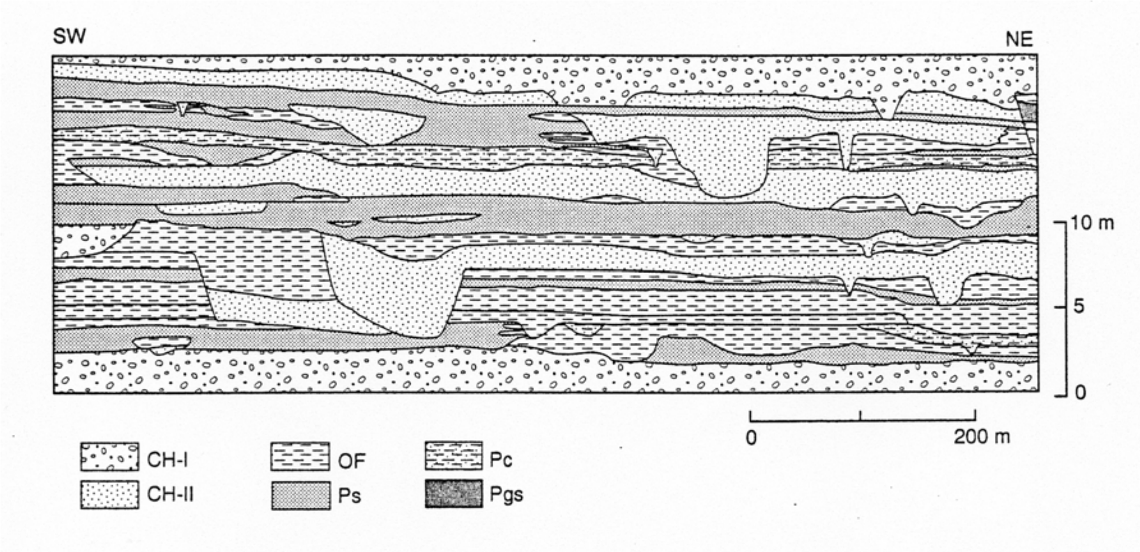

Figure 3-5. Architectural elements of Arroyo Ojito Fm near Milepost 185. Architectural elements include coarse gravelly sand channels (CH-I), medium- to fine-grained sandy channels (CH-II), overbank silt and clay (OF), and soils (sand, Ps; clay, Pc; and mixed gravel and sand Pgs). From Love et al. (1999).

53.4 **Leave I-25 at Bernardo/US-60 exit (exit 175). 0.1**

53.5 Turn left on old paved road (formerly US-85) and pass RV park/campground. You are in the valley of the Rio Puerco. Route follows geophysical line of Consortium for Continental Reflection Profiling (COCORP; de Voogd et al., 1986). Line was interpreted to show deep, shallow-angle, listric faults with steeper normal faults near the surface. **0.9**

54.4 Bridge over Rio Puerco. **0.7**

55.1 Go straight to gate to Sevilleta National Wildlife Refuge (NWR) and Long Term Ecological Research (LTER) Area. Dirt road to right leads to Riley and Magdalena, New Mexico, via the west flank of the Ladron Mts. **You must obtain permission prior to entering the refuge**. Turn right onto dirt road immediately after gate and drive west towards the Ladron Mts. **0.8**

55.9 Ascend degraded fault scarp. **0.3**

56.2 Turn left towards powerline poles on hill. Ascend mostly covered slopes. **0.8**

57.0 Low hill to left contains cemented sandstone and pebbly sandstone that are likely correlative to the Arroyo Ojito Fm (Rio Puerco and Rio San Jose fluvial facies). The exposures here also have gravel beds with abundant volcanic clasts. The volcanic component may be derived from Oligocene rocks of the Mogollon-Datil volcanic field (La Jara Peak basaltic andesite and Datil Group), exposed along the western rift margin. To southeast is degraded west-facing scarp of the Cliff fault (Machette, 1978a). **1.1**

58.1 Ascend hill of east-facing fault. **1.2**

59.3 Low hills ahead are on the hanging wall of the Loma Pelada fault and consist of cemented piedmont facies of the Sierra Ladrones Fm, which are derived from the Ladron Mts. McMahon et al. (1998) described soil spatial variability in the slopes of the piedmont for the 1998 Friends of the Pleistocene trip to the Socorro area. **0.6**

59.9 Cross under powerlines. Between 11:00-12:00 are westernmost exposures of Arroyo Ojito Fm deposits. **1.2**

61.1 Degraded scarp of Loma Blanca fault. **0.3**

61.4 Descend into Arroyo Tio Lino. Pale outcrops to east (left) are cross-stratified fluvial deposits of the Sierra Ladrones Fm (Machette, 1978b). **0.4**

61.8 Cross arroyo. **0.4**

62.2 Pull off side of road and walk to outcrop on east side of arroyo. **STOP 2**. *San Acacia 7.5' quadrangle, GPS: NAD 83, UTM Zone 013 S, N: 3,803,710 m; E: 380,350 m.*

We are on the San Acacia quadrangle, near the southwestern margin of the Belen sub-basin. The rift-border Ladron Mts. are to the west. Reconnaissance and stratigraphic studies indicate the presence of two moderately to well sorted, trough cross-stratified fluvial deposits that interfinger with transverse piedmont deposits at the western and eastern margins of the basin.

Treadwell-Steitz (1998) recognized, but did not map, fluvial sediments associated with the ancestral Rio Grande east of the Rio Grande (in Salas Arroyo and Palo Duro Wash) and east of Machette's (1978b) mapped extent of eastern margin piedmont lithofacies. Geologic mapping by Debrine et al. (1966) indicated the presence of a major axial-fluvial system along the eastern margin of the Socorro basin. Recent reconnaissance, stratigraphic studies, and geologic mapping (Fig. 3-6; Connell et al., 2001; Cather, 1996; Chamberlin, 1999; Chamberlin et al. 2001) indicate that the southern Belen sub-basin and northern Socorro basin contain the paleoconfluence of streams of the Arroyo Ojito and Sierra Ladrones Fm.

