Second-day trip 2 road log: From Albuquerque to San Ysidro, Loma Creston, La Ceja, and Sand Hill Fault

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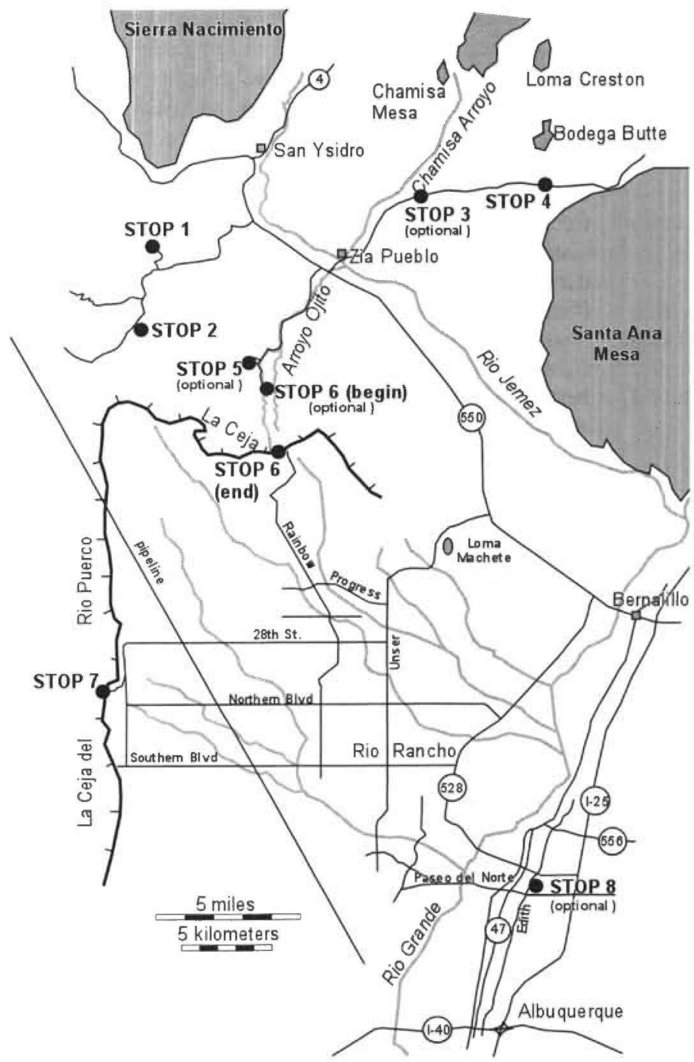
SECOND-DAY TRIP 2 ROAD LOG, FROM ALBUQUERQUE TO SAN YSIDRO, LOMA CRESTON, LA CEJA, AND SAND HILL FAULT

FRANK J. PAZZAGLIA, SEAN D. CONNELL, JOHN HAWLEY, RICHARD H. TEDFORD, STEVE PERSONIUS, GARY A. SMITH, STEVE CATHER, SPENCER LUCAS, PATRICIA HESTER, JOHN GILMORE, and LEE WOODWARD

FRIDAY, SEPTEMBER 24, 1999

Assembly point:	South end of parking lot of Hilton Hotel, Menaul and University, Albuquerque.
Departure time:	8:00 a.m.
Distance:	142.1 mi.
Stops:	6; 2 optional stops



Summary

This field trip will examine in detail the Neogene stratigraphy, sedimentology, structure, and geomorphology of the Albuquerque basin as exposed along the lower Rio Jemez valley and vicinity. Recent geologic mapping by the State of New Mexico, U.S. Geological Survey, New Mexico Bureau of Mines and Mineral Resources, University of New Mexico, New Mexico Tech, and the American Museum of Natural History has greatly enhanced our knowledge of the geologic processes responsible for rift-basin genesis and sedimentation. The ultimate goal of the mapping effort, and the sometimes tedious effort to develop a viable stratigraphy for continental basin-fill sediments (essentially a big pile of sand and gravel), is to provide a framework for understanding and better managing the finite ground-water resources of a semi-arid region. This trip will also present revisions to the stratigraphic nomenclature for the Santa Fe Group in the northern Albuquerque basin.

Mileage

0.0 Start, parking lot of Hilton Hotel. Road log follows Day 1 Road Log to Bernalillo. **15.9**

15.9 **Exit I-25 to NM-44** (NM-550). **0.3**

16.2 **Turn left** at stop light and proceed towards Bernalillo. **0.1**

16.3 Pass over I-25. **0.2**

16.5 Railroad crossing cut into alluvial fan that overlies valley-floor alluvium of the Rio Grande valley. Depth of valley alluvium at this point to the Rio Grande is approximately 82 ft (Connell, 1998). The Rio Grande valley from Cochiti Lake to El Paso is filled with a similar thickness of alluvium that sits unconformably upon the Santa Fe Group. The lower approximately 65 ft of the valley-bottom alluvium is coarse-grained sand and gravel that likely represents late Pleistocene (Wisconsinan or Pinedale age) glacio-fluvial outwash. The upper approximately 30 ft represents predominantly Holocene vertically accreted fine-grained overbank material. This late Pleistocene–Holocene valley fill is the most recent valley-bottom alluvial fill produced in the Rio Grande valley in response to glacial-interglacial and climate-hydrological changes. **0.1**

16.6 Enter Bernalillo, the county seat for Sandoval County. The town has a long pre-Spanish Native American history as a center for the Tiguex people, ancestors of the modern southern Tiwa peoples of Sandia and Isleta Pueblo. In September 1540, Francisco Vasquez de Coronado reached Kuaua Pueblo, thought to have been located to the south near the (soon to be relocated) dairy farm on NM-528, and after violent confrontations with the inhabitants, established winter headquarters here. He returned to Kuaua for the winter of 1541 after failing to find the fabled seven cities of Cibola. A century later saw the establishment of several large and prosperous haciendas and ranchos along the Rio Grande with the largest among them belonging to the Gonzales-Bernal family. Don Diego de Vargas reestablished the Spanish settlements here during the reconquest (1692–1694) and may have named the town after a member of the Bernal family. Bernalillo thrived as an important trading center for the next two centuries with "the Merc," short for Bernalillo Mercantile Company, becoming the base of operations for an expansive late 19th century commercial empire. Bernalillo was chosen as a railroad center by the Santa Fe railroad in the middle of the 19th century, but a wealthy landowner, Don José Leandro Perea, demanded such a large price for the land that the railroad relocated 20 mi to the south at Albuquerque. The rest, as they say, is history. **0.3**

16.9 Intersection with Camino del Pueblo. **0.5**

17.4 Intersection with Camino Don Tomas. **0.3**

17.7 Cross the Rio Grande (Fig. 2.2.1) and riparian bosque developed in the river's floodplain. The establishment of such a dense cottonwood forest along the Rio Grande is a recent and not wholly natural phenomena resulting from construction of jetty jacks, to channelize the river, and levees by the Middle Rio Grande Conservancy District between its founding in 1923 and 1935 (Daves, 1995). Paleobotanical studies in the Sierra Ladrones Formation, near Tijeras Arroyo in Albuquerque, demonstrate that cottonwood bosques have been present since at least the early Pleistocene (Knight et al., 1996). However, nurturing floods, necessary for cottonwood reseeding, were later all but eliminated by the construction of dams upstream on the Rio Grande and its tributaries, especially the closure of Cochiti Dam in 1975. Without flood-induced establishment of new growth, this cottonwood forest is now rather old and in substantial decline. Furthermore, the levied channel has locally resulted in aggradation such that the channel bottom may lie higher than its adjacent floodplain. An outstanding account of contemporary channel hydraulic geometry adjustments attributed to the Cochiti Dam flood control project can be found in Lagasse (1981).

FIGURE 2.2.1. Photograph of the Rio Grande at Bernalillo.

Coarse-grained rounded fluvial gravel exposed at 1:00 on the river's western bank have been correlated to the Edith Formation (Smartt et al., 1991; Lucas et al., 1988); however, the western terrace strath (basal contact) is 80–100 ft lower than the lowest exposed strath along I-25 near Mile 15 (Fig. 2.2.2). One possibility is that the Edith Formation has been deformed in the past 150 ka by faults, such as the Bernalillo fault (Connell, 1998), associated flexure attributed to the Alameda monocline (see Day 1 Road Log; Connell, 1997), or the

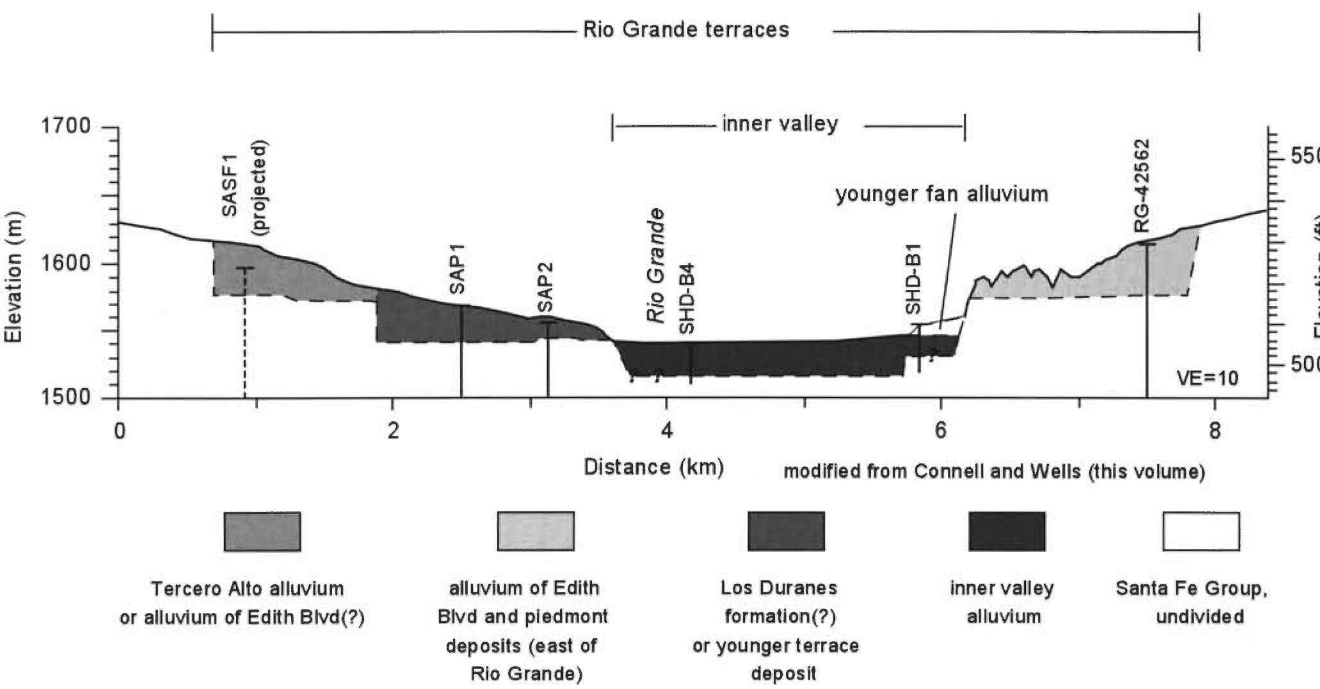


FIGURE 2.2.2. Cross-section along NM-44 through Bernalillo showing elevation of terraces.

Rio Grande fault zone of Russell and Snelson (1994). Terrace deposits mapped as Edith Formation (cf. Connell, 1997, 1998; Connell et al., 1995), east of the Rio Grande, can be traced south to the type Edith Formation section in Albuquerque (Lambert, 1968). East of the Rio Grande, the Bernalillo fault (Day 1 Road Log, Mile 13.5) accounts for only 23 ft of down-to-the-west displacement of the Edith Formation (Connell, 1995). Another fault zone that could account for deformation of the Edith Formation is the Rio Grande fault zone of Russell and Snelson (1994) that is apparently buried by Pleistocene and Holocene alluvium along much of its trace. The Rio Grande fault is postulated as a major intrabasinal fault with significant down-to-the-west displacement of basin-fill deposits. This structure is interpreted by Russell and Snelson (1994) to be a younger fault that stepped westward of other major rift-border faults (i.e., Rincon and San Francisco faults, see Day 1 road log) into the basin, thereby structurally narrowing the northern Albuquerque basin during the Pliocene. However, geomorphic and stratigraphic studies of alluvial deposits along the northern and western flanks of the Sandia Mountains do not support major Pliocene–Quaternary deformation across its projected trace (Connell and Wells, this volume) and its role in accounting for deformation of the Edith terrace strath is doubtful. Terrace deposits on both sides of the Rio Grande contain Rancholabrean-age fauna (ca. 10–500 ka). However, the presence of *Bison latifrons* in fluvial deposits exposed only several yards above base level west of the Rio Grande (Smartt et al., 1991) suggests that this terrace was deposited prior to the late Pleistocene as hypothesized by Lambert (1968). In the absence of tectonic deformation of the Edith terrace, these apparently unpaired terraces (the Edith Formation proper east of the Rio Grande and the "Edith" exposed here west of the Rio Grande) probably represent two distinct episodes of incision and partial aggradation of the ancestral Rio Grande. Thus, the Edith Formation exposed east of the Rio Grande is older than gravel exposed at 1:00 as you cross the bridge. The gravel exposed here might be coarse paleo-valley bottom alluvium intermediate (possibly correlative to marine isotope stage 4) to the Edith Formation (stage 6) and modern valley bottom (stages 1 and 2). **0.3**

18.0 Pass entrance to Coronado State Monument. The monument covers a portion of the site of two large pre-Spanish Tiguex Pueblos, Kuaua and Puaray, and is constructed on the Los Duranes surface of Lambert (1968). Recent consideration of the Quaternary stratigraphy along the Rio Grande suggests that the Los Duranes formation is underlain by the Segundo Alto terrace surface. The Los Duranes formation is underlain by middle Pleistocene (ca. 150 ka) coarse- and fine-grained valley bottom alluvium. **0.1**

18.1 Ascend the Los Duranes-Segundo Alto terrace tread. **0.2**

18.3 Exposure at 4:00 of coarse Rio Grande alluvium in the small high wall behind GL Trees and Landscape products. **0.1**

18.4 Road to Jemez Canyon Dam (U.S. Army Corps of Engineers) to your right. This road ends at a picnic area and scenic overlook of the lower Rio Jemez Valley, and faulted Pliocene (ca. 2.4 Ma, Bachman and Mehnert, 1978) basalt of the Santa Ana Mesa. **0.2**

18.6 Stop light at intersection with NM-528. San Felipe volcano, one of the sources for the Pliocene flows of Santa Ana Mesa (2.41 Ma, McIntosh, unpublished data; Connell, 1998) is visible at 2:30. The slightly older Pliocene maar, Canjilon Hill, is visible at 3:00. **0.5**

