Peñasco to Española - Third-day Supplemental Road Log

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PEÑASCO TO ESPAÑOLA
THIRD-DAY SUPPLEMENTAL ROAD LOG

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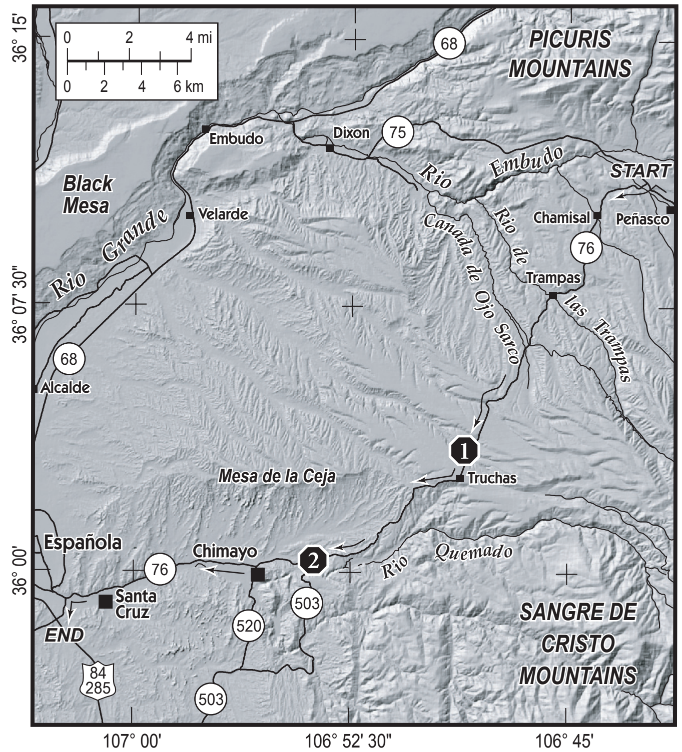
Begin: Peñasco at intersection of NM-76 and NM-75

Distance: 30 miles

Two stops



SUMMARY

This log traverses the northeastern Española Basin and provides an interesting and scenic route for those driving towards Española. The first half of the log examines rift-fill sediments and intra-rift structures within the Peñasco Embayment north of the town of Truchas. Beyond Truchas, several exposures provide opportunity for discussion of stratigraphic, sedimentologic, and structural features within the Tesuque Formation. Additionally, there are good views of geomorphic and structural features along the western front of the Santa Fe Range.

0.0 Begin log at the intersection of NM-76 and [52] NM-75 heading south on NM-76. For the next ~16 miles, NM-76 crosses the Peñasco Embayment, which is located between the Picuris Mountains on the north and the granitic-cored Santa Fe Range south of the town of Truchas (see Fig. 3.23). **0.0**

0.2 Holocene and late Quaternary alluvium fills the valley bottom. To the west are highlands underlain by Proterozoic granite and metasediments of the Hondo and Vadito Groups. At 4:00, at the base of Picuris Mountains, are prominent white outcrops of the Picuris Formation overlain by ~3 m of Quaternary gravel. The lower (white) part of the formation is composed of tuffaceous silt and fine sand, with interbedded gravel rich in Proterozoic Pilar Formation phyllite and Ortega Formation quartzite derived from the Picuris Mountains massif (see Bauer, 1993). These gravel beds become more common upward in the section, and may reflect concomitant uplift of the Picuris Mountains. The upper (orangish) part of the formation is composed of siltstone and sandy pebble conglomerate beds composed mostly of volcanic clasts that include Amalia Tuff (see Aby et al., 2004, this volume for complete descriptions). The presence of the 25.1 Ma Amalia Tuff indicates a provenance from the Latir volcanic field (Smith et. al., 2002; Lipman and Reed, 1989). Based on these observations, the Picuris Mountains were already a topographic high during deposition of the lower part of the Picuris Formation, but were then overtopped (at least partially) by volcaniclastic sediment deposited by southward-flowing streams (Smith, 2004). This breaching might have been facilitated by localized down-dropping along north-south trending normal faults that have been mapped in the Picuris Mountains (these faults are shown in Bauer et al., 2003). **0.2**