The San Acacia quadrangle is the type locality for the Sierra Ladrones Fm, which comprises fluvial deposits of a through-going river system that interfingers with piedmont deposits derived from local basin-margin uplifts. The Sierra Ladrones Fm (upper Santa Fe Group) was defined by Machette (1978b) without type or reference sections. Instead he designated the San Acacia quadrangle as a type area comprised of three major facies; a western-margin piedmont facies derived from the Ladron Mts; an axial-fluvial facies, generally considered to represent the ancestral Rio Grande, derived from the north; and an eastern-margin piedmont facies, derived from the Joyita Hills and eastern rift-border uplifts. Preliminary results of gravel petrography (Fig. 3-7) suggest that the major lithofacies assemblages are distinguishable near the southern end of the Albuquerque Basin (Fig. 3-6). The gravel clasts are similar in composition to gravel data discussed on the Day 1 road log (Fig. 1-9). The Arroyo Ojito Fm is slightly more volcanic rich near the southern part of the basin. This is likely due to the presence of Oligocene volcanic rocks of the Mogollon-Datil groups exposed along the margins of the Socorro and southern Albuquerque basins.

Although the Sierra Ladrones Fm was not defined in accordance to the North American Code of Stratigraphic Nomenclature (NACSN, 1983), it was adopted by the U.S. Geological Survey (Machette, 1978b) and subsequently used in the Socorro and Albuquerque basins (Hawley, 1978; Lucas et al., 1993; Smith and Kuhle, 1998). Conceptually, the Sierra Ladrones Fm includes the through-going Rio Grande and its major tributaries as well as local piedmont. Machette (1978b) did not define the fluvial facies as Rio Grande, *per se*; however, the use of the symbol "QTsa" suggests that he considered it an axial-stream or river (i.e., "a"= axial).

Researchers from the New Mexico Bureau of Mines and Mineral Resources and New Mexico Museum of Natural History and Science recently began a stratigraphic study of the Sierra Ladrones Fm in the southern Belen sub-basin in order to document the lithologic character of this widely mapped unit.

Recent studies in the northern part of the Albuquerque Basin demonstrate that the most areally extensive fluvial sediments in the basin are related to major western-margin tributaries to the Rio Grande, including the Rio Puerco and Rio San Jose. Connell et al. (1999) proposed the Arroyo Ojito Fm for these western-margin river deposits, which were divided into mappable members or lithofacies, thus excluding these distinct western fluvial deposits as members of a Sierra Ladrones Fm (Connell et al., 1999).

The base of the Sierra Ladrones Fm is not exposed in Arroyo Tio Lino, but is in fault contact with the Popotosa Fm (lower Santa Fe Group). Elsewhere, mostly in the Socorro and La Jencia basins (Cather et al., 1994), piedmont deposits of the Sierra Ladrones Fm rest upon the Popotosa Fm with angular unconformity. The top of this section is crosscut by Quaternary alluvium.

At Arroyo Tio Lino, over 350 m of Sierra Ladrones Fm strata are exposed between the Loma Peleda and Loma Blanca faults (Machette, 1978b). The base of the Arroyo Tio Lino section is a weakly to moderately cemented, tilted, light-gray planar to trough cross-stratified sandstone (Fig. 3-8, A). Gravel is sparse and composed mostly of white granite derived from the nearby Ladron Mts. Sparse paleocurrent data indicate deposition by a S-SE flowing river. These deposits interfinger to the west and upsection (Fig. 3-8, B) with better cemented, piedmont sandstone and conglomerate derived from the Ladron Mts. Elsewhere, fluvial deposits are faulted against older rocks. The top of the section contains piedmont deposits with medium bedded fluvial sandstone interbeds (Fig. 3-8, C). These fluvial deposits are typically light-gray to very pale-brown, moderately to well sorted, weakly to