19.1 Ascend terrace riser between Segundo Alto and Tercero Alto. The Tercero Alto terrace is an informal term referring to a high-level terrace gravel 230–260 ft above the Rio Grande. This terrace is inset against the Llano de Albuquerque (Machette, 1985), an abandoned constructional surface that marks the highest level of basin aggradation in the Santa Fe Group, west of the Rio Grande. The Llano de Albuquerque will be discussed in more detail between Stops 6 and 7. The Tercero Alto alluvium is overlain by the middle Pleistocene (~156 ka; Peate et al., 1996) basalts of the Albuquerque volcanoes. The maximum vertical extent of incision by the Rio Grande during the Pleistocene is approximately 330–660 ft. **0.3**

19.4 Exposure of a soil with about stage II+ calcic horizon development in the roadcut at 3:00. As we proceed west out of the Rio Grande Valley, we pass the westernmost limit of inset fluvial terrace deposits laid down by the ancestral Rio Grande. We ascend a valley margin with numerous complex Quaternary arroyo fills reflecting a long-term reworking of the Santa Fe Group and a well-developed soil that underlies the constructional top of the Santa Fe Group deposits to our immediate west. The entire valley margin here, and West Mesa for that matter, is also mantled by several late Quaternary eolian deposits which will be well exposed by housing developments ahead of us on the left side of the road. **0.9**

20.3 Calcic soil exposed at 1:00–12:00 marking a broad, high-level east-sloping alluvial slope. **0.3**

20.6 Roadcut contains exposure of the Luce fault (Fig. 2.2.3). The Luce fault is an important down-to-the east fault on the western margin of the Rio Grande rift. This fault marks the western margin of the San Felipe graben, which roughly defines the southwestern margin

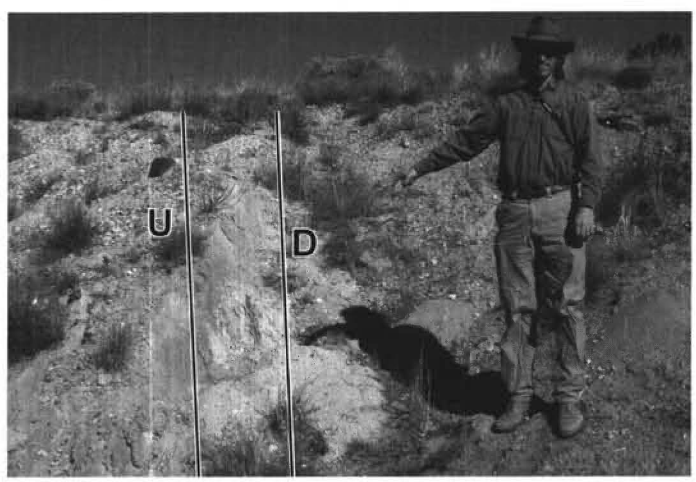


FIGURE 2.2.3. Photograph of the Luce fault.

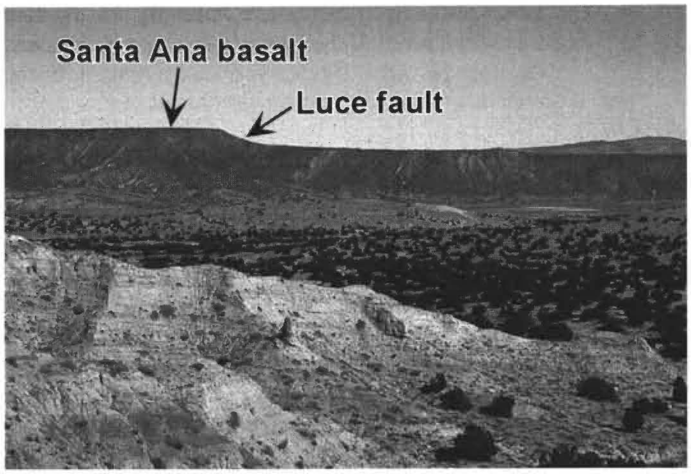


FIGURE 2.2.4. Photograph of offset of the Santa Ana basalt by the Luce fault.

of the Santo Domingo basin. One of the main reasons why older syn-rift sediments are exposed ahead of us is because they lie in the footwall of this fault. The fault here is buried by younger Quaternary alluvium with a well-developed calcic soil. To the north, this fault is well expressed as a prominent down-to-the-east scarp in the Pliocene basalt of Santa Ana Mesa. This relatively strongly developed soil suggests that the latest ground-rupture event on the Luce fault at this location occurred prior to the late Pleistocene. **1.6**

22.2 Offset basalt of Santa Ana Mesa by the Luce fault at 4:00 (Fig. 2.2.4) with the Santa Fe Range and Truchas Range of the Sangre de Cristo Mountains marking the skyline. **0.5**

22.7 Badlands at 9:00 expose the Loma Barbon Member of the Arroyo Ojito Formation, conformably capped by possible Ceja Member conglomeratic sand of the Arroyo Ojito Formation, and unconformably capped by coarse-grained fault-scarp-derived alluvium and colluvium (Pantadeleon Formation). Two down-to-the-west faults are well exposed here and responsible for the obvious change in dips from west to east in the Loma Barbon Member (Fig. 2.2.5). The westward-dipping coarse-grained material in the westernmost portion of the badlands exposure is Quaternary alluvium and colluvium derived from erosion of the uplifted eastern footwall of the faults exposed here. Loma Barbon at 9:00–10:00. A volcanic ash exposed on a ridge less than 1.25 mi to the northeast yields a $^{40}Ar/^{39}Ar$ date (on sanidine) of 6.82 Ma (W. C. McIntosh, written commun., 1998; Connell, 1998). **0.7**

23.4 Sierra Nacimiento exposed ahead at 11:00 with White Mesa between 10:00 and 11:00. The eastern limb of the Ziana anticline is visible between 9:00 and 10:00. A distinct angular unconformity between Quaternary alluvial slope deposits and more steeply-dipping sediments of the Arroyo Ojito Formation (possibly the Navajo Draw Member) and the pinkish beds of the Cerro Conejo Formation is visible even from this distance. The Ziana anticline is defined by dipping beds of the Santa Fe Group associated with a well-defined horst. At this location we cross several down-to-the-east faults on the eastern flank of the horst. Stop 3 will be on the Santa Ana fault, an important down-to-the-east fault exposed along the southern flank of the Jemez Mountains between 1:00 and 3:00. The oldest portion of the rift fill, the Zia Formation, is exposed in the core of the Ziana anticline. The anticline was penetrated by the oil-test-well Shell Santa Fe Pacific No. 1, drilled to a depth of 10,955 ft where it ended in Precambrian rocks (Black and Hiss, 1974; see note for mile 86.4). **0.5**

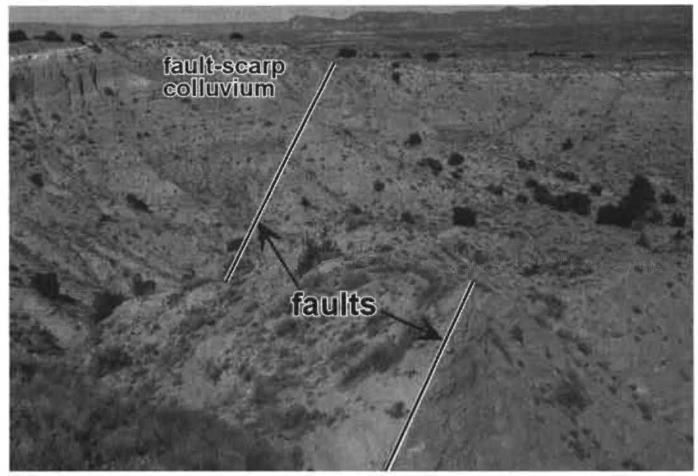


FIGURE 2.2.5. Annotated photograph of the faults exposed in the NM-44 badlands. View is to the northwest. Note west-dipping Quaternary(?) fault scarp colluvium.

23.9 Cross broad valley fill inset into Santa Fe Group. The valley fill is part of an abandoned alluvial slope that once graded to a now eroded terrace of the ancestral Rio Jemez. **1.0**

24.9 Cross valley incised into the Cerro Conejo Formation 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, unpublished data) to match two Snake River Plain/Yellowstone hotspot tephra from the Trapper Creek section of southern Idaho. Age estimate of the best match is 11.2 ± 0.1 Ma (Perkins et al., 1998) or 11.1 ± 0.1 Ma if U.S. Geological Survey Menlo Park hornblende standards are used. A weaker match to a higher tephra in the same section is dated at 10.94 ± 0.03 Ma (all dates are feldspar laser-fusion $^{40}Ar/^{39}Ar$). The 11-Ma age of this ash agrees well with biostratigraphic data obtained from the Cerro Conejo Formation here and elsewhere which place this body of rock in the latest Barstovian-Clarendonian land-mammal "age" (cf. Tedford, 1981). **0.4**

25.3 Outcrop of ledgy, cemented sandstone beds in the Zia Formation. **0.2**

25.5 Volcanic ash exposed in arroyo at 3:00. **0.3**

25.8 Outcrops of Zia Formation at 3:00. **0.6**

26.4 Roadside viewpoint and historical marker of the old Pueblo of Santa Ana on the north side of the Rio Jemez at 3:00. **1.0**

27.6 Volcanic rocks and Santa Fe Group sediments are well exposed at the southern flank of the Jemez Mountains between 1:00 and 2:30. From left to right is Chamisa Mesa, capped by the 10.8-Ma Chamisa Mesa basalt (Bailey and Smith, 1978) and thought to be the oldest volcanic rock preserved along the southern flank of the Jemez Mountains. Other features underlain by basaltic

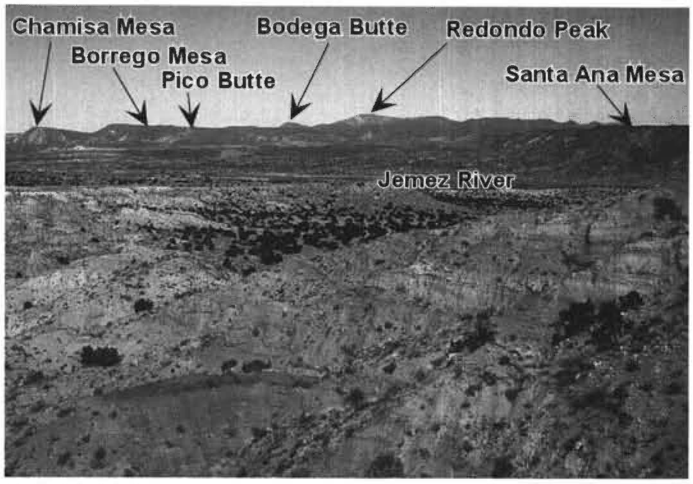


FIGURE 2.2.6. Annotated photograph of the southern flank of the Jemez Mountains.

rocks include Chamisa Mesa, Borrego Mesa, and Bodega Butte (Fig. 2.2.6). **0.5**

28.1 Cross arroyo. Note that many arroyos tributary to the Rio Jemez are not incised, which stands in contrast to the deeply entrenched arroyos of the Rio Puerco valley farther west. **3.5**

31.6 Roadcuts of the Zia Formation, probably the Chamisa Mesa Member. The Zia Formation is predominantly poorly cemented eolian sand and is poorly exposed, except in regions undergoing recent rapid fluvial incision. **2.7**

34.3 Entrance to Zia Pueblo at 3:00. The Pueblo sits atop a middle Pleistocene terrace tread (Qt4, Formento-Trigilio and Pazzaglia, 1998) north of the Rio Jemez. **1.6**

35.9 The western flank of the Rio Grande rift, eastern margin of the Colorado Plateau, and southern tip of the southern Rocky Mountains can be seen from 11:00–3:00. The high peak at 2:00 is Pajarito Peak of the Sierra Nacimiento. In the foreground of Sierra Nacimiento are two monoclines marked by the trace of the yellow Agua Zarca Formation of the Upper Triassic Chinle Group. The Permian–Upper Triassic section is exposed beneath the eastern monocline at 2:30. Moving to the left (west) and upsection from the Agua Zarca Formation is the Chinle Group and Jurassic section capped by the Todilto Formation underlying White Mesa at 12:00. The Jurassic and Cretaceous section continues between 11:00 and 12:00, and is faulted against the Santa Fe Group between 10:00 and 11:00. **1.0**

36.9 **Move into left hand lane. 0.3**

37.2 Outstanding view of the Rio Jemez Valley incised through an ignimbrite sheet of the upper Bandelier Tuff (ca. 1.2 Ma) and Permian sandstone at 3:00. The 1996 NMGS Jemez Mountains field guide (Goff et al., 1996) provides a detailed description of the geology through this valley. **0.5**

37.7 **Turn left** onto Cabezon Road and stay straight, passing onto Zia Pueblo land. Road to right leads to gypsum mine leased from Zia Pueblo, and operated by the Centex American Gypsum Company, formerly American Gypsum Company. The operation provides a supply of gypsum for its two wallboard manufacturing plants in Albuquerque, and Bernalillo. Traditional mining practice was to extract gypsum in two lifts of up to 10 m, using explosives to break apart the deposit. American gypsum currently utilizes a Roto-Mill Pavement Profiler that is normally used in highway maintenance. In mining gypsum the profiler removes successive layers, 4 in. thick and 7.2 ft wide by means of a revolving drum fitted with cutting teeth. Profiled gypsum is directly conveyed into trucks moving alongside the profiler, or windrowed to the side of the mined area for later front-end loading. At the current rate of mining, the operation has reserves to last for the next several decades. **0.3**

38.0 Road traverses Summerville Formation with Todilto gypsum to your right, and Morrison Formation (Brushy Basin Member) to your left. **0.3**

38.3 Cross north-striking, down-to-the-east San Ysidro segment of the Jemez fault system (Woodward and Ruetschilling, 1976). The Jemez fault is an important structure along the western margin of the Rio Grande rift. To the north, it places Precambrian against Neogene basin fill. To the south, it places the lower and middle Santa Fe Group (Zia Formation) against the uppermost Santa Fe Group (Ceja Member of the Arroyo Ojito Formation). This fault has clear evidence for Pliocene and early Quaternary displacement exposed along La Ceja. **0.9**

39.2 Pass narrows through the Salt Wash Member of the Morrison Formation. **0.6**

39.8 Cross arroyo. Jackpile Member of the Morrison Formation at 2:00. **0.3**

40.1 Strike ridge underlain by southwest-dipping yellow Jackpile Member of the Morrison Formation overlain by white, carbonaceous Encinal Canyon Sandstone of the Dakota Formation (Aubrey, 1988; Lucas et al., 1998). **0.3**

40.4 Strike valley developed in shale of the Oak Canyon Member of the Dakota Formation with west-dipping cuesta of the Cubero Sandstone Tongue of the Dakota Formation (Cretaceous) at 2:00. **0.4**

40.8 Road bends west and traverses a broad synclinal valley underlain by the Cretaceous Mancos Formation. The Juana Lopez Member of the Mancos Formation, here a fossiliferous calcareous sandstone with numerous ammonites and the ribbed oyster *Lopha lugubris* (Landis et al., 1973), forms the south-dipping butte at 9:00. Beyond the Juana Lopez ridge to your south lies Neogene basin fill and the distinctive north-facing escarpment called La Ceja (Spanish for "the edge" or "the eyebrow"). **0.6**

41.4 Emergent nose of south-plunging syncline, outlined by the Cretaceous Two Wells Tongue of the Dakota Sandstone (Dane et al., 1971) at 3:00. The eastern flank of the Tierra Amarilla anticline is at 1:00. **0.3**

41.7 Pass onto public (BLM) land. East-dipping strike ridges underlain by Jurassic and Cretaceous sandstones mark the eastern limb of a south-plunging anticline. **0.6**

42.3 Slow and **turn right** through gate. *This gate is typically locked and vehicle access is restricted. You must obtain permission from the Bureau of Land Management in Albuquerque to drive to Stop 1.*

FIGURE 2.2.7. Annotated panorama of photographs, looking north from Stop 1.

