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 sub-surface. 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.

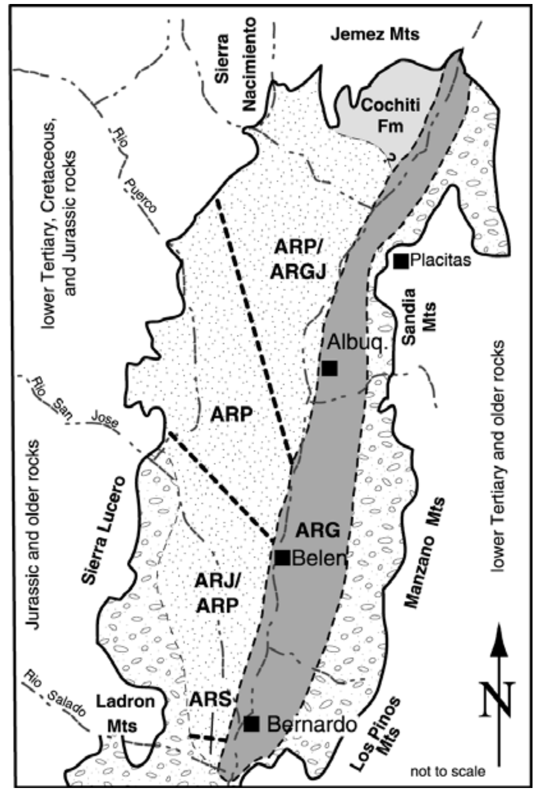

Figure 3-2. Schematic map showing the approximate areal distribution of major lithofacies in Pliocene sediments of the upper Santa Fe Group (modified from Connell et al., 1999). The south-flowing ancestral Rio Grande (ARG) is the axial-fluvial facies (moderate gray shading). The Arroyo Ojito Fm (stippled 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).

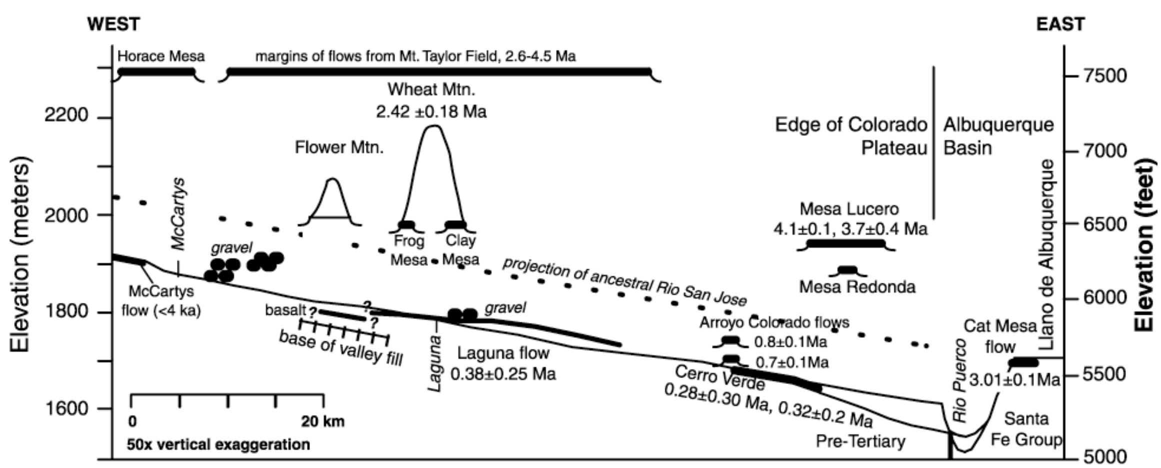

Figure 3-3. Longitudinal profile of the Rio San Jose from the distal end of McCartys flow to the confluence with the Rio Puerco and western edge of the Llano de Albuquerque surface (modified from Love, 1989 with date of Cat Mesa flow from Maldonado et al., 1999). Stratigraphic data indicate that the 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.