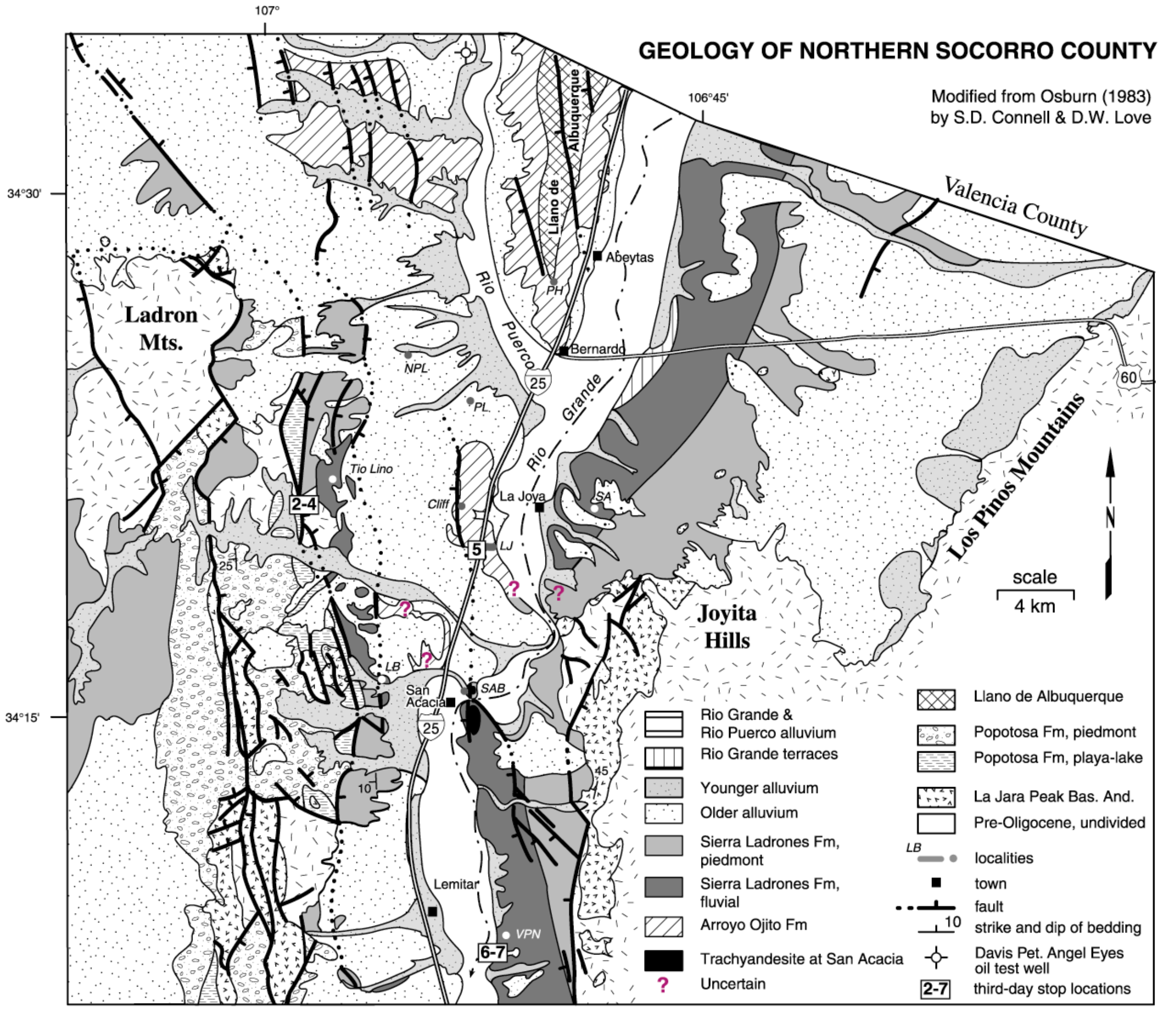

Figure 3-6. Generalized geologic map of the southern Albuquerque and northern Socorro basins in Socorro County. Geologic map was modified from Osburn (1983) using unpublished reconnaissance mapping, including Cather (1996), Chamberlin (1999), and Chamberlin et al. (2001). Queried areas indicate localities in the basin-fill that are currently being studied. Stop locations are noted on the map. Localities mentioned in text include Arroyo de la Parida-North (VPN), Loma Blanca (LB), San Acacia (SAB), Salas Arroyo (SA), La Joya (LJ), Tio Lino (TL), and Picho Hill (PH). Other localities, not mentioned in text, include the Powerline (PL) and north Powerline (NPL) sites.

well cemented sandstone with trough cross stratification; mudstone is commonly preserved as rip-up clasts. Also at this site, the beds are chaotically bedded, probably due to liquefaction during paleo-earthquakes. Machette (1978b) delineated this facies south to Loma Barbon, where we described a section of similar cross-bedded sandstone with sparse rounded heterolithic gravel that includes rounded quartzite.

The Loma Blanca section is part of this western outcrop belt that extends north into the Tio Lino section. Gravel at the Loma Blanca reference section is more diverse than at Arroyo Tio Lino. Machette (1978b) also considered exposures at Loma Blanca to be most representative of his axial-fluvial facies (unit QTsa of Machette, 1978b). Measurements on imbricated gravel and cross stratification indicate deposition by a S-SE flowing river. A fluvially recycled pumice pebble at Loma Blanca was analyzed by N. Dunbar and W.C. McIntosh (NM Bureau of Mines and Mineral Resources) and is geochemically and age-equivalent to the Peralta

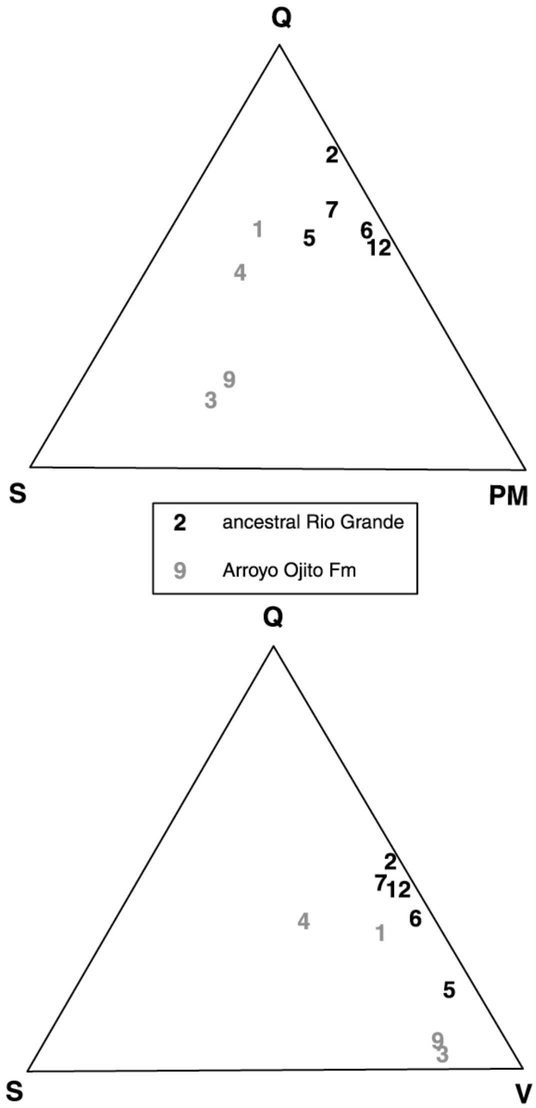

Figure 3-7. Preliminary results of gravel petrography from selected sites in the Belen sub-basin and northern Socorro basin (see Fig. 3-6 for localities). Localities include, La Joya unit 4 (1), Loma Blanca unit 14 (2), La Joya unit 23 (3), Picho Hill (4), La Joya unit 1 (5), Parida North unit 1 (6), San Acacia fluvial (7), La Joya unit 16 (9), Salas Arroyo unit 3 (11), Salas Arroyo unit 4 (12). Black numbers indicate deposits correlated to the ancestral Rio Grande (Sierra Ladrones Fm). Gray numbers indicate deposits provisionally assigned to the southern Arroyo Ojito Fm. Abbreviations include quartz, quartzite, and chert (Q), sedimentary (S), volcanics (V), and plutonic-metamorphic (PM) gravels. Marker point 3 is an inset fluvial deposit of the Rio Salado (Qag of Machette, 1978b), which is similar in composition to marker point 9 of the La Joya section.