Otherwise, pull off to side of the road and walk the log to Stop 1. **0.2**

42.5 Stay right on unimproved dirt road. **0.1**

42.6 **Turn left** and ascend dirt road to parking area on gypsum of the Todilto Formation. **0.6**

43.2 **STOP 1.** Overview of Day 2 stops and Tierra Amarilla anticline (Fig. 2.2.7). The purpose of this stop is to obtain an unparalleled vantage point of the Day 2 stops and lay out the general tectonic, stratigraphic, and structural setting for the western margin of the Rio Grande rift. This stop is at the southern nose of a south-plunging anticline. The anticline is breached by streams that expose from core to flank: Triassic Chinle Group (maroon), Jurassic Entrada Sandstone (orange and white), Jurassic Todilto Formation (white), Jurassic Summerville Formation (dark red, yellow, and brown), Jurassic Morrison Formation (variegated red, purple, buff, and green), Cretaceous Dakota Formation, and Cretaceous Mancos Formation.

This stop is a unique place where three physiographic provinces and a volcanic lineament are all juxtaposed. From this vantage point, the southern Rocky Mountains (Sierra Nacimiento) lie to the north, the Colorado Plateau lies to the west, and the Rio Grande rift lies to the east and south. Several volcanic plugs, including Cabezon (2.66 ± 0.06 Ma, Hallett et al., 1997), and the Mesa Prieta and Mesa Chivato basalt flows lie to the west and northwest (Fig. 2.2.8). Collectively the plugs and flows are part of the Rio Puerco necks associated volcanism (Hallett et al., 1997) that lie on the Jemez lineament. The Jemez lineament is a northeast-trending line of Neogene and Quaternary rhyolitic volcanic centers stretching from the Arizona-New Mexico border, through the Jemez Mountains in front of you between 1:00 and 2:00, and on into northeast New Mexico. The lineament has long been recognized as an important Precambrian suture (reviewed in Karlstrom and Humphreys, 1998), and is currently underlain by an anomalous low-velocity asthenosphere (Plate E). Regional crustal deformation associated with Jemez Mountains volcanism and the Jemez lineament asthenospheric anomaly has been proposed as a cause for regional, recent fluvial exhumation in the San Ysidro area (Formento-Trigilio and Pazzaglia, 1998).

Looking north, the Sierra Nacimiento marks the southwestern margin of the southern Rocky Mountains Province. Sierra Nacimiento was first uplifted as the Peñasco axis during late Paleozoic ancestral Rocky Mountain deformation and later reactivated along a high-angle, west-verging reverse fault during Laramide tectonism. The uplifted range is divided into at least two major segments (Woodward, 1987) with at least 10,000 ft of structural relief between the highest part of the uplift and the San Juan Basin (Colorado Plateau) to the west. The Phanerozoic sedimentary cover preserved on the eastern margin of the Colorado Plateau is folded into a broad syncline, that plunges into a steep monoclinal flexure, locally cut by the Laramide reverse fault, over Sierra Nacimiento. Northwest-plunging en-echelon anticlines and synclines are superposed on the broad syncline, which become anticlinal and synclinal bends adjacent to the Nacimiento range front. The youngest rock affected by the en echelon folds is the Eocene San Jose Formation (Diamond Tail and lower Galisteo Fm equivalent) that unconformably overlies Cretaceous and Paleocene rocks and thins over the anticlines. These structural and stratigraphic relationships suggest that the en-echelon folds formed pre- and syn-San Jose Formation time in response to a highly debated amount of dextral slip ranging from 1.25 mi (Woodward et al., 1987) to ~3.0 mi (Baltz, 1967), to ~12–20 mi (Cather, in press) between the Colorado Plateau and the Nacimiento block. The en-echelon folds were later deformed by continued convergence and westward-thrusting of the Nacimiento block. The breached anticline here at Stop 1 represents buckling

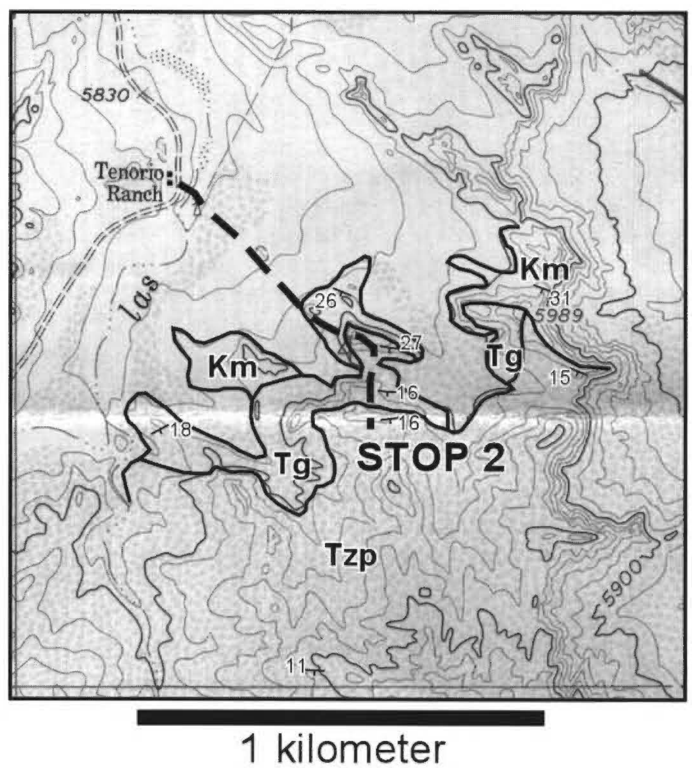


FIGURE 2.2.8. Simplified geologic map (geology by J. Pederson) of the region immediately surrounding Stop 2, including walking path.

and deformation of Mesozoic strata at the southern terminus of the Pajarito segment of the Nacimiento range front. The north-trending mound in the center of the breached anticline is a constructional mound of travertine fed by springs oriented along the southern projection of the Pajarito fault.

To the west, the Colorado Plateau extends as a relatively undeformed crustal block with a well-preserved Phanerozoic sedimentary cover. The Colorado Plateau was a relatively low-standing crustal block throughout the Paleozoic and Mesozoic. Minor deformation and uplift in the Laramide was followed by Neogene deposition of relatively thin (<0.6 mi) volcaniclastic, fluvial, eolian, and lacustrine deposits. Preservation of the various volcanic necks such as Cabezon (Spanish for "big headed") are evidence for this former Neogene sedimentary cover. More recent epeirogenic uplift, coupled with Pliocene–Quaternary climate change, have worked to strip the former sedimentary cover on the Colorado Plateau. The tectonic evolution to our south and east was decidedly different. At the close of Laramide deformation, a broad basin received up to 4265 ft of clastic deposits of the upper Paleocene(?) to upper Eocene Diamond Tail and Galisteo formations (Lucas et al., 1997). The Galisteo basin formed in response to deformation unrelated to the later development of the Albuquerque basin, so syn-rift sediments have different distributions than the older rocks.

Neogene–Quaternary extension throughout the western U.S. pulled the Colorado Plateau to the south and west, resulting in the structural inversion of much of the former high-standing Laramide topography that would have extended from Sierra Nacimiento east to the Front Range (Santa Fe Range south through the Manzano Mountains) and thick accumulations of syn-rift sediments. The Neogene strata are approximately 3300 ft thick in outcrop, and more than 13,000 ft thick in the depocenter to the southeast. Their present western limit of Neogene fill is constrained by major down-to-the-east syn-rift faults. Western-rift bounding faults strike north and bend more to the northeast as they approach the Jemez lineament. A high-angle normal fault in the axis of the Milpas valley to our immediate west, and the San Ysidro fault that we crossed at Mile 38.3 are some of the western-most rift-related structures that separate the Colorado Plateau from the Albuquerque basin. Unlike the rift-bounding structures near Albuquerque, the western margin of the rift does not have a high-standing rift flank footwall uplift. At least three other important rift structures are visible from this vantage point. The San Ysidro fault continues farther south; the juxtaposition between 5:00 and 6:00 of predominantly reddish-colored basin fill to the west against yellowish-colored basin fill to the east occurs along this fault. We will see the San Ysidro fault more clearly from Stop 6. The Sand Hill fault, which we will observe at Stop 7, continues north as the Garcia-Tenorio fault to our immediate southwest (Stop 2). And lastly, the Santa Ana fault, Stop 4, is visible at about 2:00 along the southern flanks of the Jemez Mountains. The Santa Ana fault is an important down-to-the-east fault on the eastern flank of the Ziana anticline. Older syn-rift sediments of the Zia Formation are brought to the surface by the Ziana anticline and are visible from 3:00 to 7:00. East of the Santa Ana fault only younger rift sediments are exposed. We will traverse a nearly complete section of the basin fill for Optional Stops 4 and 5.

FOSSIL SITES OF THE MORRISON FORMATION, SAN YSIDRO AREA, CENTRAL NEW MEXICO

Kim Manley

4691 Ridgeway Dr., Los Alamos, NM 87544

Approximately 6.5 km northwest of the Tenorio Ranch is an area of at least nine dinosaur fossil sites in the Jurassic Morrison Formation (Schwartz and Manley, 1992) including the *Seismosaurus* sauropod site (Gillette, 1991). The sites are located within a distance of 3 km of each other. Stratigraphically, all the sites except one are within 55 m of the base of the Brushy Basin Member. The exception is in the upper 15 m of the underlying Salt Wash Member. Each site contains dinosaur bone and/or bone fragments; teeth were present at one site. In two instances the bones are those of sauropods (*Seismosaurus* and *Camarasaurus*); in another instance the bones are from a theropod.

The most extensive find in the area to date has been the *Seismosaurus* skeleton. It consists of a partial pelvis, part of a long bone, numerous vertebrae, chevrons and ribs. This diplodocid sauropod is estimated to be between 39 and 52 m in axial length (Gillette, 1991). Another fossil site, about 8-km east, is reported to have contained a partial (~20%) skeleton of a *Camarasaurus* (vertebrae, several chevrons and rib fragments, the pubis and partial illium) (Rigby, 1982). *Allosaurus* teeth were found at both these sites and one other.

Numerous gastroliths were found throughout the area and with bone at two sites. Many (>150) were associated with the *Seisomosaurus* skeleton (Gillette et al., 1990; Manley, unpubished report, 1994). The clast size (large-pebble to medium-cobble) and lithology (mainly quartzites with lesser amounts of chert and quartz, and minor amounts of silicified shales and foliated clasts) indicate that the gastroliths of this area were not procured locally (Manley, 1991). Studies quantifying the degree of polish show that some gastroliths have higher polish than comparable clasts from either beaches or streams (Manley, 1993).

The Brushy Basin Member here is about 80 m thick and consists of variegated claystone (including altered volcanic ash), siltstone, sandstone (a few of which are well-indurated), and rare limestone (Flesch, 1974; Schwartz and Manley, 1992). Sandstone is generally arkosic arenite with minor detrital grains of heavy minerals and rock fragments—mainly volcanic. Flow directions at the *Seismosaurus* site were primarily east and northeast. The fossil sites were found in both fine-grained and sandy facies. These deposits represent fluvial channel, floodplain, pond, and playa lake deposits. Ages for the Morrison are 124 ± 28 Ma for the Brushy Basin Member (Della Valle, 1981) and 131 ± 26 Ma for the Salt Wash Member (Lee and Brookins, 1980), though these are probably anomalously young estimates.

The Morrison Formation in this area dips west to southwest <10°. It is cut by many NNW–ENE-trending faults that are predominantly down to the southwest. The southwest flank of the southern end of the Nacimiento uplift and the western margin of the Rio Grande rift are both nearby to the east. Tertiary diagenetic K/Ar ages from the Brushy Basin of 30–56 Ma reflect Laramide deformation (Woldegabriel and Hagan, 1990).

Return to vehicles and retrace path to Cabezon Road. **0.5**

43.7 **Bear right. 0.3**

44.0 **Turn right** onto Cabezon Road. **0.2**

44.2 Continue straight through the intersection with Gasco road and north-striking, down-to-the-east Milpas fault. The Las Milpas Gas Storage Facility is located to the north of the intersection of Cabezon and Gasco roads. The facility, developed by Southern Union Production Company, has been in existence since the middle 1970s and is now managed by PNM. Earlier work was conducted in the 1950s by the Ohio Oil Company. Natural gas from San Juan Basin production is brought to the facility by a trunk pipeline that leaves the main gas line located approximately 6 mi to the west of the facility. Gas is injected, stored, and extracted as demand dictates and placed back into the main line. The "reservoir" rock for the injected gas is in the Cañada de las Milpas anticline and within the Agua Zarca Formation. Depth to the reservoir rock varies from 1900 to 2400 ft. The anticline is truncated on the east by the north–south-trending Milpas fault, with a structural displacement at the surface of about 500 ft. A storage fee for gas withdrawn is paid to the Mineral Management Service on the Federal Oil and Gas leases that make up the gas storage facility. **1.1**

45.2 Cross arroyo. **0.1**

45.3 Cañada de las Milpas intersection. **Bear left** towards Tenorio Ranch. **0.2**

45.5 Cross fence. **0.4**

45.9 **Pull off road into field. STOP 2**. The Zia Formation and base of syn-rift sediments at Tenorio Ranch. The purpose of this stop is to observe the contact between pre- and syn-rift rocks and discuss the sedimentology, paleoenvironmental, and structural setting of the Zia Formation. Stop 2 is a short 0.6-mi walk to the south, beyond the windmill and across Cañada de Las Milpas (Fig. 2.2.8).