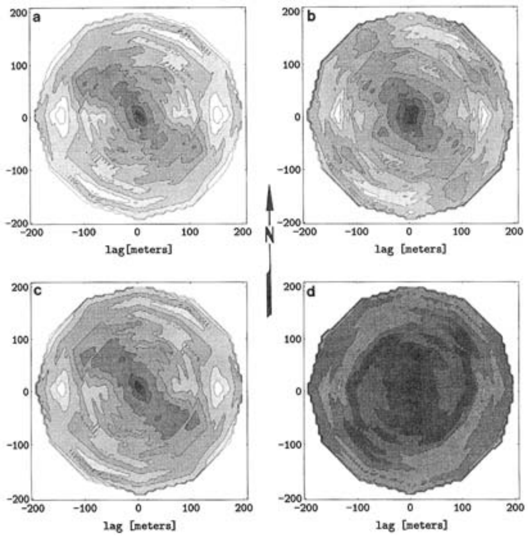

Figure 3-4. Azimuthal horizontal variograms constructed by combining horizontal variograms estimates of N0E, N30E, N90E, N30W, and N60W. (a) Log-permeability data set; (b) CH-II element indicator data set. (c) OF element indicator data set. (d) P_s element indicator data set. Contours are in units of 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**

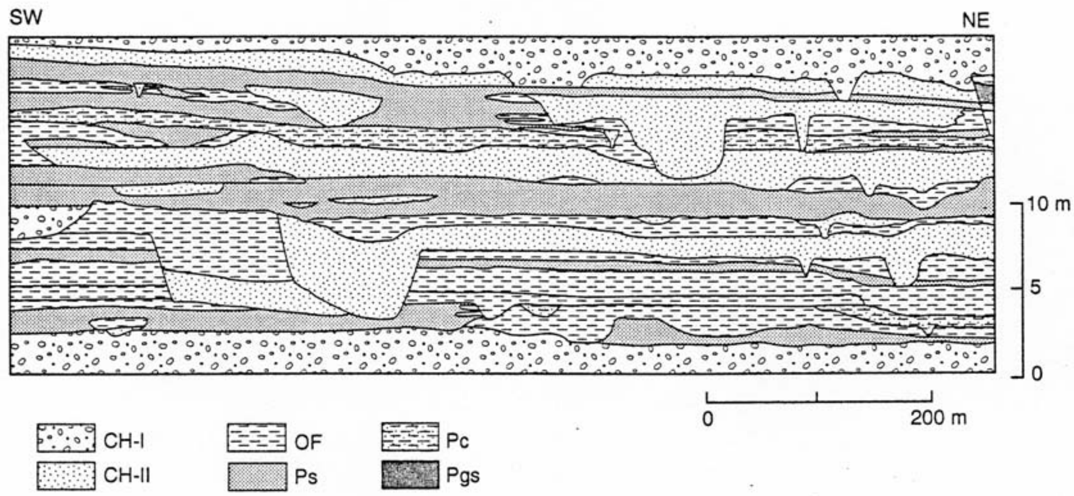

Figure 3-5. Architectural elements of Arroyo Ojito Fm near Milepost 185. Architectural elements include coarse gravelly sand channels (CH-I), medium- to fine-grained sandy channels (CH-II), overbank silt and clay (OF), and soils (sand, Ps; clay, Pc; and mixed gravel and sand Pgs). From Love et al. (1999).