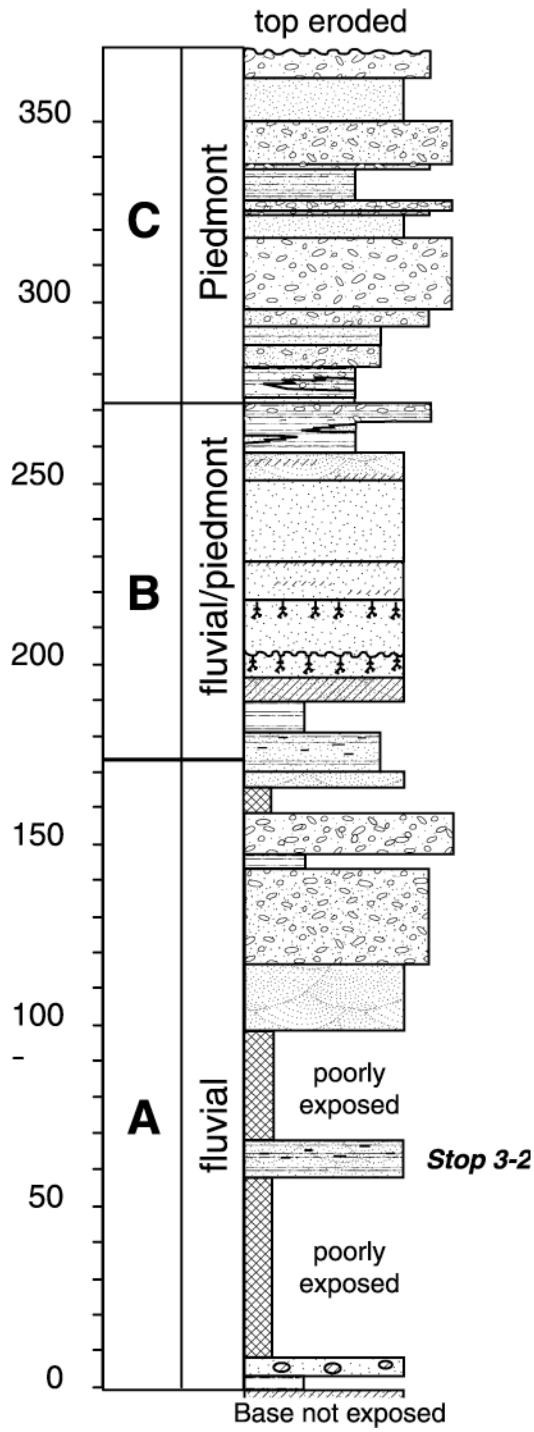

Figure 3-8. Stratigraphic column of the Tio Lino section illustrating fluvial and piedmont facies of the Sierra Ladrones Fm. Thickness is in meters.

Tuff, which is exposed along the eastern margin of the Santo Domingo sub-basin and southeastern Jemez Mts. The presence of this pumice pebble indicates a post-late-Miocene south-flowing fluvial drainage that is likely correlative to the ancestral Rio Grande (Connell et al., 2001). Geologic reconnaissance and additional stratigraphic studies are planned to document the distribution of lithofacies in the southern Belen sub-basin. Fluvial deposits exposed along the western part of the basin are similar in character to deposits recognized east of the Rio Grande at Salas Arroyo (Connell et al., 2001).

Both the Tio Lino and Loma Blanca sections are exposed in structurally higher fault blocks along the western margin of the basin are possibly correlative to an older ancestral Rio Grande; however, definitive correlation of the Tio Lino section to ancestral Rio Grande deposits in the Socorro basin has not yet been established. Alternatively, the Tio Lino section may represent deposition by a major western-margin tributary to the Rio Grande.

Continue driving west on dirt road. **0.4**

62.6 Increase in cementation of outcrops. In lithofacies assemblage B of Tio Lino measured section (Fig. 3-8). **0.1**

62.7 Yellowish-brown concretionary sandstone beds. Cross transition between fluvial and piedmont beds between here and the mileage 63.1. **0.3**

63.1 Crest of hill on lithofacies assemblage C (Fig. 3-8). Bear Mts. on skyline between 11:00-1:00. The Bear Mts. contain volcanic deposits of the Mogollon-Datil volcanic field. Descend into Cañada Popotosa and type area of the Popotosa Fm (lower Santa Fe Group), which was originally defined by Denny (1940) for a reddish-brown playa-lake mudstone and interfinging basin-margin piedmont deposits that he thought pre-dated the Santa Fe Group. **0.1**

63.2 Cross splay of Loma Peleda fault. Note reddish-brown playa-lake facies of the Popotosa Fm to your right. To your left is tilted, cemented piedmont conglomerate of the Sierra Ladrones Fm.

Pull off road for optional Stop 2b.

Continue along dirt road into valley. **0.5**

63.7 Pull off road.

Stop 3. Popotosa Fm overview. *San Acacia 7.5' quadrangle, GPS: NAD 83, UTM Zone 013 S, N: 3,803,535 m; E: 317,055 m.*

The Popotosa Fm consists of more than 2600 m of debris-flow breccia, conglomerate, sandstone, and mudstone that extend in several rift-related basins from south of the Socorro accommodation zone to the Belen sub-basin of the Albuquerque Basin (Fig. 3-9). It was defined by Denny (1940) who thought it preceded Santa Fe group deposition, but later workers recognized that it is related to early rifting, as basins and uplifts developed and facies extended from proximal debris flows to sandy alluvial aprons to central basin mudstone playas (Bruning, 1973; Cather et al., 1994). During Popotosa Fm deposition, rift-related basins remained closed (internally drained). Basal Popotosa breccias rest on the 27.37±0.07 Ma South Canyon ash-flow tuff and the 26.3±1.1 Ma (Bachman and Mehnert, 1978) andesite at Cerritos de las Minas (Machette, 1978b). Overlying conglomerates contain the 16.2±1.5 Ma Silver Creek andesite. Numerous thin silicic tuffs are preserved in the playa facies. The youngest tuff within playa facies near Socorro overlies the 7.85±0.03 Ma rhyolite dome at Grefco Mine (Newell, 1997; R.M. Chamberlin, 2001, oral commun.). Playa deposits are buried by the 6.88±0.02 Ma trachyandesite of Sedillo Hill southwest of Socorro.

Conceptually, Popotosa Fm deposition ended as rift basins became integrated from north to south. The earliest evidence for an ancestral axial stream in the formerly closed Popotosa basin in the Socorro area is some southward-directed cross-bedded fluvial sandstone underlying the 3.73±0.1 Ma basalt of Socorro Canyon. (R.M. Chamberlin and W.C. McIntosh, written commun., 2000). The ancestral Rio Grande fluvial system reached southern New Mexico as early as 4.5-5 Ma (Mack et al., 1998).

The basins containing Popotosa Fm have been reconfigured several times during Miocene time, particularly with the uplift and extension of the Chupadera-Socorro-Lemitar-Ladron "horst" block in the center of a former more extensive basin. It is possible that the early and late Miocene playas occupied different basins or different parts of an evolving basin. Popotosa Fm is primarily exposed in the faulted margins of uplifts and few wells have penetrated the formation in basinal positions.