The parking area at Tenorio Ranch lies on steeply dipping Cretaceous rocks near the axis of a south-plunging syncline. The Cretaceous rocks north and west of the parking area are cut by numerous high-angle faults with likely Laramide and rift-related histories. Red-colored sandstone of the Galisteo Formation rises on the south side of the alluvial-floored Cañada de las Milpas valley. The Galisteo Formation dips between 16 and 35° to the south and west. In this area, the Tenorio fault forms the structural western boundary of the Albuquerque basin, and in the fault block defined by this fault on the west and the Jemez fault zone on the east, the syn-rift Zia Formation lies unconformably upon the Eocene Galisteo and Cretaceous Menefee formations. To the south, the rift-basin boundary is formed by the Navajo and Moquino faults, east of which the contact with the Zia Formation on the Menefee Formation is exposed. At this stop, the Piedra Parada Member of the Zia Formation unconformably overlies older rocks with a slight angular unconformity (dips are all less than 16° to the south). This unconformity is marked by a thin basal gravel that represents a stony desert strewn with intermediate-composition, ventifacted volcanic rocks of unknown provenance (Fig. 2.2.9), accompanied by well-rounded siliceous pebbles reworked from local Mesozoic and early Cenozoic rocks. The volcanic clasts could be derived from the Abiquiu Formation to the north, Mogollon-Datil volcanic field to the south, or the Espinaso Formation to the east. A thick sequence of intermediate-composition volcanic rocks is described from a well in the Puerco Valley to our southwest, so a local source is also possible. What is clear from this outcrop is that syn-Laramide(?) deformed Galisteo Formation experienced a period of subaerial erosion characterized by both coarse fluvial transport of sediment from a volcanic source and wind abrasion prior to rift-related subsidence and deposition of the Zia Formation. This period of erosion presumably occurred during the Oligocene.

The initiation of rift-basin subsidence, as indicated by preservation of the Zia Formation, began in the early Miocene approximately 21 Ma (Arikareen land-mammal "age"). The eolian facies exposed here are typical for the Piedra Parada Member of the Zia Formation. The Piedra Parada Member is a 325–395-ft-thick pinkish-white, gray, and yellow, quartz-rich, cross-stratified fine- to coarse-grained eolian dune sandstone (Galusha, 1966) and minor planar-stratified, muddy interdune sandstone (Gawne, 1981). Cross-bed orientations indicate a south and east transport direction. The Piedra Parada Member is overlain by approximately 680 ft of red, yellow, and buff-colored fluvial and eolian quartzose sandstone and siltstone interbedded with greenish silty sandstone of the Chamisa Mesa Member. At the type Chamisa Mesa Member section, deposits are characterized by a lacustrine facies with well-indurated carbonate and opaline beds.

Return to vehicles and retrace route back to NM-44. **0.5**

46.4 **Turn right** onto Cabezon Road. **1.9**

48.3 Pass from BLM land to Zia Pueblo. **4.0**

52.3 **Turn right** onto NM-44. **3.2**

55.5 Slow and **move into left turn lane. 0.1**

55.6 **Turn left** and proceed towards Zia Pueblo. From this point on to Stop 4 we will be travelling on lands of Zia Pueblo. Our access to Zia Pueblo has been granted by The Governor and Pueblo Manager. You must obtain permission to travel on the Borrego Canyon Road from Pueblo administration. The Pueblo is built on the tread of middle Pleistocene fluvial terrace Qt4. **0.6**

56.2 Cross Rio Jemez. **0.1**

56.3 **Turn right** onto Borrego Canyon Road. **0.4**

56.7 Cross Chamisa Arroyo. Note thick alluvial fill of terrace Qt4. Four major Quaternary fill terraces (Qt1 = oldest through Qt4 = youngest) are preserved in the Rio

FIGURE 2.2.9. Photograph of ventifacts at the base of the Zia Formation.

Jemez Valley (Rogers, 1996; Formento-Trigilio and Pazzaglia, 1998). Terrace Qt4 is closest to the modern alluvial valley bottom and interpreted to be approximately 150 ka (Formento-Trigilio and Pazzaglia, 1998). Long-term rates of Rio Jemez incision, calculated from this suite of terrace-treads, is 0.01 in./yr. Here the alluvial fill underlying the Qt4 terrace alluvial fill contains a mixture of clasts derived from the ancestral Rio Jemez (rich in carbonate and Bandelier Formation rock-types) and Chamisa Arroyo (virtually all basaltic in composition). **0.9**

57.6 Road passes to improved gravel cover. Exposures of Quaternary alluvium unconformably overlying Zia Formation at 9:00. **0.2**

57.8 Road crosses terrace riser between Qt4 and Qt3. **0.8**

58.6 Well-developed calcic soil exposed in Qp2 in roadcut at 3:00. This deposit slopes to the west where it merges with Qt2. **0.2**

58.8 The view to the north (9:00) displays Chamisa and Borrego Mesas rising behind a foreground underlain by Zia Formation. The highest-standing portions of the Zia Formation are capped by Quaternary alluvium composed entirely of basalt eroded from Chamisa and Borrego Mesas, and Quaternary terrace alluvium marking the former location of the Rio Jemez (Pazzaglia et al., 1998). The highest and oldest Rio Jemez alluvial deposits (Qaj0) projects to approximately 390 ft above the Rio Jemez and is contains abundant gray, car-size boulders of lower Bandelier Tuff (D. Love, personal commun., 1999) that may have been deposited as a debris flow or hyperconcentrated flood flow in the ancestral Rio Jemez soon after emplacement of this early Pleistocene ignimbrite. All subsequent Rio Jemez deposits are inset against Qaj0 and young to the west, indicating that the Rio Jemez has adjusted its course to the southwest over the past 1 m.y. Radial movement away from the Jemez Mountains by the Rio Jemez and its tributaries, including Chamisa Arroyo, suggest Quaternary land-surface deformation associated with Jemez Mountains volcanism. **0.5**

59.3 **OPTIONAL STOP 3**. Quaternary fault exposed along Borrego Canyon Road. The north-striking, down-to-the-west Zia fault exposed in this road outcrop clearly displaces Quaternary alluvial deposits (Fig. 2.2.10) that are an ancestral valley bottom of Chamisa Arroyo mapped as Qp2 (Pazzaglia et al., 1998). This fault was originally mapped as the Rincon fault by Galusha (1966), however, to avoid confusion with the rift-bounding Rincon fault of the Sandia Mountains, we use the name Zia fault as mapped by Kelley (1977). Qp2 is correlated by map distribution and long-profile projection to Qt2 in the Jemez Valley, determined to be approximately 400 ka (Formento-Trigilio and Pazzaglia, 1998). Diffusion modeling of topographic profiles of this scarp suggest a diffusion age commensurate with a surface rupture of at least 100 ka (Fig. 2.2.11). This and other down-to-the-west faults collectively offset the Piedra Parada Member against the Chamisa Mesa Member along the western flank of the Ziana anticline. To the south, this fault decreases in throw and is buried by the alluvium in the Rio Jemez valley bottom. On the south side of the Jemez valley a down-to-the-east fault emerges (the Rincon fault of Galusha, 1966) and continues as a well expressed structure along La Ceja where we will observe it at Stop 6 (note change in fault polarity). **0.5**

59.8 Windmill and production well for Zia Pueblo. The well is ~655 ft deep. The Chamisa Mesa Member here is covered with up to 46 ft of Quaternary eolian sand. **1.3**

61.1 Cross cattle guard. **0.8**

61.9 Ridge at 12:00 is capped by basalt-bearing alluvium that marks a former valley bottom of Arroyo Arenoso. **0.5**

62.4 Descend into the Arroyo Arenoso valley. **0.5**

62.9 Cross Arroyo Arenoso. The exposures at 9:00 are of the Cerro Conejo Formation, a red-brown to pink interbedded fluvial and eolian sandstone (sublitharenite) sandstone stratigraphically above the Chamisa Mesa Member. Fragmentary fossil mammal remains obtained from these exposures (NW¼ sec. 17, T15N, R3E, Jemez Pueblo quadrangle) are similar to those recovered from the Cerro Conejo Formation exposed in the Rincones de Zia, south of the Rio Jemez, which are of late Barstovian land-mammal "age" (11–14 Ma; Tedford, 1981; Tedford and Barghoorn, 1997). **0.4**

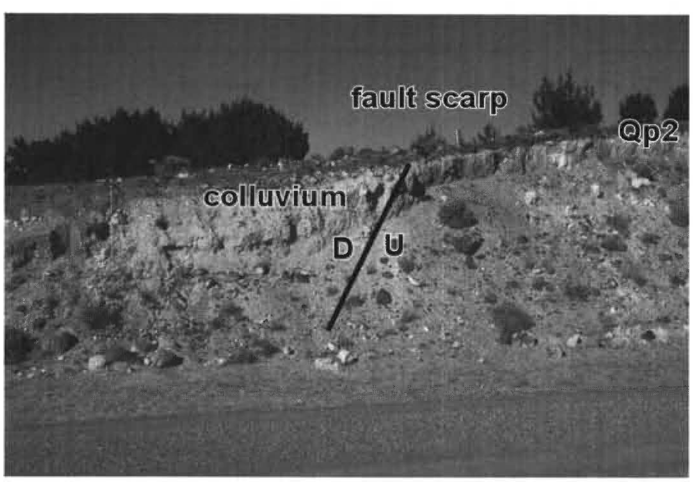


FIGURE 2.2.10. Annotated photograph of the Zia fault offsetting Qp2 along the Borrego Canyon road at Optional Stop 3.

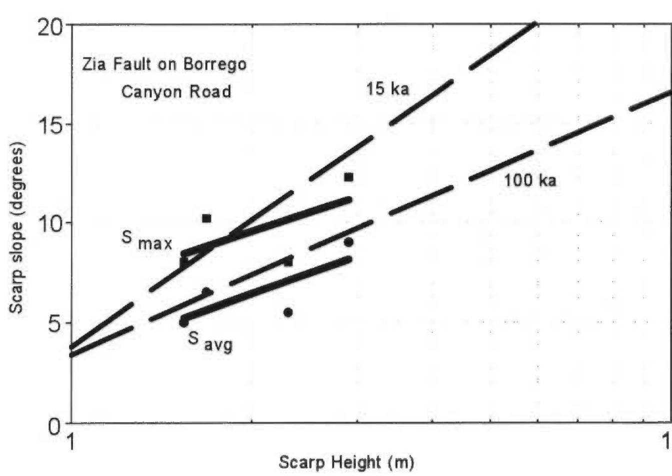


FIGURE 2.2.11. Fault-scarp profile slope-height model plot. Data suggest an age for this scarp between ~15 and 100 ka.

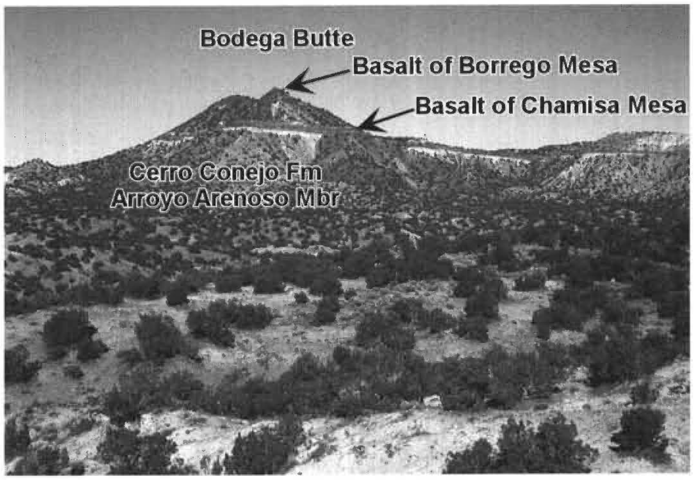


FIGURE 2.2.12. View to northeast of Bodega Butte and basalts interbedded with the Arroyo Arenoso Member of the Cerro Conejo Formation.

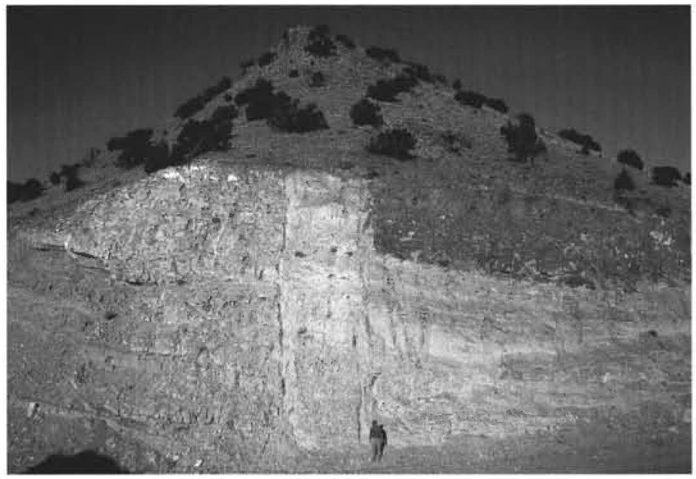


FIGURE 2.2.13. View of the Santa Ana fault zone looking north. Fault is down-to-the-east.

63.3 Roadcut exposures of fine- to medium-grained cross-bedded eolian(?) sandstone of the Cerro Conejo Formation at 3:00. **0.5**

63.8 Cross cattle guard and pass from Jemez Pueblo quad into Loma Creston quadrangle. A down-to-the-west fault displaces Quaternary deposits at 3:00. The prominent ridge at 9:00 (Fig. 2.2.12) is underlain by the Cerro Conejo Formation and two interbedded basalts, all of which dip ~15° to the east. The fault exposed in the roadcut here strikes to the northeast through the Arroyo Arenoso valley, repeating the section in the next ridge to the east. The two basalts exposed on Bodega Butte are the same two basalts exposed in the ridge at 3:00. **0.8**

64.6 **Pull off the road to the right and park. STOP 4.** Roadcut exposure of Santa Ana fault. The purpose of this stop is observe an important down-to-the-east fault near the western boundary of the Rio Grande rift and discuss the volcanic rocks, stratigraphy, and sedimentology of the Santa Fe Group proximal to the Jemez Mountains. The fault zone exposed in this roadcut (Fig. 2.2.13) is one of several major down-to-the-east faults which collectively define a middle to late Miocene, narrowing of rifting in the Albuquerque basin. This particular fault zone is typical of several others proximal to the Jemez Mountains in that it is extensively cemented, presumably by mineralized ground waters derived from the volcanic highlands to the north. These mineralized fault zones have produced economic deposits of manganese.

The Santa Ana fault zone offsets east-dipping sandstone and conglomerate of the Cerro Conejo Formation (Fig. 2.2.14). The sublitharenite sandstone exposed at Arroyo Arenoso has coarsened significantly upsection to this location. Clasts are dominantly rhyolitic and intermediate volcanic rocks derived from the Canovas Canyon Formation, with lesser amounts of basalt, presumably from Chamisa Mesa, or Borrego Mesa, and minor granite. Upsection these deposits become progressively coarser grained and rich in granitic clasts. We place the contact between the Cerro Conejo Formation (middle Santa Fe Formation of Bryan and McCann, 1937) and the Arroyo Ojito Formation (upper Santa Fe Group) at the lowest occurrence of significant gravel in the section (Chamberlin et al., in progress). A distinct, yellowish sandstone called the Navajo Draw Member of the Arroyo Ojito Formation is not present here, but we will see these deposits at the next stop.