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

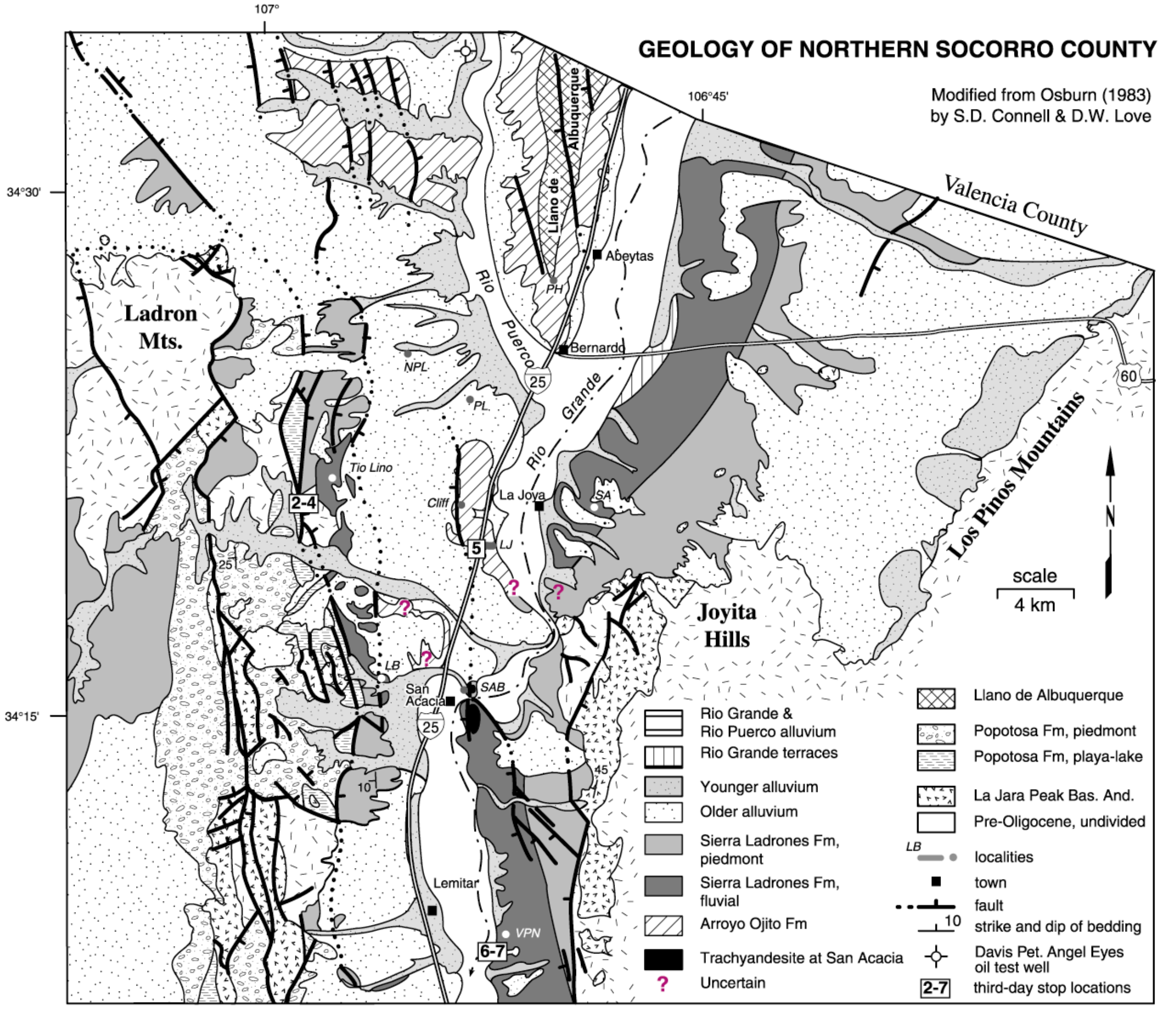

Figure 3-6. Generalized geologic map of the southern Albuquerque and northern Socorro basins in Socorro County. Geologic map was modified from Osburn (1983) using unpublished reconnaissance mapping, including Cather (1996), Chamberlin (1999), and Chamberlin et al. (2001). Queried areas indicate localities 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

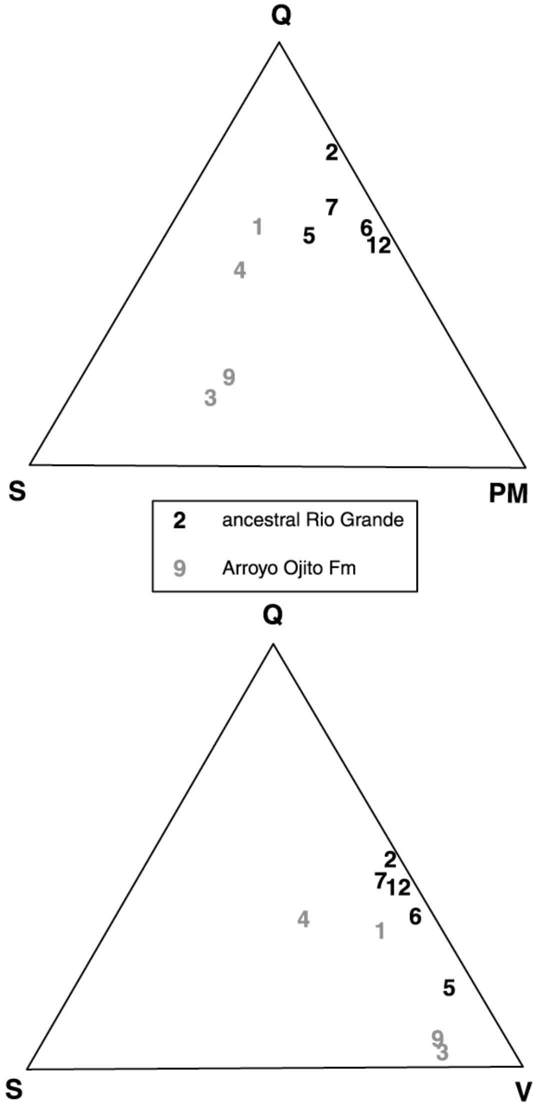

Figure 3-7. Preliminary results of gravel petrography from selected sites in the Belen sub-basin and northern Socorro basin (see Fig. 3-6 for localities). Localities include, La Joya unit 4 (1), Loma Blanca unit 14 (2), La Joya unit 23 (3), Picho Hill (4), La Joya unit 1 (5), Parida North unit 1 (6), 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.