Turn around and retrace route to I-25. **10.2**

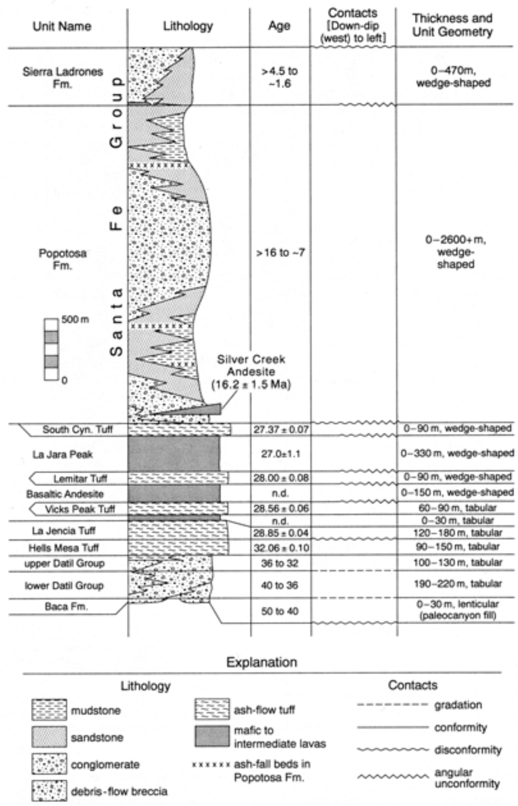

Figure 3-9. Simplified stratigraphic column for Cenozoic rocks in the southern Belen sub-basin, and Socorro and La Jencia basins. From Cather et al. (1994).

73.9 Turn right onto southbound onramp of I-25. Magdalena Mts. between 12:00-1:00. Polvadera and Strawberry Peaks between 11:00-12:00. Socorro Range at 11:00. **1.0**

74.9 Cross Rio Puerco. The Village of La Joya is on the east side of the river at 10:00. Bluffs above the town are capped with thin gravels of Arroyo de los Alamos and Salas Arroyo (lower Palo Duro Wash). These surface gravels rest on sandy fluvial beds here interpreted as an older river-channel deposit inset against fluvial deposits of the ancestral Rio Grande (upper Santa Fe Group). Treadwell-Steitz (1998) described the Palo Duro Wash soil chronosequence. **1.1**

76.0 White beacon at 10:00 is on terrace of Salas Arroyo on the eastern part of the Sevilleta NWR. Deposits in Salas Arroyo contain light-gray, trough-cross bedded, fluvial sandstone that interfingers with reddish-brown piedmont deposits derived from the Joyita Hills and Los Pinos Mts. The fluvial sandstone is correlated to ancestral Rio Grande deposits of the Sierra Ladrones Fm and lies east of the mapped limit of piedmont deposits (unit Tsp of Machette, 1978b) derived from the eastern margin, according to Machette (1978b). **2.9**

78.9 **Leave I-25 at exit 169 to Sevilleta National Wildlife Refuge**. **0.2**

79.1 Turn right at stop sign. **0.1**

79.2 Gate at entrance to refuge. **0.1**

79.3 Turn right to University of New Mexico Field Station. **0.4**

79.7 Lunch at UNM Field Station. Retrace route to I-25. **0.6**

79.8 Ascend I-25 southbound onramp (MP 171). **1.3**

81.1 **Pull off highway. STOP 4**. La Joya State Wildlife refuge to left. Sevilleta NWR to right. **0.6**

The La Joya section represents deposition by streams of the ancestral Rio Puerco/San Jose/Salado fluvial system, not streams from the eastern basin-margin piedmont, as previously interpreted (*cf*. Machette, 1978b).

A measured section, about 3 km southwest of La Joya, NM (Fig. 3-10), was described near here. Deposits are provisionally correlated to the Arroyo Ojito Fm. Blancan (Pliocene) vertebrates (*Equus simplicidens*, and *E. scotti(?))* were found in light-brown sandstone, conglomerate, and bedded mudstone downsection and west of this stop. The upper part of the La Joya section is interpreted to have been deposited by an E-NE flowing ancestral Rio Salado. Much of the section, however, was deposited by S-SE flowing streams (Fig. 3-11).

The Salas Arroyo section, just east of the Rio Grande, contains trough cross-bedded, locally tephra-rich, fluvial sand that interfinger to the east with piedmont deposits derived from adjacent basin-bounding uplifts.

Exposures near I-25 were originally correlated by Machette (1978b) to the piedmont deposits derived from the eastern margin of the rift; however, paleocurrent data, regional lithofacies patterns, and paleogeography (Figs. 3-7, 3-10, and 3-11) suggest that these deposits were not derived from the eastern margin, but from the western margin instead. Preliminary results of gravel composition studies suggest a closer correlation to the Arroyo Ojito Fm than eastern-margin piedmont or ancestral Rio Grande deposits. Piedmont deposits to the E and SE of this stop contain abundant granite and reddish-brown sandstone, which are rare or absent in the La Joya section.

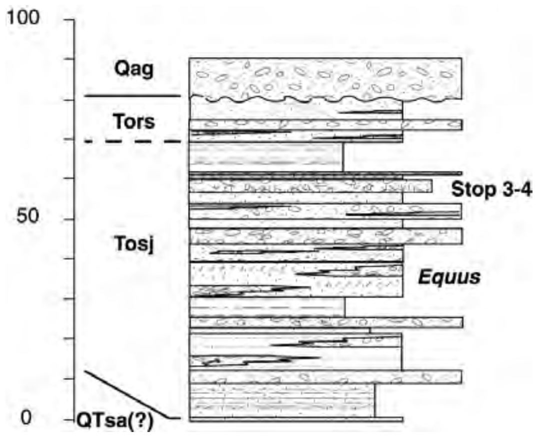

Figure 3-10. Stratigraphic column of La Joya site, Stop 4. The base contains a light-gray sand that is possibly correlative to the ancestral Rio Grande facies (Sierra Ladrones Fm). This is overlain by deposits of the Arroyo Ojito Fm, which are provisionally subdivided into a Rio San Jose (Tosj) and overlying Rio Salado (Tors) facies. The section is unconformably overlain by Quaternary terrace gravel of the Rio Salado (unit Qag of Machette, 1978b). Thickness in meters.