Volcanic rocks interbedded with basin fill throughout the Loma Creston quadrangle afford excellent age control and reconstruction of the tectonic evolution of this

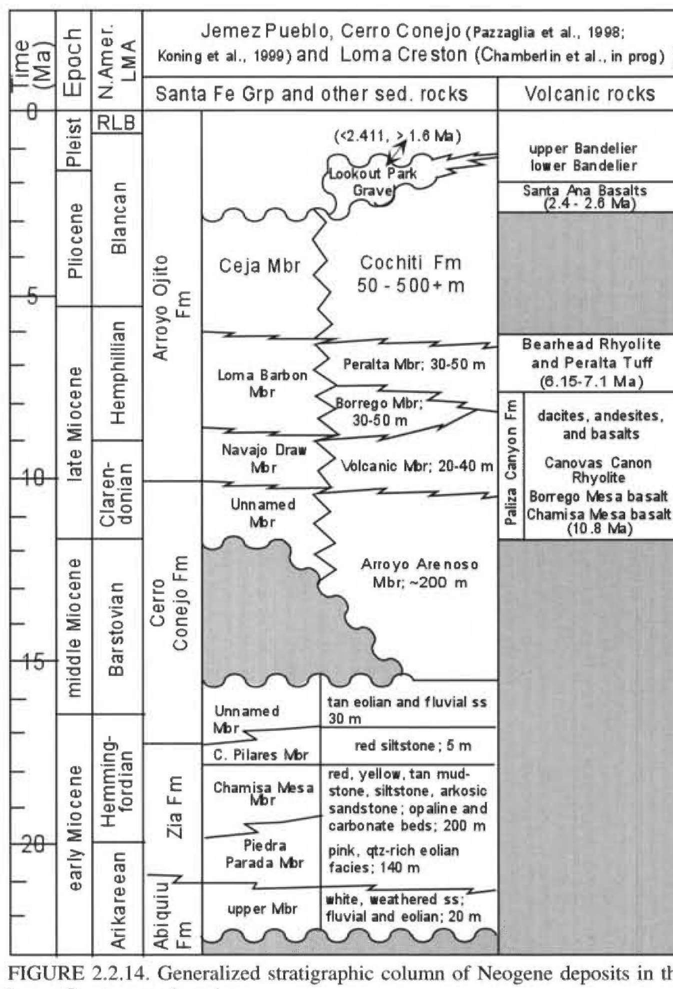


FIGURE 2.2.14. Generalized stratigraphic column of Neogene deposits in the Loma Creston quadrangle.

portion of the Albuquerque Basin (Fig. 2.2.14). The basalt exposed at the outcrop is an olivine-augite basalt of Borrego Mesa. This and other Paliza Canyon Formation volcanic rocks interbedded with the upper portion of the Arroyo Arenoso Member of the Cerro Conejo Formation further support the ~10-Ma age for the top of this package of middle Santa Fe Group sediment.

Return to vehicles and retrace route back through Zia Pueblo and out to NM-44. **1.8**

66.4 Cross Arroyo Arenoso. **1.0**

67.4 Mt. Taylor at 11:00 and Cabezon at 1:00. **2.0**

69.4 Pass water-well at windmill. **3.1**

72.5 Cross Chamisa Arroyo. **0.3**

72.8 **Turn left. 0.8**

73.6 Intersection with NM-44. **Right turn** onto NM-44, for OPTIONAL STOP 5 and beginning STOP 6, **or left turn** onto NM-44 for end of STOP 6.

0.0 **Turn right onto NM-44 for OPTIONAL STOP 5 and beginning STOP 6. 0.3**

0.3 **Turn left** onto Indian Route SP784. This **OPTIONAL LOG** is entirely on Zia Pueblo land. Our access to Zia Pueblo has been granted by The Governor and Pueblo Manager. ***NOTE:*** *You must obtain permission to travel on Zia tribal lands from the Pueblo administration.* Proceed through gate. This portion of the road log traverses territory mapped by Koning et al. (1999). The reader is referred to Connell et al. (this guidebook; fig. 2,) for a discussion of the stratigraphy and simplified map of this quadrangle. Figure 2.2.15 shows the route of the Optional Log. **0.9**

1.2 **Proceed straight ahead through left fork in road.** The Chamisa Mesa Member of the Zia Formation is exposed in the mesas to your right (west). **0.7**

1.9 **Proceed straight ahead through left fork in road. 0.3**

2.2 **Bear left** and cross Arroyo Ojito (Cañada de Zia of Galusha, 1966). **0.5**

2.7 **Bear right**, proceed past windmill. **0.1**

2.8 **Bear right**, drop back into Arroyo Ojito. Follow arroyo channel south. **0.5**

3.3 Pass through gate. Continue south in arroyo channel. **0.1**

3.4 Contact between white, poorly consolidated, eolian sandstone of the Chamisa Mesa Member of the Zia Formation and the pink, better-indurated, dominantly fluvial sandstones of the Cerro Conejo Formation. The lower contact of the Cerro Conejo Formation is placed at the lowest appearance of medium-bedded mudstone and presence of steeper slopes. Although similar in appearance to the Cañada Pilares Member of the Zia Formation, detailed biostratigraphic work by Gawne (1981) concluded that these particular red mudstones do not correlate to the Cañada Pilares Member, as they have yielded Barstovian-aged fauna (cf. Zia prospect and Rincon quarry of Galusha, 1966). Gawne's (1981) biostratigraphic contact occurs at the foot of the 50-ft-high cliff of sandstone above an apparent unconformity (please refer to her fig. 2B). However, this unconformity did not prove to be mappable, so the contact shown on the map was placed at the first appearance of the reddish-brown mudstone. The mapped contact corresponds better to a lithostratigraphic definition of the Cerro Conejo Formation and is laterally continuous across the Cerro Conejo (formerly Sky Village NE) quadrangle. Our mapping throughout the San Ysidro region has concluded that the Cañada Pilares Member is not present in the Cerro Conejo quadrangle, but does occur along the Ceja del Rio Puerco as well as in the Jemez Pueblo quadrangle at the Chamisa Mesa Member type section (Galusha, 1966).

Deposits of the Cerro Conejo Formation are generally fine- to coarse-grained, tabular to locally cross-bedded, well-sorted sandstone. These deposits are inter-

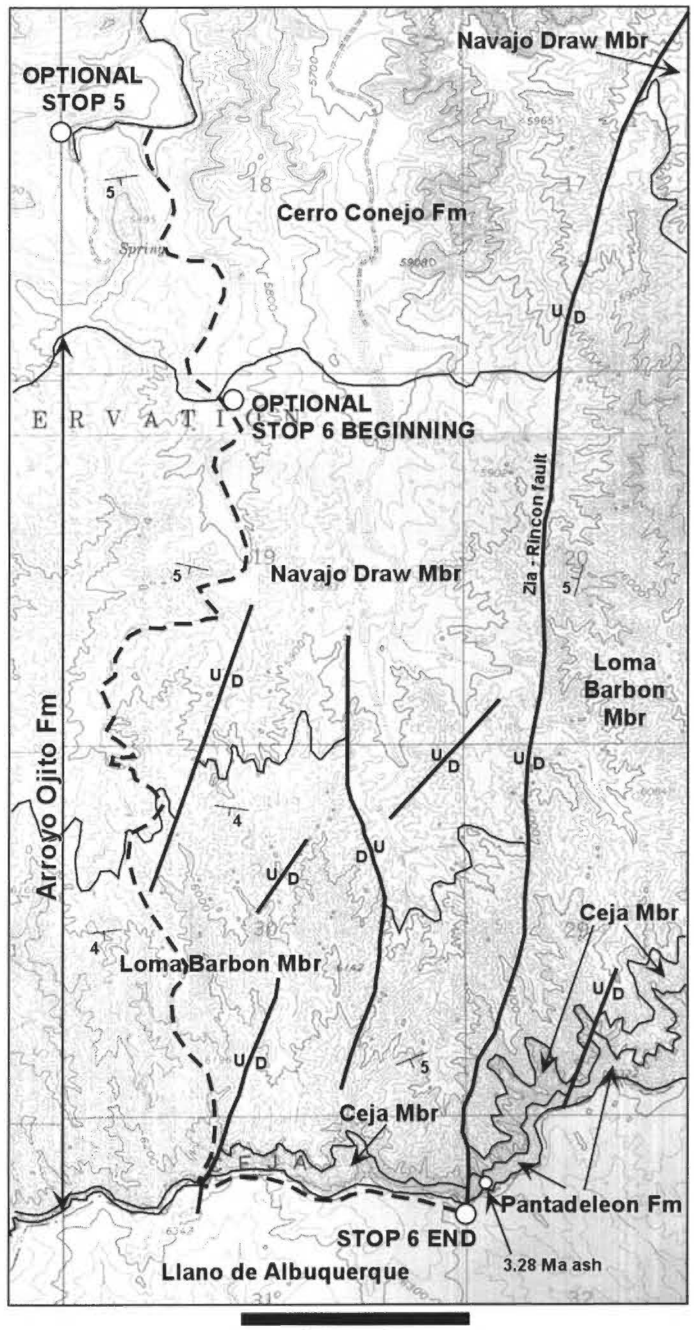


FIGURE 2.2.15. Map showing route of Optional Log for Optional Stop 5 and Optional Stop 6 beginning, including walking portion to Stop 6 end . The geology is from Koning et al (1999).

preted to represent mixed sandy fluvial and eolian depositional environments. Deposition of the Cerro Conejo Formation signifies the establishment of large, perennial, through-going fluvial systems characterized by deep sandy channels. This depositional environment stands in contrast to the predominantly eolian, and more limited fluvial and lacustrine environments during Zia Formation time. The large perennial fluvial systems of Cerro Conejo Formation time are supported by large-scale fluvial cross-stratification that requires sustained, steady flows. There are several 30-ft-scale packages of sediment within the Cerro Conejo Formation that begin with the large-scale cross-bedded fluvial facies at their base, contain a finer-grained, overbank-dominated facies in their middle, and are capped with a fine-grained-sand eolian facies. **0.3**

3.7 **Take right fork** in arroyo channel, proceed west. **0.2**

3.9 Exposure of the fluvial base of a Cerro Conejo Formation depositional package is exposed on the arroyo wall at 3:00. At 9:00 is the middle overbank-dominated portion of the cycle containing several distinct white and gray volcanic ash beds. These ashes occur near the upper portion of the Cerro Conejo Formation section and may be correlative to ashes well exposed along NM-44 at Mile 24.9. Here the ashes are strongly altered because the Cerro Conejo Formation is exposed along the hanging wall of the San Ysidro fault and have spent a significant portion of their history below the water table. Correlative ashes on the footwall are less altered. To appreciate the amount of offset on the San Ysidro fault, these ashes are displaced down-to-the-east by approximately 1800 ft. **1.1**

5.0 Exposures of Cerro Conejo Formation to your right. **0.8**

5.8 **OPTIONAL STOP 5**. Cerro Conejo Formation. The purpose of this stop is to observe the sedimentology of the Cerro Conejo Formation and ground-water cementation features (Fig. 2.2.15) particularly well preserved in these rocks. The Cerro Conejo Formation in the Cerro Conejo quadrangle is a very pale-brown to pink and yellowish-red, relatively ash-rich, cliff-forming, moderately to well-sorted arkose–lithic arkose with variable proportions of thinly to medium-bedded silt, and reddish-brown mudstone. The sandstone and muddy sandstone beds are tabular, thin to very thickly-bedded. These tabular beds contrast with the overlying lenticular beds of the Navajo Draw Member. The Cerro Conejo Formation is correlative to Tedford and Barghoorn's (1997) "Unnamed Member" of the Zia Formation. A major and important distinction of the Cerro Conejo Formation in the Cerro Conejo quadrangle with respect to Cerro Conejo Formation farther north is the virtual lack of any coarse-grained facies. In the Cerro Conejo quadrangle, only one thin gravel bed has been observed in this member.

Cerro Conejo Formation outcrops north of La Ceja (Rincones de Zia of Galusha, 1966) have been a prolific source of fossil mammal remains. The biostratigrahy of the unit indicates that these deposits range from late early Barstovian (15 Ma) through much of the late Barstovian, perhaps into the Clarendonian, at about 12 Ma. Paleontologic and magnetostratigraphic evidence from the Ceja del Rio Puerco (Stop 7) suggests a significant temporal hiatus or condensed section may exist at the contact between the Cerro Conejo Formation and Chamisa Mesa Member of the Zia Formation. The ash sequence that lies in the middle of the Cerro Conejo Formation type section can be traced westward along La Ceja to the Tenorio fault. Similar ash beds lie within Chron 5Acn, in the Ceja del Rio Puerco outcrops where one was K-Ar (on biotite) dated at 13.64 ± 0.09 Ma (Berkeley Geochronology Center). In that area, late Barstovian fossil mammal assemblages, similar to those in the type area, are also known.

Turn vehicles around and retrace route down stream for approximately 0.2 mi. **0.2**

6.0 **Turn right** into tributary arroyo. Proceed south. **0.5**

6.5 Exposures of an eolian facies near the top of a Cerro Conejo Formation cycle is exposed to your left. **0.7**

7.2 **OPTIONAL STOP 6 beginning.** Basal contact of the Navajo Draw Member of the Arroyo Ojito Formation (Fig. 2.2.15). The purpose of this stop is to observe exposures of the upper Santa Fe (Arroyo Ojito Formation) from this point to the crest of La Ceja. This is the beginning of a 2.75-mi-long walking log that will ascend 600 ft up an unnamed tributary of Arroyo Ojito along the measured section of Connell et al. (this volume) (Fig. 2.2.16). The walking log starts at the contact between the Cerro Conejo Formation and the Navajo Draw Member of the Arroyo Ojito Formation. The Arroyo Ojito Formation is the upper Santa Fe Group equivalent to the Sierra Ladrones Formation along the western margin of the basin. The walk proceeds through the yellow Navajo Draw Member to a distinct, reddish-yellow to light yellowish-brown sequence of sandstone, mudstone, and granite-rich conglomerate of the overlying Loma Barbon Member, which we saw exposed in the badlands north of Loma Barbon at mile 22.7. The walking log leaves the arroyo bottom and ascends to a narrow ridgeline where we will encounter the coarse-grained Ceja Member (Kelley, 1977). Please refer to paper and figures in Connell et al. (this volume). We will follow the ridgeline to La Ceja and a rendezvous with the vans at Optional Stop 6 end.