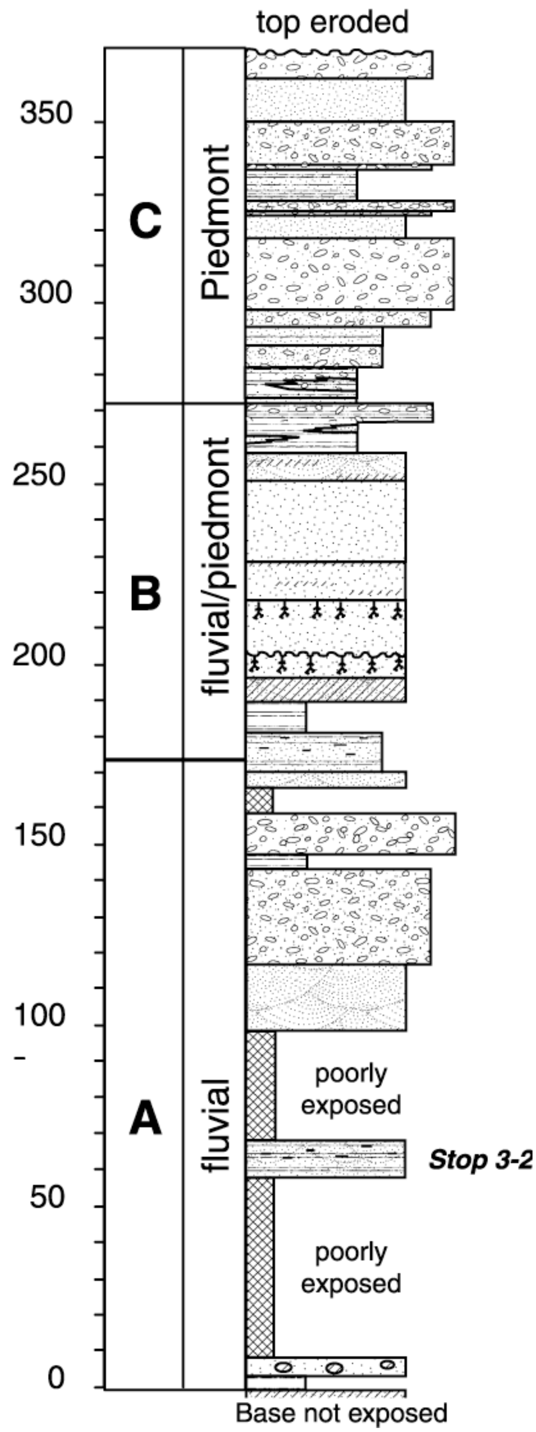

Figure 3-8. Stratigraphic column of the Tio Lino section illustrating fluvial and piedmont facies of the Sierra Ladrones Fm. Thickness is in meters.

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**

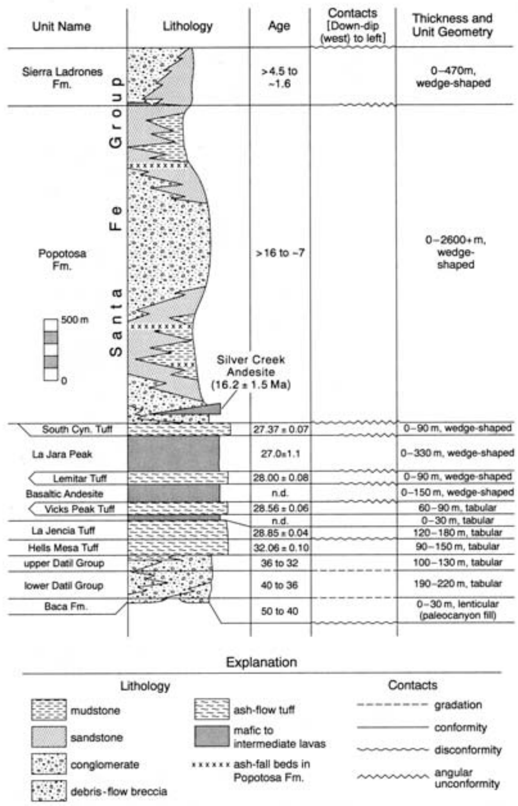

Figure 3-9. Simplified stratigraphic column for Cenozoic rocks in the southern Belen sub-basin, and Socorro and La Jencia basins. From Cather et al. (1994).