81.7 Milepost 168 The well-preserved fan-terrace surface (Qag of Machette, 1978b,c) is graded to a level about 130 ft (40 m) above the present floodplain. Denny (1940) also describes cut-and-fill terraces in the La Joya area. **0.8**

82.5 Descend into valley of the Rio Salado, near the southern margin of the Albuquerque Basin. Sand dunes on both sides of I-25. From here to San Acacia, NM (MP 163), is the area of maximum uplift above the Socorro Magma body, a 3,400 km^2 pancake-shaped sill recognized at a depth of 18.75 km (Sanford and Long, 1965; Reinhart and Sanford, 1981; Ake, and Sanford 1988; Hartse, 1991; Hartse, et al., 1992; Balch et al., 1997). The rate of magmatic inflation at the center of the uplift near San Acacia has been estimated using repeated conventional geodetic surveys yielding an uplift value of 1.8 mm/yr (Reilinger and Oliver,1976; Larsen et al, 1986) and using Interferometric Synthetic Aperture Radar (InSAR) from satellites yielding a value of 3-4 mm/yr (http://igpp.ucsd.edu/~fialko/res_socorro.html[2001]). **0.1**

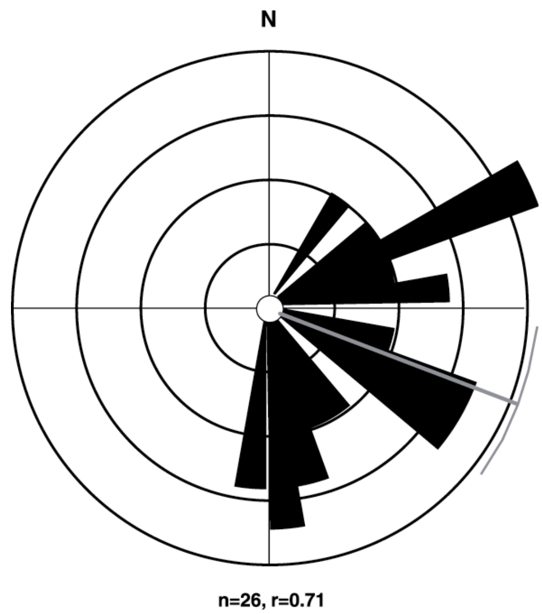

Figure 3-11. Paleocurrent rose (in 10° intervals) for Arroyo Ojito Fm (upper Santa Fe Group) near Stop 4, including correlation coefficient (r). The NE-trending cluster is from the upper part of the section (Fig. 3-10), which contains abundant volcanic gravel correlated to the ancestral Rio Salado.

82.6 Rest area on right. **1.2**

83.8 Bridge over Rio Salado. At 9:00 note tilted red-beds of the Joyita Hills, which define the eastern margin of the basin. The Joyita Hills are a complex fault block of Proterozoic, upper Paleozoic, and lower to middle Tertiary rocks (Foster and Kottlowski, 1963; Beck, 1991). The Tertiary sequence includes a thin conglomerate of the Baca Fm (Eocene), which rests on an erosion surface cut nearly through the Triassic beds, and a thick sequence of Oligocene andesitic to rhyolitic volcanic rocks. Ash-flow tuffs derived from areas west of the rift are found east of the Joyita Hills. **0.8**

84.6 Milepost 165. Low dark mesas on both sides of river at 10:00 consist of the trachyandesite at San Acacia, which overlies easterly-derived distal piedmont deposits of the Sierra

Ladrones Fm. Recently the trachyandesite has been $^{40}Ar/^{39}Ar$-dated at 4.87±0.04 Ma (W.C. McIntosh, and R.M. Chamberlin, unpubl. data). The western face of the north mesa exposes down-faulted light-gray fluvial sand with scattered gravel correlated to the ancestral Rio Grande facies of the Sierra Ladrones Fm. These fluvial deposits are faulted against the piedmont deposits beneath the lava. To the south, the cliffs along the eastern margin of the valley are piedmont deposits with interbedded fluvial deposits of the ancestral Rio Grande. A water well drilled on the floodplain east of I-25 penetrated 27 m of late Pleistocene-Holocene fill of the Rio Grande valley. **2.0**

86.6 San Acacia overpass. Loma Blanca at 3:00 is rounded hill formed on sandy fluvial beds of the Sierra Ladrones Fm. The Rio Grande at 9:00 is cut through the trachyandesite into eastern piedmont facies. Slump blocks of trachyandesite and at least two terrace levels are preserved downstream from this watergap. **1.0**

87.6 Milepost 162. On Rio Grande floodplain. Dark-reddish-brown hills are 3:00 are the Cerritos de las Minas. They are formed on 26-m.y.-old basaltic andesite correlated with the La Jara Peak andesite (Machette, 1978b; Osburn and Chapin, 1983). Type Popotosa Fm (Bruning, 1973) is farther west. **1.0**

88.6 Crossing San Lorenzo Arroyo. **2.9**

91.5 Milepost 158. Gravel pits on left are quarrying inset fluvial deposits of the ancestral Rio Grande. These exposures contain Mastodon teeth and fluvially recycled gravels containing obsidian from the Jemez Mts. (R. H. Weber, oral commun. 2001). **1.0**

92.5 Milepost 157. The east slope of the Lemitar Mts. at 1:00-3:00 includes Proterozoic granite, schist, pegmatite, and diabase dikes. Just below the high point of the range, Polvadera Mountain, Pennsylvanian (Madera) limestone is in fault contact with Proterozoic rocks. Near the south end of the range Mississippian and Pennsylvanian rocks overlie the Proterozoic. The peak is formed on Oligocene volcanic rocks (rhyolite ash-flow tuffs and andesite flows) that overlie the Pennsylvanian and in places the Proterozoic. The southern and northern ends of the range are overlapped by Santa Fe beds, including fanglomerate and playa mudstone facies of the Popotosa Fm (Miocene) and piedmont gravel and fluvial sand facies of the Sierra Ladrones Fm. **0.6**

93.1 **Leave I-25 at Lemitar exit (156)**. **0.2**

93.3 Left at stop sign, towards Lemitar to east. **0.5**

93.8 Turn right onto Severo Vigil Road to Escondida Lake Park. Travel along toe of valley border fans. **1.8**

95.6 Valley of Arroyo de la Parida east of the river at 9:00. Reddish-brown fan gravels to fanglomerate (derived in part from Permian red beds in the Loma de las Cañas) interfinger westward with finer grained distal-piedmont to basin-floor facies that include tongues of gray pebbly sands deposited by the ancestral river. The sequence consists of the eastern piedmont and fluvial facies of the Sierra Ladrones or Palomas fms; interfingering relationships were first described by DeBrine et al. (1963). Vertebrate fossils collected from fluvial sands in the south bluff of the arroyo valley are of medial Blancan age (*see mini-paper by Morgan and Lucas, this volume*). The sparse fauna was originally described by Needham (1936). According to Bachman and Mehnert (1978, p. 288), the basal fluvial sand zone in the Arroyo de la Parida exposures rises "85 m [280 ft] in altitude northward over a distance of about 11 km [7 mi.] along the east side of the Rio Grande, representing a gradient of about 7.7 m/km [about 40 ft/mi], compared with the existing gradient of about 1.0 m/km [about 5 ft/mi]." This upwarped part of the upper Santa Fe sequence extends north almost to San Acacia and coincides with the area where the preliminary studies of railroad level-line data by Reilinger and Oliver (1976) indicate high (4-6 mm/yr) rates of present uplift (*see discussion at mileage 82.5*). **0.5**