The contact between the Cerro Conejo Formation and Navajo Draw Member suggests a major change in the source and depositional style of rift-fill sedimentation. The sublitharenite of the Cerro Conejo Formation, presumably derived from a northerly early pre-Jemez Mountains source, rapidly cede to yellow-colored, pebbly arkose, subarkose, and feldspathic litharenite, probably derived from the ancestral Rio Puerco on the Colorado Plateau. The yellow color is probably derived from the abundant Mesozoic rocks in the source area. Clasts include intermediate and rhyolitic volcanic rocks (~60%), sandstone (11%), <5% red granite, petrified wood, and Pedernal chert. Although the volcanic clasts resemble andesite that could have been derived from the Jemez volcanic field, it is more likely that they represent clasts reworked from the Abiquiu Formation that formerly covered the Sierra Nacimiento and eastern margin of the Colorado Plateau. Bedding in the Navajo Draw member is lenticular and typically <3 ft thick, mudstone beds are only about 4 in. thick; gravel

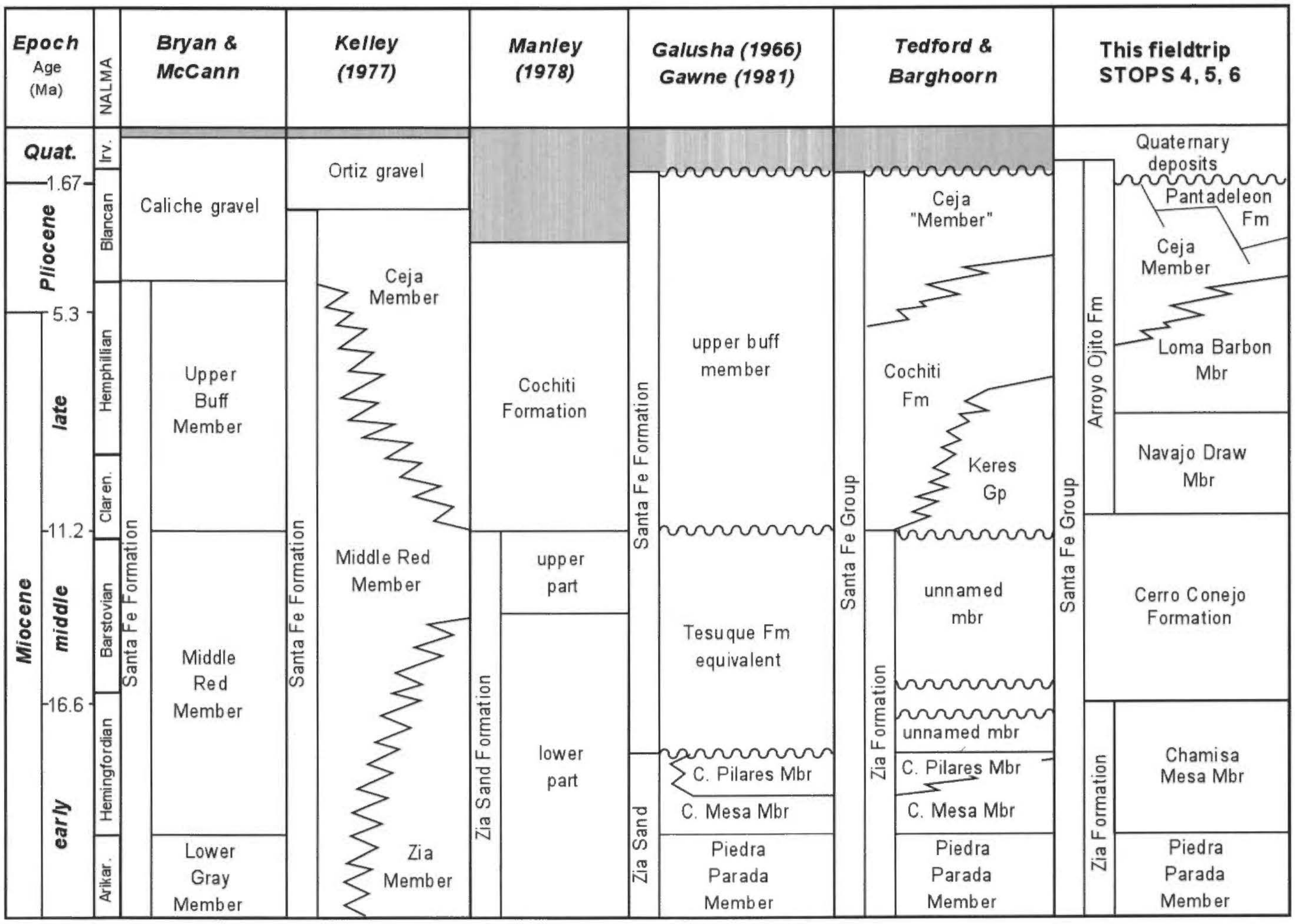


FIGURE 2.2.16. Revised stratigraphy of the Santa Fe Group exposed along the northwestern margin of the Rio Grande rift. This chart is modified from Connell et al. (this volume). The differences in nomenclature for the exposures in Arroyo Ojito reflect the biases of the senior author of this road log, based upon mentorship of the student mappers who completed the mapping of the Cerro Conejo quadrangle (Koning et al., 1999).

commonly fills channels that are less than 3 ft deep. To the west and southwest, in the footwall of the San Ysidro fault, and at Navajo Draw, the basal transition mudstones are missing, and the Navajo Draw Member rests with erosional disconformity on the Cerro Conejo Formation. Paleocurrent observations on imbricated clasts indicate a south-southeasterly direction of flow. These sedimentary structures suggest deposition of the Navajo Draw Member by smaller, more numerous, perhaps ephemeral channels with more narrow floodplains in comparison to the streams during Cerro Conejo Formation time. Member thickness is approximately 750 ft.

Approximately 1 mi south of the base of the Navajo Draw Member, a distinct, reddish-yellow to strong-brown sequence of interbedded sandstone, mudstone, and pebble conglomerate of the Loma Barbon Member conformably overlies very pale-brown pebble conglomerate and sandstone of the Navajo Draw Member. Note that clasts in the Loma Barbon Mesa Member are dominated by subangular red granite. The Loma Barbon Member is a reddish-yellow to brownish-yellow and very pale brown, sequence of cliff-forming, lenticular claystone, sandy mudstone, and clayey to silty sandstone, intercalated with minor sandy conglomerate. Generally, the base of the Loma Barbon Member is finer grained than its top, and upward-fining sequences are relatively common. This member may be roughly correlative to the "Atrisco Member" of Connell et al. (1998). Continuing upsection, conglomeratic beds increase in frequency and clasts generally become larger up to the coarse-grained Ceja Member of the uppermost Arroyo Ojito Formation. The muddy sandstone and sandstone in the Loma Barbon Member occur in lenticular beds which extend a few tens of yards laterally into the hanging wall proximal to faults. Gravel clasts are composed of >10% granite, <9% Pedernal chert, 20–38% sandstone, and <1% red siltstone. The member is approximately 650 ft thick. Paleoflow observations, presence of upward-fining sequences, and the generally sandy and muddy character of this unit suggest deposition by meandering streams.

The Ceja member contains lenticular-bedded, light-brown, cobble-to-boulder conglomerate, interbedded with reddish-yellow to pink, muddy, medium-grained sand and sandy conglomerate (Fig. 2.2.17). The lower contact of the Ceja Member is conformable with the

FIGURE 2.2.17. Photograph of the Ceja and Loma Barbon members from La Ceja. View is to the northwest.

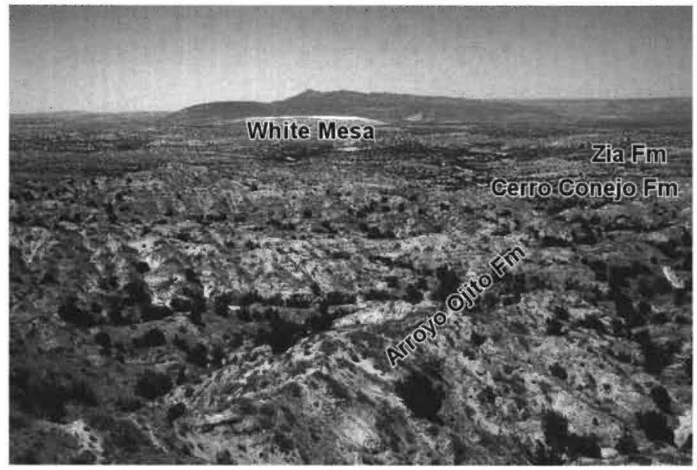


FIGURE 2.2.18. Photograph of the Santa Fe Group exposures from La Ceja. View is to the north.

Loma Barbon Member, and is placed at the lowest appearance of a relatively thick, coarse-grained conglomerate just below the rim. Clast composition shows >20% basalt, >5% Pedernal chert, >30% sandstone, and >10% red granite and foliated granite and gneiss. The upper contact of the Ceja Member is placed at a prominent soil with a stage III–V petrocalcic (K) horizon and just below sandstone and conglomeratic sandstone containing rounded, recycled calcic peds. The deposit is from 33 to 156 ft thick here and approximately 215 ft thick at its type locality (Kelley, 1977). These differences in thickness are attributed to syntectonic influences on deposition. The presence of several calcic soils throughout the Ceja Member marks the beginning of episodic deposition in this part of the basin.

The Loma Barbon Member progressively coarsens upsection where it interfingers with coarse sand and gravel underlying La Ceja (Fig. 2.2.17). These coarse-grained, rim-capping deposits are assigned to the Ceja Member of the Arroyo Ojito Formation. Relatively weak (Bk) buried soils become common near the top. In geologic mapping on the Bernalillo NW quadrangle to the east, Manley (1978) assigned similar strata to the Cochiti Formation and discussed three unmapped subunits that are similar to members of the Arroyo Ojito Formation. The upper portion of the Arroyo Ojito Formation, in particular the Ceja Member, correlates to Manley's (1978) Cochiti Formation to the east, Smith and Lavine's (1996) Cochiti Formation to the north, and the Sierra Ladrones Formation to the east and southeast (Smith and Kuhle, 1998).

A very thin light-brown sandstone and sandy pebble conglomerate of the Pantadeleon Formation unconformably overlies the Arroyo Ojito Formation here. The deposit here <3 ft thick and contains reworked calcic peds. This formation is named for Arroyo Pantadeleon, which heads near Stop 6. The Pantadeleon Formation is proposed for discontinuous, generally poorly sorted, wedge-shaped sequence of silty sandstone and conglomerate associated with the creation of local accommodation space along major intrabasinal faults. Other such deposits have been described for the County Dump (Machette, 1978) and Sand Hill fault (Wright, 1946). Less than 1.25 mi to the east, along the hanging wall of the Zia fault, the Pantadeleon Formation thickens to 62 ft and unconformably overlies a very strongly developed soil on the Ceja Member. This soil-bounded contact contains pedogenic features indicative of stage IV and V calcium-carbonate morphology. The Pantadeleon Formation at the Zia fault is coarse grained and was probably deposited by south-flowing streams flowing subparallel to the strike of the fault. A lens of white fine-grained volcanic ash near the top of the Pantadeleon Formation has been geochemically correlated to the 3.28-Ma Nomlaki Tuff of the Tuscan and Tehama Formations in eastern California (A. Sarna-Wojciki, written commun., 1998).

Participants rendezvous with vans at La Ceja at the **end of Stop 6** (Fig. 2.2.18). Vans retrace route, return to NM-44 and proceed to rendezvous point on La Ceja. **1.2**

8.4 **Turn right** into the road following main arroyo. Stay in main arroyo, following it downstream. **2.3**

10.7 Pass through gate. **0.5**

11.2 **Turn right** out of arroyo and follow road as it bears to the left (north) past windmill. **0.1**

11.3 Bear left, cross arroyo, stay to your right. Proceed north. **2.1**

13.4 Stay straight on Indian Route SP-784. **0.2**

13.6 Pass through gate and **turn right** onto NM-44; **end of OPTIONAL LOG;** rejoin main log. **0.3**

73.6 **Turn left** onto NM-44 for **STOP 6. 2.6**

76.2 Outstanding view of the Sandia Mountains at 12:00. **3.5**

79.7 Hill at 3:00 is capped by Quaternary terrace deposit of Rio Jemez affinity. **2.8**

82.5 Note prominent white volcanic ash in Cerro Conejo Formation exposed in arroyo ahead at 11:00 (see note for Mile 24.9). **2.0**

84.5 **Move into right turn lane. 0.1**

84.6 **Turn right** onto extension of Unser Blvd. and entrance to the New Mexico National Guard Armory. **1.1**

85.7 **Turn left. 0.7**

86.4 Ascend Loma Machete, a topographic high on the Ziana anticline. A deep petroleum exploration well, Shell Santa Fe Pacific No. 1 was drilled less than 0.6 mi to the east from this point, on the eastern flank of the Ziana anticline. The well penetrated 2970 ft of Santa Fe Group (primarily Zia Fm), 673 ft of Eocene Galisteo Fm, and 7310 ft of Mesozoic and upper Paleozoic rocks, ending in the Precambrian at 10,955 ft (Black and Hiss, 1974). The well spudded into the Zia Formation (the Tslms unit of Personius et al., in prep.). A sample from a prominent ash bed 1.5 mi to the north, but in the same stratigraphic level as the spudded interval yielded a chemical correlation to a ~11 Ma ash of the Trapper Creek Tephra (see note for Mile 24.9). The recent detailed mapping of the Loma Machete quadrangle (Personius et al., in prep.) demonstrates that the Ziana anticline is not a fold at all, but is a fault-bounded horst, flanked by outward dipping beds on the east and west. These observations are consistent with what we have already demonstrated on the north side of Rio Jemez (Stop 4). **0.5**

86.9 The water tank of Rio Rancho well No. 15 on Loma Machete is to your left. Other landmarks include Picuda Peak at 3:00, the Albuquerque volcanoes and the Ladron Mountains at 12:00–1:00, Los Lunas volcano at 12:00, Sandia Mountains at 9:00–10:00, and Manzano Mountains at 10:00–11:00.

At 12:00 in the middle foreground is a low, reddish-colored hill that lies just south of Northern Blvd. at the new Rio Ranch High School. That hill, called Loma Colorado de Abajo, exposes a section of Santa Fe Group strata about 108 ft thick. The lower 33 ft of the section are red beds consisting of reddish orange and grayish orange-pink sandy mudstones and trough-crossbedded, litharenites. Above these strata is a sharp and distinctive lithologic break beneath about 72 ft of light brown and pale orange, trough crossbedded sandstones and conglomeratic sandstones. Most of the conglomerate clasts are volcanic rocks.

Fossils collected recently by the New Mexico Museum of Natural History come from a sandstone bed about 23 ft below the lithologic break between red and brown strata. These fossils are of a small land tortoise, a ground squirrel (*Spermophilus* sp.) and a primitive pocket gopher (*Geomys* [*Nerterogeomys*] sp.) (see Morgan and Lucas, this volume). They are definitely of Pliocene age (Blancan land-mammal "age"), but are not more precise age indicators.

Also present in the fossil-bearing sandstone bed are burrows, probably made by the same rodents represented by body fossils. These burrows are composed of indurated sandstone and are shaped like a boot or thick golf club. They thus consist of a tall, thick shaft and a short, rounded living chamber that meets the shaft at an angle of about 120º. Locally, the sandstone bed with these trace fossils is intensively bioturbated by what appear to be networks, possibly colonies, of these burrows. Life on Albuquerque's West Mesa during the Pliocene was thus much as it is now, with a large biomass of burrowing, ground-living rodents.