0.3 Outcrop of the upper, volcanic clast-rich part of the Picuris Formation in bluffs ahead, which generally consist of coarse channel deposits together with subordinate flood-plain or extra-channel sediments consisting of silt and sand. **0.1**

0.5 Junction with Acequia del Sur Road; continue [53] straight on NM-76. Approximately 0.1-0.2 miles down Acequia del Sur Road is an exposure of a fault that bounds the western side of a horst block. Immediately beyond the Acequia del Sur Road junction, on the right side of NM-76, are small exposures of silica-cemented conglomerate composed predominantly of Proterozoic granite, quartzite, amphibolite, and local Tertiary volcanic clasts. In exposures of this silica-cemented part of the Picuris Formation along the Picuris mountain front are beds containing abundant pumice clasts and/or sandy gravel composed of either Proterozoic clasts (as seen here) or Tertiary volcanic clasts. In the cliff exposures just east of the highway here, this unit also contains a >10 m-thick sandy-silty boulder-to-pebble conglomerate composed entirely of Proterozoic clasts. This conglomerate is overlain by thinly to thickly bedded, pebbly-to-silty sand with beautifully preserved dewatering/soft-sediment deformation features. **0.2**

1.0 Outcrop on right is of the Dixon member (Steinpress, 1980), which here consists of a sand and pebble-conglomerate underlain by floodplain sediment of mud and very fine- to fine-grained sand. A fault trends subparallel to the road at the base of the cliffs to the east, and the splay exposed on Acequia del Sur Road passes under the road at this point. These two faults are west-down and merge to the south. The mesa to the west is capped by 6-12 m of sandy gravel containing boulders up to 3 m in diameter. This surficial gravel represents a high-level Quaternary alluvial deposit. **0.5**

1.8 Outcrop on right side of road consists of the Dixon member of the Tesuque Formation (here, a small channel deposit overlying fine-grained floodplain deposits). Gravelly deposits on left side of road belong to the upper part of the Picuris Formation. The volcanic clasts of the Picuris Formation serve to differentiate it from the Dixon member of the Tesuque Formation. The latter is dominated by Paleozoic limestone, sandstone, and siltstone clasts in addition to quartzite clasts. The west-bounding horst fault juxtaposes the two units at this location. **0.8**

2.2 Lucero Store in the town of Chamisal. Note that the broad alluvial valley developed in Tertiary sediments narrows abruptly approximately 2.5 km downstream, where the stream has incised into Proterozoic bedrock. This pattern is repeated in other settled tributaries of Embudo Creek, such as the Peñasco, Trampas, and Ojo Sarco drainages. Not surprisingly, settlers in the 1700s-1800s established homesteads and communities upstream from these bedrock constrictions. **0.4**

3.5 View of Truchas Peaks at 11:00. These peaks are largely composed of quartzite from the lower Ortega Formation (Miller et al., 1963). The high-level surface adjacent to the road is underlain by silt to fine sand, which are in turn underlain by Quaternary gravel. A strong calcic soil horizon is evident by the chalky appearance of the soil. **1.3**

4.2 Outcrops of the Dixon member of the Tesuque Formation are present in road-cuts on the right. The Dixon member here is composed of silt and fine sand with less than 10% coarser channel deposits. Fossil data near Dixon indicate a late Barstovian North American Land Mammal Age assemblage (14.5-11.8 Ma; Tedford and Barghoorn, 1993; Tedford et al., 1987), but the Dixon member may be older at this locality. **0.7**

5.3 Outcrops of Puntiagudo granite porphyry (Bauer and Helper, 1994) intruded by both felsic and mafic dikes. This bedrock may possibly have formed a topographic high in the middle Miocene, around which the Dixon member of the Tesuque Formation was deposited by west-southwest flowing streams. It is safest to pull off on the left side of the road if one wishes to inspect these outcrops more closely. **1.1**

5.5 On left side of the road, a photogenic wooden flume carries water for the Trampas Ditch. Enter into town of Trampas adjacent to the Rio de Trampas. Trampas was established in 1751 by 12 families from Santa Fe. **0.2**