96.1 Road cuts exposing piedmont deposits derived from the Socorro Range. **0.7**

96.8 Turn left to Escondida Lake. **0.1**

96.9 Cross railroad tracks, Escondida Lake to north (left). **0.2**

97.1 Bridge over Rio Grande. **0.5**

97.6 Ascend hill of Pueblito and turn left onto dirt road toward Valle de la Parida. **1.3**

98.9 Ascend Johnson Hill and climb out of Valle de la Parida. **0.3**

99.2 Ancestral Arroyo de la Parida deposit that is inset into gently east-tilting Santa Fe Group strata. **1.0**

100.2 Turn left onto high-level piedmont/tributary deposit inset against basin fill of upper Santa Fe Group. **0.2**

100.4 Bear right and park along loop. **STOP 5.** *Mesa del Yeso 7.5' quadrangle, GPS: NAD 83, UTM Zone 013 S, N: 3,779,760 m; E: 329,555 m.*

The following discussion is modified (comments indicated by brackets, "[ ]") from minipaper in New Mexico Geological Society Guidebook 34 (Hawley, 1983, p. 13) on the *Geomorphic Evolution of Socorro area of Rio Grande valley*:

Johnson Hill offers a good vantage point for reviewing the post-Miocene geomorphic evolution of the Socorro area. The lithologic composition of upper Santa Fe Group basin fills and post-Santa Fe valley fills reflect major structural and topographic elements of the Rio Grande rift that had formed by early Pliocene. The erosional valley of the Rio Grande, formed since mid-Pleistocene time, was the only major geomorphic feature not yet present. Earlier deposits of intrarift basins, the bolson-fill facies and volcanics of the upper Oligocene-Miocene Popotosa Fm, are here deeply buried; they reflect terrains largely obliterated by erosion, sedimentation, and structural deformation in the past 10 Ma.

The geomorphic setting, in terms of hydrologic and biologic conditions, was probably not much different from that of the late Quaternary. Calcic paleosols associated with buried and relict geomorphic surfaces indicate that climatic conditions were semiarid to arid. Basin- and valley-fill facies patterns clearly show that ephemeral, high-gradient (arroyo) tributaries dominated piedmont-slope depositional environments, while a perennial, low gradient fluvial (axial-river) system occupied the basin floor.

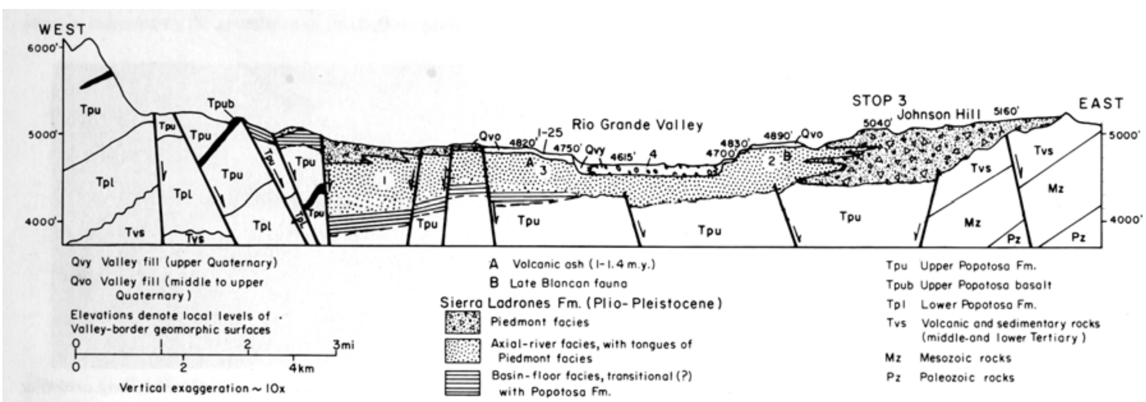

Figure 3-12. Diagramatic cross section across the Socorro basin. "STOP 3" on cross section is near Stop 5 of this guidebook. From Hawley (1983).

The diagrammatic cross section from the Nogal Canyon area (north of Socorro Peak) to the vicinity of this stop [Fig. 3-12] illustrates the complex history of late stages of basin filling and the episodic nature of middle to late Pleistocene valley cutting. The earliest axial-river deposits (3-5 Ma) were apparently emplaced along the western margin of the basin and are now partly incorporated in the uplifted Socorro Mtn block [Chamberlin, 1980; 1999]. Fluvial sands exposed along the lower reach of Arroyo de la Parida contain a Blancan vertebrate fauna of late Pliocene to early Pleistocene age (more than 1.5 m.y., Tedford, 1981; Lucas and Morgan, this guidebook). This unit is extensively preserved in bluffs east of the Rio Grande and intertongues with thick fan deposits of the eastern piedmont facies of Sierra Ladrones Fm. Debrine et al. (1963) clearly show these facies relationships in the valley-border area between San Acacia and Arroyo de las Cañas. Between 1.5 and 0.5 Ma ago, the ancestral Rio Grande had again shifted westward to a position just west of the present valley in the Socorro-Escondida area. Volcanic ash from caldera-forming eruptions in the Jemez Mts between 1.1 and 1.4 Ma [*now 1.2-1.6 Ma*] ago is present in axial-river deposits of the Sierra Ladrones Fm exposed in the Luis Lopez quadrangle (Chamberlin, 1999). Tephra and pumice from these eruptions is also present in Sierra Ladrones fluvial facies about 3 mi. NE of San Antonio. Culmination of basin filling and the end of Santa Fe Group (Sierra Ladrones Fm) deposition occurred about 0.5 Ma ago throughout the Albuquerque to El Paso region (Hawley et al., 1976; [*now considered to be earlier; 1.0-0.7 Ma*]). The summit area of Johnson Hill probably approximates the ultimate level of basin aggradation. The history of late stages of basin filling represented by the Sierra Ladrones Fm is obviously complicated by significant structural deformation (Machette, 1978b) as well as by shifts in hydrologic regimes. Detailed surface, subsurface, biostratigraphic and tephrochronologic studies of Sierra Ladrones Fm are just getting started in the Socorro area and much work still needs to be done.