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.

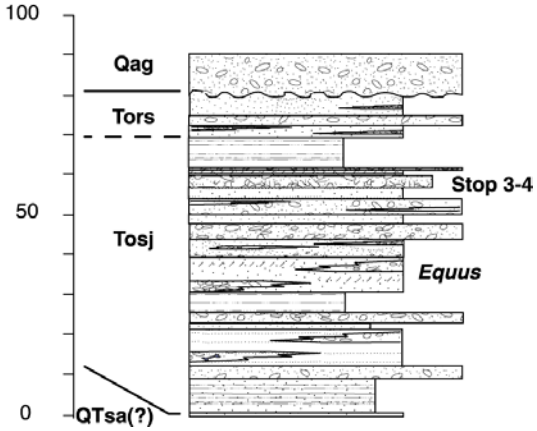

Figure 3-10. Stratigraphic column of La Joya site, Stop 4. The base contains a light-gray sand that is possibly correlative to the ancestral Rio Grande facies (Sierra Ladrones Fm). This is overlain by deposits of the Arroyo Ojito Fm, which are provisionally subdivided into a Rio San Jose (Tosj) and overlying 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**

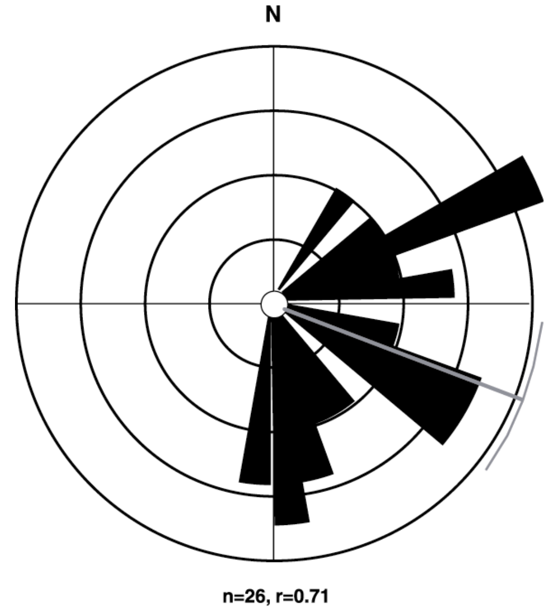

Figure 3-11. Paleocurrent rose (in 10° intervals) for Arroyo Ojito Fm (upper Santa Fe Group) near Stop 4, including correlation coefficient (r). The NE-trending cluster is from the upper part of the section (Fig. 3-10), which contains abundant volcanic gravel correlated to the ancestral Rio Salado.

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.

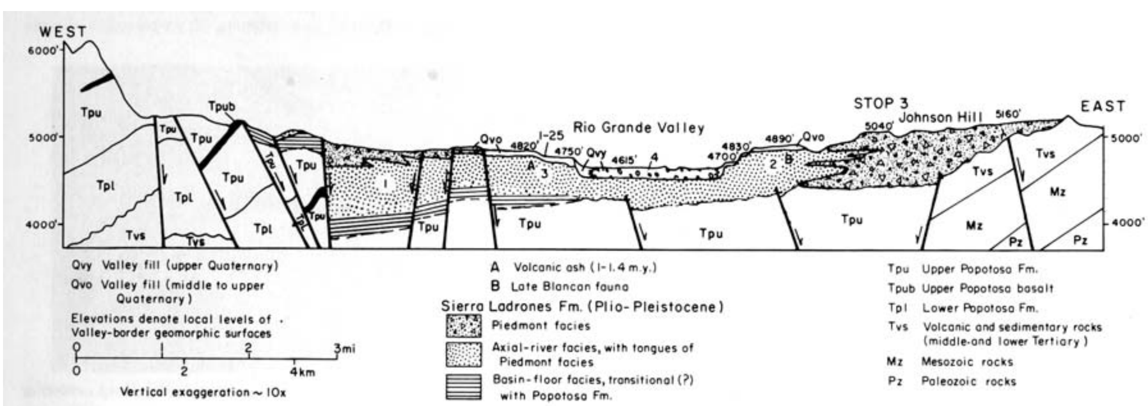

Figure 3-12. Diagramatic cross section across the Socorro basin. "STOP 3" on cross section is near Stop 5 of this guidebook. From Hawley (1983).

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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