The Santa Fe Group outcrops at Loma Colorado de Abajo are isolated from other outcrops and thus not easily correlated on a purely lithostratigraphic basis. Indeed, one clearly incorrect lithostratigraphic correlation would identify the red beds at Loma Colorado de Abajo as the "middle red member" of the Santa Fe Formation of Bryan and McCann (1937) overlain by strata of their "upper buff member." However, Bryan and McCann's (1937) "middle red member" is early–medial Miocene in age; these strata are now the middle–upper Zia Formation (Connell et al., this volume). The Blancan mammals from Loma Colorado de Abajo indicate the red beds are much younger than the "middle red member."

An alternative is to assign the entire exposed section at Loma Colorado de Abajo to the Ceja Member of the Arroyo Ojito Formation (originally Ceja Member of the Santa Fe Formation of Kelley, 1977), a unit that is mostly of Pliocene age. However, the red-bed facies at Loma Colorado de Abajo is an unusual lithotype for the Ceja Member. The overlying brown sandstones and conglomerates are lithotypes characteristic of the Ceja Member.

A third alternative is to assign the red beds at the Loma Colorado de Abajo to the Loma Barbon Member of the Arroyo Ojito Formation and the overlying brown sandstones to the Ceja Member. This makes most sense on a lithologic basis (i.e., the Loma Barbon Member includes red beds much like those at the base of the section exposed at Loma Colorado de Abajo). However, the Loma Barbon Member elsewhere is of late Miocene age, so this would force a younger age for part of the unit. **0.7**

87.6 Cross Arroyo Venada. **1.4**

89.0 Subdued hills of Loma Duran at 10:00. We are traversing extensive Quaternary eolian sand deposited over a fluvially dissected landscape. Picuda Peak at 3:00 is capped by the Ceja Member. **0.6**

89.6 Cross valley of Arroyo de la Baranca. The piedmont and mountain front of the Sandia Mountains are at 10:00 (Fig. 2.2.19). Note the broad sloping topography of the piedmont in front of Rincon Ridge. The low-standing portion of the piedmont results from a lack of sediment to fill the accommodation space produced by the range-bounding Rincon fault. Drainages on the north and south flanks of Rincon Ridge, both of which head behind the ridge, provide most of the sediment to the Juan Tabo and Del Agua alluvial fans, leaving a sediment deficit in the interfan portion of the piedmont that is fed only from short, steep drainages on the west

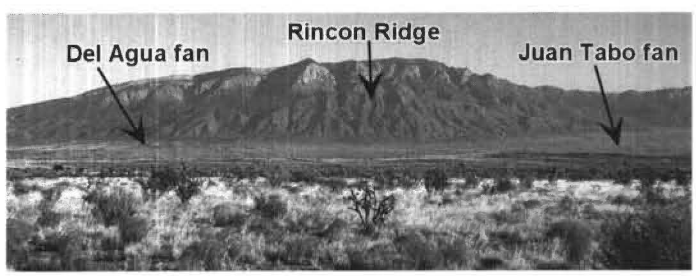


FIGURE 2.2.19. Photograph of the Sandia mountain front and Rincon Ridge showing the two large alluvial fans that spill onto the piedmont north and south of Rincon Ridge. Note the broad depression in front of Rincon Ridge, which is tectonic accommodation space, underfilled by west-flowing streams draining Rincon Ridge.

side of Rincon Ridge. **0.5**

90.1 **Turn right** onto Progress Boulevard (turn is before you reach the power lines) and proceed to intersection with Rainbow Blvd. This road follows the drainage divide between Arroyo de la Baranca and Arroyo de los Montoyas. **0.1**

90.2 Ascend gently a divide that is parallel to the Arroyo Pantadeleon valley to the east. **2.7**

92.9 **Turn right** onto Rainbow Blvd. **2.5**

95.4 Rainbow Boulevard bears to the right. At this point, the road begins to parallel the Arroyo Pantadeleon valley to the east. Arroyo Pantadeleon is a good example of a discontinuous arroyo system that has extensively reworked the constructional surface of the Ceja Member (Llano de Albuquerque surface). **0.8**

96.2 Rainbow Blvd. bears to the left. **0.2**

96.4 Road to left. **0.1**

96.5 Road to right. **0.1**

96.6 Rainbow bears right. **0.05**

96.65 **Turn right. 0.15**

96.8 Road turns left. **0.1**

96.9 **Turn right**. **0.05**

96.95 Cross Arroyo Pantadeleon. **0.1**

97.05 Cross an exposed calcic soil. **0.15**

97.2 Crest of divide and another exposure of a calcic soil. Stay straight. **0.2**

97.4 Road curves to the left and climbs a little hill. **0.1**

97.5 Road curves right. A township and range section boundary for sections 31 and 32 is on the right shoulder of the road. Stay straight as road makes several twists and turns. **0.3**

97.8 **Bear right at fork onto two-track road. 0.2**

98.0 Road approaches section 31-32 boundary. Follow fence straight north. **0.3**

98.3 **Follow road to the left. 0.1**

98.4 Bear right at fork in the road. **0.1**

98.5 Park at hole in fence at the big juniper tree. This is **STOP 6—La Ceja**. The purpose of this stop is to observe the Ceja Member of the Arroyo Ojito Formation, overlying Pantadeleon Formation, and discuss rationale for proposed new stratigraphy of the Santa Fe Group (Fig. 2.2.16). Zia Pueblo land is north of the fence. ***NOTE:*** *You must obtain permission from Zia Pueblo before entering.* From the crest of La Ceja (Rincones de Zia of Galusha, 1966), the Santa Fe Group stratigraphic succession can be seen across the Jemez and Zia faults. This stop also affords a good view of the local and regional effects on sedimentation attributed to syntectonic movement on rift-margin faults. Outstanding exposures of fossiliferous, ash-bearing rift sediments in the north-facing badlands of La Ceja afford one of the best opportunities to describe a tectonically compressed, but complete section of the Santa Fe Group (Fig. 2.2.18). Among the first to use these exposures to understand Santa Fe Group stratigraphy were Bryan and McCann (1937), who were clearly influenced by the basic variation in color from the base to top in their tripartite "lower gray," "middle red," and "upper buff" members.

Numerous refinements in the stratigraphy came first from Spiegel (1961) and Kelley (1977), and with the extensive paleontological and magnetostratigraphic work of the American Museum of Natural History (Galusha, 1966; Galusha and Blick, 1971; Gawne, 1981, Tedford, 1981, 1982; Tedford and Barghoorn, 1997). Our proposed stratigraphy (Fig. 2.2.16) is an outgrowth of an attempt to produce 1:24,000-scale geologic maps in the San Ysidro region. As such, our stratigraphy both builds on these earlier efforts and places an emphasis on mapable and regionally correlative lithostratigraphic rock units. An important key in our recent efforts includes an unpublished field map of the Cerro Conejo quadrangle by George Bachman. Given the inherent lithostratigraphic bias of the revised stratigraphy, it is hoped that it will be useful in hydrostratigraphic zonation of the Santa Fe Group.

This stop is located between two major down-to-the-east faults. It is in the hanging wall of the Jemez fault, and the footwall of the Zia fault (Manley 1978). The U.S. Geological Survey (Machette et al., 1998) proposes using the name Zia fault, following from Kelley (1977). This usage eliminates confusion with the Rincon fault, which marks the rift border along the western margin of the Sandia Mountains. The Arroyo Ojito Formation thickens significantly in our direction as it crosses the San Ysidro fault. Deposition of the Arroyo Ojito Formation was clearly syngenetic with movement on the Jemez fault as shown by the increased frequency of paleosols in the hanging wall proximal to the fault. The San Ysidro fault acted as a growth fault at least since the middle Miocene as shown by syndepositional thickening of Cerro Conejo Formation and younger units, which resulted in increasing stratigraphic separation down section. Fault movement continued after deposition of the Ceja Member ceased resulting in extensive fault scarp colluvium, alluvium, and eolian deposits trapped in local hanging wall basins. These deposits, which contain numerous paleosols and dip to the west, are collectively mapped as the Pantadeleon Formation. In the hanging wall of the Zia fault, a 3.28-Ma volcanic ash helps constrain the timing of the end of Ceja Member deposition and initiation of dissection of the Llano de Albuquerque.

Spiegel (1961) extended Bryan and McCann's (1937) stratigraphic concepts in a reconnaissance of the southern portion of Sandoval County. Ted Galusha (1966) provided the first formal subdivision of the Santa Fe with the definition of the Zia Sand. Galusha (1966) defined the basal Piedra Parada Member for exposures in Arroyo Piedra Parada, on Zia Pueblo lands, and the overlying Chamisa Mesa Member for exposures west of Chamisa Mesa, on Jemez Pueblo lands. Galusha (1966) considered beds of the Zia Sand to be pre-Santa Fe Group; however, Hawley and Galusha (1978) later considered it to represent the lower part of the Santa Fe Group. Gawne (1981) defined a thin reddish-brown mudstone overlying the Chamisa Mesa Member as the Canada Pilares Member exposed along the Ceja del Rio Puerco. This member does not extend much further to the north or east of the type section. Tedford (1982) extended the Zia Formation to include an unnamed upper member. Tedford and Barghoorn (1997) later refined the stratigraphic position and age of this unnamed member. The Cerro Conejo Formation now replaces Tedford and Barghoorn's (1997) unnamed member (Connell et al., this volume).

Kelley (1977) modified Bryan and McCann's nomenclature to include the Zia and his newly named Ceja as members of the Santa Fe Formation. In particular, Kelley (1977) correlated the main body of the Santa Fe Formation with the "middle red" member. However, Bryan and McCann's (1937) reconnaissance clearly shows that their concept of the middle red member belongs to part of the Cerro Conejo and Chamisa Mesa members. Unfortunately, the terms "middle red" and "upper buff" have different meanings to different workers, resulting in the evolution of a rather confusing nomenclature. Exposures at Arroyo Ojito and Arroyo Piedra Parada represent the most complete and exposed stratigraphic section of the Santa Fe Group in the northern Albuquerque basin. Composite thickness of the Santa Fe Group here is 3480 ft, which is much thinner than the approximately 16,400 ft of basin fill reported in boreholes to the southeast (Lozinsky, 1994). The presence of only 20% of the total known section is probably due to our location near the northwestern margin of the hanging wall of the northern Albuquerque half graben (cf. Russell and Snelson, 1994). The Arroyo Ojito Formation thickens considerably east of the San Ysidro fault and continues to thicken across the Zia fault. This thickening of the Santa Fe Group section presumably results from decreasing erosional truncation towards the central basin depocenter (Hawley and Galusha, 1978).

Deposits of the Piedra Parada and Chamisa Mesa members are well exposed on the footwall of the Jemez fault. On the hanging wall, the Cerro Conejo and Arroyo Ojito formations are well exposed. Data collected from these exposures can help constrain the subsurface stratigraphy encountered in boreholes drilled beneath the Llano de Albuquerque.

The base of the coarse-grained Ceja Member is at least 650 ft above the water table here. Several down-to-the-west faults lower the elevation of these deposits to the east, where part of the Ceja Member becomes saturated with water near the Rio Grande Valley.

Participant rendezvous with the vans at this point. Vans turn around and retrace route south along Rainbow Blvd. **0.1**

98.6 **Turn right** to follow fence south. **0.3**

98.9 **Bear right onto two-track road. 0.05**

98.95 Stay right. **0.2**

99.15 Join "main" road, bear left. **0.95**

100.1 **Turn left. 0.1**

100.2 Road turns right. **0.1**

100.3 Intersection with Rainbow Blvd. **Turn left.** Rainbow is constructed upon the highest preserved constructional surface of the Llano de Albuquerque along Arroyo de las Montoyas. The Llano de Albuquerque is a south-sloping table land that represents a prominent surface of aggradation that was abandoned soon after cessation of Ceja Member deposition. The Llano de Albuquerque is not a pediment as Kelley (1977) had reported, but is an abandoned constructional surface that marks the maximum level of basin aggradation, and thus, defines the top of the Santa Fe Group. However, definition of a single terminal Santa Fe Group constructional surface, as proposed by Spiegel and Baldwin (1963) for the Española basin, is not likely here. This surface is underlain by Pliocene rocks (Blancan land-mammal "age," Morgan and Lucas, this volume; and Wright, 1946) that has been displaced down-to-the east by numerous faults that bring this constructional surface to 360–705 ft above the Rio Grande. Early Pleistocene Irvingtonian mammals are reported in deposits underlying the Sunport surface (Lambert, 1968), an abandoned basin plain associated with the ancestral Rio Grande. Ancestral Rio Grande deposits overlie and interfinger with western-margin facies of the Arroyo Ojito Formation. The Sunport surface is approximately 295–360 ft above the Rio Grande and represents an early Pleistocene surface aggradation. These age constraints suggest that the Llano de Albuquerque and Sunport surfaces represent two distinct constructional surfaces that mark the cessation of Santa Fe Group deposition at different times and places in the basin. Preservation of these surfaces is likely controlled by the location and activity of intrabasinal faults. **1.0**

101.3 Picuda Peak, capped with Ceja Gravel, is visible at 8:00. **0.7**

102.0 Loma Duran, also capped with Ceja Gravel, is visible at 10:00. **2.2**

104.2 Intersection with Progress Blvd. **1.4**

105.6 Intersection with King Blvd. **0.8**

106.4 Cross cattle guard. **0.1**

106.5 **Turn right** onto 28th Street. 0.1

106.6 A Rio Rancho well is visible at 9:00. This well is at least 985 ft deep and penetrates coarse-grained Ceja Member deposits derived from ancestral Rio Puerco, all in the vadose zone. **0.6**

107.2 Outcrop of a Quaternary sand dune. **0.5**

107.7 Cross an unnamed down-to-the-east fault. A calcic soil developed on the Llano de Albuquerque is exposed in the uplifted footwall ahead of us. **0.2**

107.9 A deposit inset into the Llano de Albuquerque is visible to the left. The surface exposes a soil with stage III carbonate morphologic development. The Llano de Albuquerque is deeply dissected by numerous arroyos that head on this constructional surface. **0.3**

108.2 Pass into Arroyo de las Calabacillas (formerly Sky Village SE) quadrangle. Cross a trace of a splay of the Zia fault (Cather et al., 1997). Syntectonic wedge deposits of the Pantadeleon Formation related to down-to-the-west movement on this splay overlie Arroyo Ojito Formation beds in the upper reaches of the arroyo to the right. **0.2**

108.4 Albuquerque volcanoes are visible at 9:00. This line of 156-ka vents were the source of petroglyph-adorned, mesa capping olivine-tholeiite lava flows. The south-flowing drainages we are crossing are tributary to the southeast-flowing Arroyo de las Calabacillas. Crossing an obscure trace of the Zia fault. This fault can be mapped southward from La Ceja using the aeromagnetic anomaly map (Plate B). **0.4**

108.8 Calcic soil developed on the Llano de Albuquerque exposed in road bed. **0.1**

108.9 More soil of the Llano de Albuquerque exposed in road bed. Mount Taylor is visible at 11:00–12:00. **0.4**

109.3 Intersection with a major cross road. Rio Rancho municipal well No. 9 is to your right at 2:00. The well penetrated 1640 ft of the Arroyo Ojito and Zia formations. **0.5**