The modern valley is a relatively narrow erosional feature of a river system that is just beginning to cut its way into an enormous volume of older fluvial deposits. Valley landforms represent at least 4 major episodes of river entrenchment separated by periods of partial valley back filling or relatively steady-state conditions in terms of local floodplain base levels. Episodes of widespread valley incision appear to correlate with major expansions of pluvial lakes and alpine glaciers in the southern Rocky Mountain and Basin and Range provinces. The extensive remnants of graded surfaces flanking the inner Rio Grande valley in this region represent not only early valley degradational stages, but also long periods of valley-floor aggradation or relative gradational stability. The latter intervals probably reflect interglacial environments of the type exhibited in the Holocene when tributary (arroyo) drainage systems delivered more sediment to valley floors than master streams could remove from the middle Rio Grande basin.

The Socorro area is a classic area in terms of being the site of early studies on desert-valley evolution by Kirk Bryan and his students. Most of the early geomorphic work was done by Denny (1940). As in the case of studies on the upper Santa Fe Group, structural and paleoclimatic complications are not conducive for simplistic models of evolution of valley-border landforms; much detailed work remains to be done before geomorphic surfaces and stratigraphic units can be formally defined.

Follow road back down Johnson Hill to valley of Arroyo de la Parida. **0.3**

100.7 White exposures across Rio Grande valley are the Grefco perlite mine (7.85 Ma) at the eastern flank of the Socorro Range. The 3.78 Ma Socorro Canyon flow south of the mine overlies ancestral Rio Grande deposits and is faulted down-to-the-east by the Socorro Canyon fault (Chamberlin, 1999; Ayarbe, 2000). **1.6**

102.3 Turn right onto dirt road on north bank of Parida Arroyo. **0.7**

103.0 Bear right at top of hill onto Quaternary tributary/piedmont deposits. **0.4**

103.4 Cross arroyo. **0.2**

103.6 Cross arroyo. **0.4**

104.0 Proceed through gate. **0.1**

104.1 Pull off road near arroyo floor. **Stop 6.** Look at detailed sedimentary structures of the ancestral Rio Grande. Upstream are cemented faults cutting the fluvial deposits. *Mesa del Yeso 7.5' quadrangle, GPS: NAD 83, UTM Zone 013 S, N: 3,779,975 m; E: 327,235 m.*

Gordon (1910) first described deposits of Arroyo de la Parida as the Palomas gravels (now Fm). The Palomas Fm is one of the oldest stratigraphic terms in the Rio Grande rift (*see* Lozinsky and Hawley, 1985a), however, it was not formally defined until Lozinsky and Hawley (1986b) designated a type section near Truth or Consequences, NM, about 120 km south of Socorro, NM. Although Gordon (1910) mapped the Palomas gravels near San Marcial, NM, about 50 km south of this stop, a photograph of Arroyo de la Parida was shown as an example of the Palomas gravels. The antiquity of the ancestral Rio Grande system was demonstrated by Needham (1936) who reported the presence of the Pliocene elephant *Rynchotherium* in fluvial deposits in Arroyo de la Parida (*see Morgan and Lucas, this volume*). Debrine et al. (1963) delineated piedmont and fluvial facies in the northern Socorro basin, which were subsequently assigned to the Sierra Ladrones Fm by Machette (1978d) in his compilation of the Socorro 1º x 2º, and later by Osburn (1983) in the Socorro County geologic map. Hawley (1978) extended the term Sierra Ladrones Fm to the Albuquerque and Socorro basins. Subsequent mapping differentiated additional lithofacies in the axial-fluvial and piedmont units (Cather, 1996; Chamberlin, 1999, 2001, Chamberlin and

Eggleston, 1996), although recent work suggests that deposits in Arroyo de la Parida, and perhaps the throughout the Socorro basin, should be assigned to the Palomas Fm (Morgan et al., 2000).

The Albuquerque Basin is 30-55 km in width and represents the southernmost major contributory basin of the Rio Grande system (Lozinsky and Hawley, 1991), where the Rio Grande fluvial system received water and sediment from large perennial tributaries, such as the Rio Puerco, Rio Jemez, and Rio Chama, that originated in the southern Rocky Mountains and Colorado Plateau. With an area of 19,040 km^2 the Rio Puerco drainage basin is the largest tributary to the Rio Grande in New Mexico and drains uplands that reach about 3200 m (10,500 ft) in elevation (Heath, 1983). The Rio Puerco currently enters the Rio Grande near the southern terminus of the Albuquerque Basin. The Rio Puerco system and other large drainages that originate along the western margin of the basin are part of the Arroyo Ojito Fm concept of Connell et al. (1999). The contributory aspect of the Albuquerque Basin is expressed in the concept of the Arroyo Ojito Fm, which forms the largest (volumetrically and areally) component of the upper Santa Fe Group basin-fill system in the Albuquerque Basin. The boundary between the Socorro and Albuquerque basins lies between the Rio Salado and San Lorenzo Arroyo. At this transition, the Arroyo Ojito Fm is difficult to distinguish, and presumably becomes integrated with the Rio Grande.

The Socorro, San Marcial, Palomas, and Engle basins are considerably narrower than the Albuquerque Basin and form fairly simple half-graben basins. The Socorro basin is about 9-12 km wide and was formed as the Lemitar and Socorro ranges were uplifted during late Miocene time (Cather et al., 1994). The Rio Grande system converges into a single trunk river, with local distributary and tributary drainages, in the northern Socorro basin, where both the ancestral and modern rivers are bound within a relatively narrow half-graben basin with relatively well defined footwall and hangingwall drainages. In these basins the Rio Grande system is confined to a relatively narrow axial zone in the deepest part of these half-graben basins (Lozinsky and Hawley, 1991). The presence of larger tributary drainages, such as Palomas and Cuchillo Creeks, influences sedimentation in these well-defined half-graben basins, but probably not to the extent as in the Albuquerque Basin.

Near the northern margin of the Mesilla basin, just south of Hatch, NM, and about 175 km south of Socorro, NM, the Rio Grande system forms a large, distributary fluvial braidplain of the Camp Rice Fm extending southward into closed basins of the Texas-Chihuahua border region (Lozinsky and Hawley, 1991).

We provisionally favor re-assignment of deposits in Arroyo de la Parida to the Palomas Fm for the following reasons: 1) Arroyo de la Parida was part of the original Palomas Fm concept of Gordon (1910); 2) the transition from contributory drainage in the Albuquerque Basin to trunk-river deposition to the south, as delineated by the distribution of the Arroyo Ojito Fm, suggests the presence of single axial-fluvial system south of San Acacia, NM; and 3) the structural setting of the Socorro basin (i.e., well defined half graben) and stratigraphic architecture of its deposits are quite similar to those of the Palomas and Engle basins, which have been assigned to the Palomas Fm; however, further study is underway to test this proposed assignment.

Retrace route back to I-25. End Day 3 road log.

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