109.8 On a dissected and corrugated land surface of the Llano de Albuquerque. The Centipede fault (Cather et al., 1997; County Dump fault, Machette, 1978; Machette et al., 1998), also well expressed on the aeromagnetic anomaly map (Plate B), begins to the south in this general vicinity. **0.8**

110.6 Cross Arroyo de las Calabacillas. This is a fairly large arroyo system developed on the Llano de Albuquerque, covering 79 mi^2. Buff sandstone of the lower Arroyo Ojito Formation (Loma Barbon Member?) exposed in cut banks to the right. **0.3**

110.7 Crossing trace of unnamed down-to-the-east fault that offsets Llano de Albuquerque paleosol. This fault is defined primarily from the aeromagnetic anomaly map (Cather et al., 1997). **0.2**

110.9 Pass outcrops of the Ceja Member conglomeratic sandstone. **0.2**

111.1 Prominent calcic soil developed on the Llano de Albuquerque exposed in the road here lies at an elevation of about 6100 ft and is exposed in the footwall of a down-to-the east fault. We are in the axis of a long recognized ground-water trough (Titus, 1963) that plunges to the south. The Rio Rancho municipal well to your left at about 8:00 produces from the Cerro Conejo Formation. It is at least 1000 ft to the water table here. **0.9**

112.0 Cross the pipeline road. **0.5**

112.5 Cross a down-to-the-east fault, possibly a splay of the San Ysidro fault (Cather et al., 1997). This fault displaces the moderately dissected Llano de Albuquerque surface by approximately 65 ft down to the east. **0.7**

113.2 Continue rising to the highest preserved remnant of the Llano de Albuquerque surface. Proceed to the Ceja del Rio Puerco. **0.3**

113.5 Cross the main splay of the San Ysidro fault. **0.4**

113.9 Cross powerline. Proceed straight for less than 0.1 mi then **turn left**. **0.9**

114.8 Note Ceja del Rio Puerco to the west. Mount Taylor is visible at 9:00. Road traverses the Quaternary eolian and fluvial deposits that overlie the Ceja Member. **0.1**

114.9 Pass intersection with King Ranch Road. This road descends the Ceja del Rio Puerco onto a large ranch owned and operated by the King family. *You must obtain permission to travel on the King Ranch.* Outstanding exposures of the Zia Formation described and interpreted by Gawne (1981) and Tedford and Barghoorn (1997) form the basis for our modern understanding of the lower portion of the Santa Fe Group. **0.3**

115.2 Albuquerque volcanoes visible at 10:00. **0.2**

115.4 **Make a sharp right, turning back slightly,** pass through the gate, **then make an immediate left**, following the fence. **0.5**

115.9 Stay straight. **0.5**

116.4 Red Hill visible at 2:00. Red Hill is in the footwall of the Sand Hill fault, which lies just to your west. There is a thin (<30 ft) veneer of Ceja Member gravel on the footwall of the Sand Hill fault. Cobble and boulder gravel in this outcrop show evidence of southeast paleoflows and are incised into sandy beds of the Cerro Conejo Member (Cather et al., 1997). These gravel appear to represent a remnant of Ceja-age canyon fill incised into the footwall of the Sand Hill fault. A significantly thicker (~325 ft) of sequence of Ceja sand and gravel lie in the hanging wall. **0.2**

116.6 **Turn right on access road to Red Hill, proceed to base of hill** and park, **STOP 7—Sand Hill fault and Zia Formation**. The purpose of this stop is to observe the structural and hydrostratigraphic significance of the Sand Hill fault (Fig. 2.2.20). Other important features at this stop include the exposures of the Zia Formation, including the stromatolitic beds in the upper Cerro Conejo Formation (Fig. 2.2.21). We refer the reader to the guidebook article by Tedford and Barghoorn for figures that pertain specifically to this stop.

Red Hill lies at the rim of the Ceja del Rio Puerco, its western flank drained by the north fork of Cañada Moquino. The syn-rift Sand Hill fault passes across its

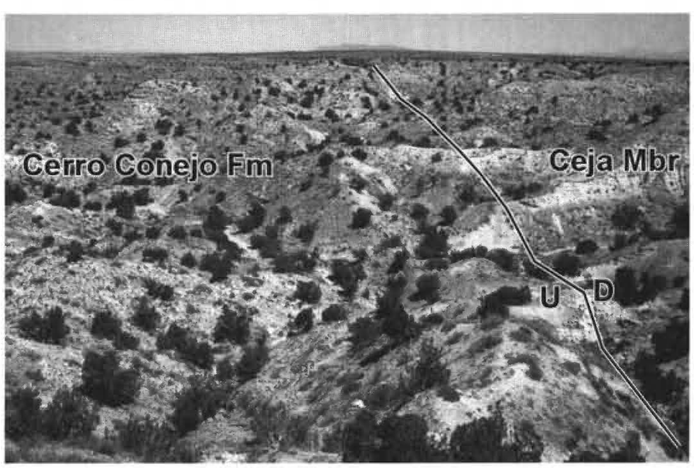


FIGURE 2.2.20. View to northwest along the (approximate) trace of the Sand Hill fault displacing light-brown sandstone and conglomerate of the Arroyo Ojito Formation (Ceja Member) down-to-the-east against reddish-yellow sandstone of the Cerro Conejo Formation of the Zia Fm.

FIGURE 2.2.21. Photograph of the algal stromatolite beds in the Cerro Conejo Formation.

eastern flank isolating a spectacular cap rock of polymictic boulder conglomerate of the Ceja Member of the Arroyo Ojito Formation from the main mass of the unit exposed across the fault in the canyon to the east. The varied clast composition of the remnant agrees better with the coarse beds at the top of the Arroyo Ojito Formation, suggesting that at the time these conglomerates were laid down Arroyo Ojito Formation had locally extended into the footwall of the Sand Hill fault as paleocanyon fill. Other similar occurrences (but with less spectacular gravel) can be seen along the Sand Hill fault to the south of Red Hill.

The reddish-brown mudstone and fine sandstone to the west and below the gravel cap are facies of the Cerro Conejo Formation, the top of a locally 500-ft-thick sequence of fluvial and minor eolian sediments that include two widely traceable green lacustrine claystone beds in mid-sequence. The upper green bed is marked by large stromatolites, mostly prostrate forms, that are the result of calcareous algal growth around logs and local bottom irregularities in a saline lake environment. The lower lacustrine bed lacks stromatolites but is remarkable for the wide occurrence within it of remains of the musk-rat like aquatic beaver, *Eucastor*, implying a somewhat fresher lake. South of Red Hill, 330 ft of additional Cerro Conejo Formation are exposed due to the difference in strikes of the Neogene strata and the Sand Hill fault. The upper 100 ft of this section contains pebble conglomerate lenses composed mostly of siliceous clasts reworked from Mesozoic and early Cenozoic rocks, but also rare pebbles of intermediate volcanic composition. A complete magnetostratigraphic section through the 820 ft thick Cerro Conejo Formation in this area (calibrated with an ash date and fossil mammals), extends from Chron 5AD nearly through Chron 5An1 (14.6–12.0 Ma, using the Cande and Kent, 1995, calibration).

The Cerro Conejo Formation lies conformably on a thick (130 ft) dune sand that we regard as a facies of the red mudstone of the Cañada Pilares Member of the Zia Formation (Gawne, 1981) from evidence of intertonguing with over 50 ft of the red claystone at the top of the Cañada Pilares Member. Conformably beneath the Cañada Pilares Member is a buff, thick, planar-bedded, fine-grained sand of the Chamisa Mesa Member of the Zia Formation. These rocks mark a mixed fluvial-eolian environment between the upper dune field of the Cañada Pilares Member and those of the Piedra Parada Member of the Zia Formation (Galusha, 1966; Gawne, 1981). The latter is over 1000 ft of light gray, large scale, cross-bedded, fine- to medium-grained sand that rest unconformably on the Cretaceous Menefee Formation. Nearly everywhere this contact is exposed, it is overlain by ventifacts of intermediate composition volcanic rocks. Fossil mammals and magnetostratigraphy suggests that the Cañada Pilares Member-Cerro Conejo Formation contact, although not marked by evidence of pedogenesis or striking lithic change, represents a hiatus corresponding to the length of Chron 5B and 5Adr or 2.6 m.y.

The syn-rift deposits are limited westward by the down to the east Moquino fault that may be continuous (in a serpentine fashion) northward with the Navajo and Tenorio faults. To the south this fault zone crosses the Rio Puerco and appears to be continuous with the fault forming the western boundary of the Apache graben (Wright, 1946; Kelley, 1977), the graben that contains the westernmost outcrops of the Tertiary succession exposed along the Ceja del Rio Puerco.

Return to vans and exit Red Hill access road. **0.9**

117.5 **Stay right. 0.5**

118.0 **Sharp right turn**, pass through fence, and stay right. **0.9**

118.9 **Turn left** at the junked water heater. **0.5**

119.4 **Turn right. 0.6**

120.0 The ridge at 3:00 is a Holocene sand dune. **0.6**

120.6 A right turn here will take you up into the sand dunes and to the Ceja del Rio Puerco. This is called the "shooting gallery" because of the abundance of sometimes exuberant gun enthusiasts that visit here on the weekends. This stop is also discussed in Hawley et al. (1982, stop 3 of day 3 road log, p. 86–88). There are excellent exposures of fault-scarp colluvium preserved in the hanging wall of the San Ysidro fault in the escarpment exposures (Fig. 2.2.22). These deposits were first described by Wright (1946). **0.1**

120.7 Microwave tower at 3:00. **1.0**

121.7 **Turn left** onto Southern Blvd. **0.4**

122.1 Cross exposure of Llano de Albuquerque soil. Corrugated ridge-and-swale topography is developed on the footwalls of faults. **0.6**

122.7 Cross Centipede fault near this point. **0.9**

123.6 Cross exposures of soils developed on the Llano de Albuquerque. **0.7**

124.3 Low roadcut exposes complex, polygenetic soil developed on the Llano de Albuquerque at 3:00. The soil is exposed in the footwall of the Zia fault. A Paleoindian, Folsom (~10.2–10.9 ka) campsite occurs south of this point. Between 1965 and 1967 the site was excavated by Jerry Dawson, then a graduate student at UNM. The site consisted of five discrete artifact concentrations or loci, scattered along 1150 ft of a ridge. Each locus yielded from a few hundred to a few thousand artifacts that represent repair of weapons, manufacture of new

FIGURE 2.2.22. View to the southeast of the Ceja del Rio Puerco escarpment from the "shooting gallery." The numerous light-colored bands are buried calcic soils, each representing soil formation through a colluvial deposit shed to the east off of the uplifted footwall of the Sand Hill fault.

spear points, processing of meat and hides, and maintenance of other stone tools. **3.4**

127.7 Cross Calabacillas Arroyo. **0.8**

128.5 Pass Rainbow Boulevard. Begin descending scarp of the Star Heights fault zone and eastern limit of Llano de Albuquerque surface. **0.8**

129.3 Pass Baltic Ave. **1.6**

130.9 **Turn right** onto Unser Blvd. **1.7**

132.6 Road narrows to two lanes. **0.8**

133.4 Cross Calabacillas Arroyo. Note basalt flows from the Albuquerque volcanoes beneath the Paradise Hills subdivision. **0.2**

133.6 Intersection with Irving Ave. **0.6**

134.2 **Turn left** onto Paradise Ave. **1.1**

135.3 **Turn right** onto Golf Course Road. **0.8**

136.1 Get into left lane and **turn left** onto Paseo del Norte. **0.8**

136.9 Continue straight on Paseo del Norte. At about this point you cross the down-to-the-west East Paradise fault zone. Despite the lack of geomorphic expression, thermoluminescence dating of a fault on the north side of Calabacillas Arroyo showed evidence for three surface rupture events in the last 200 ka, with the two most recent events in the last 75 ka (Personius, 1997; Machette et al., 1998). Eolian processes can nearly completely mask the slow rates of west-facing fault scarp growth. **1.3**

138.2 Cross the Rio Grande. **1.5**

139.7 **Exit Paseo del Norte** at 2nd St. **0.3**

140.0 **Turn left** at stop light onto 2nd St. **0.2**

140.2 **Turn right** onto Ortega Road. **0.3**

140.5 Cross railroad tracks. **0.2**

140.7 **Turn left** onto Edith Blvd. **0.1**

140.8 **Pull over to right, park in wide berm along Edith Blvd. OPTIONAL STOP 8.** Recycled clasts of Otowi pumice exposed in ancestral Rio Grande channel deposits. The purpose of this stop is to observe the rock-type and outstanding sedimentary structures of the pumiceous upper portion of ancestral Rio Grande deposits. Outcrops on the east side of Edith Blvd. are composed of trough-cross-bedded, pebbly sand-channel deposits and silty floodplain and bar-top facies. Lateral relationships between channel and floodplain deposits suggest deposition in a channel 165–260 ft wide with a bankfull depth of about 5 ft. Abundance of quartzite pebbles and the quartzo-lithic nature of the sand are typical of ancestral Rio Grande deposits in the Sierra Ladrones Formation. Less typical are the abundant fluvially transported pumice lapilli and bombs, 0.4–16 in. across. The pumice clasts have the quartz and sanidine assemblage common to the Bandelier Tuff, erupted in the Jemez Mountains. This pumice probably relates to 1.6-Ma emplacement of the Otowi Member of the Bandelier Tuff (Lambert, 1968). Flood deposits comprised mostly of pumice from this eruption are known from many sites along the Rio Grande, nearly to Las Cruces (Mack et al., 1996). The relatively large size of many of the pumice clasts indicates derivation from the Otowi ignimbrite rather than the precursor Guaje pumice-fall deposit, which is substantially finer grained; however, Guaje pumice may be intermixed. The Otowi outflow sheet inundated most of the central and eastern Santo Domingo basin and extended southward at least as far as the north edge of Santa Ana Mesa, about 22 mi north of here (Smith and Kuhle, 1999). Most, if not all, of the ignimbrite that buried the former Rio Grande valley, and likely impounded the drainage within or north of White Rock Canyon, was nonwelded and was probably relatively easily entrenched by overflow from the episodically dammed river. The deposits seen here were probably deposited during re-establishment of the river across distal outflow-sheet ignimbrite within decades of the eruption. Quartzite-rich gravel at the top of the roadcut outcrops is along the strath of the middle Pleistocene Edith Formation, which has been stripped off by open-pit gravel quarries.

Return to vehicles and proceed south on Edith Blvd. **0.2**

141.0 Pass under Paseo del Norte. **0.1**

141.1 **Turn left** onto Paseo del Norte frontage road. **0.9**

142.0 Intersection with Jefferson Blvd. **Turn left.** **0.1**

142.1 Stop light. **Turn right** onto Paseo del Norte. Proceed to interchange with I-25.

End of Second-day Trip 2 Road Log.