6.3 Outcrops of fine-grained Dixon member on the right, with one cemented sandstone channel exposed. **0.8**

6.7 Roadcuts in conglomeratic Tesuque Formation here are correlated to the Dixon member. These beds consist of about equal proportions of Proterozoic quartzite and Pennsylvanian sedimentary clasts. The provenance is consistent with a river drainage basin comparable to the modern Rio Embudo. **0.4**

7.3 Roadcuts in Dixon member conglomerate, which dips about 10° to the west. Although the beds in this roadcut contain almost nothing but quartzite and Paleozoic sedimentary clasts, similar strata near the community of Ojo Sarco, 1.5 km to the northwest, contain variable abundances of volcanic clasts. The volcanic clasts are probably eroded out of the older Picuris Formation. The flat mesa visible to the west is Mesa de Cejita. Coarse gravel comprising the upper half of the visible east slope of the mesa was assigned to the Cejita Member of the Tesuque Formation by Manley (1977). Although their composition is approximately similar, the Cejita Member is overall coarser grained than the Dixon member. Along the north flank of Mesa de Cejita south of Dixon, the two gravelly members of the Tesuque Formation are separated by eolian sandstone of the Ojo Caliente Sandstone Member. Where the Ojo Caliente Sandstone is absent to the south, it is difficult to distinguish the two gravel members except in rare high-quality exposures. The top of Mesa de Cejita is an erosional remnant of the Oso geomorphic surface, described further at mile 9.7. **0.6**

7.6 Enter the Cañada de Ojo Sarco. To the east-northeast of this canyon, Proterozoic outcrops such as the one noted at mile 5.3 are common, and the contact between Proterozoic bedrock and Tertiary sediments is exposed in many places along the Cañada de Ojo Sarco. To the west-southwest of this canyon, however, exposures are entirely of Tesuque Formation strata. **0.3**

8.3 The highway exploits a relatively gentle slope that is a remnant of a once extensive hillslope geomorphic surface, which is graded to terraces along the Cañada de Ojo Sarco and rises to the forested mesa ahead. **0.7**

9.7 Here, the road crosses the Oso surface of Manley (1976a). The Oso surface is the highest and oldest of four geomorphic surfaces that record former courses of the Rio Quemado, which drains basinward from the Truchas Peaks. The

Oso surface projects close to 2.8 Ma basalt flows near Velarde (Manley, 1976a and 1976b), some 22 km to the northwest. All four of the surfaces are actually compound surfaces recording local re-grading of stream profiles during the base level drop from one surface to the next lowest one (Smith et al., 2004). The Oso surface is cut on Miocene sandy gravel of the Tesuque Formation, which is exposed in upcoming roadcuts on the highway grade. Discontinuous concentrations of quartzite boulders are the only recognizable deposits of the stream that cut the Oso surface. **1.4**

10.9 This forested mesa is the Pliocene Entrañas surface of Manley (1976a), which marks a former course of the Rio Quemado about 30 m lower than the Oso surface. Like the Oso surface, there is little in the way of unambiguous fluvial sediment associated with the cutting of the Entrañas surface on top of the coarse-grained Tesuque Formation. **1.2**

12.2 STOP 1. Overview of Peñasco Embayment.

[54] Pull out in the old roadside rest area on the right.

This stop is located at the south edge of the Entrañas surface, just above the late Pliocene Truchas surface (Manley, 1976a; Fig. S1.1). The village of Truchas is visible along the road to the south (See Fig. S1.1). The Santa Fe Range rises south of Truchas and marks the southern margin of the Peñasco embayment of the Española Basin. Looking westward is a view across the Española Basin to the Jemez Mountains. **1.3**

Smith and Roy (2001) and Smith (2004) interpret the Peñasco embayment to be part of a formerly more extensive eastern Española Basin, which has been uplifted and exhumed by Neogene uplift of the Santa Fe Range. The glaciated Truchas Peaks loom high to the southeast, and are separated from the Santa Fe Range by the north-striking Picuris-Pecos fault, along which Neogene, as well as Laramide, uplift of the Santa Fe Range is hypothesized to have occurred (Miller et al., 1963; Bauer and Ralser, 1995; Kelley, 1995; Kelley and Chapin, 1995).

The roadcuts opposite the rest area and descending the grade to the southeast are in coarse Tesuque Formation that is dipping two-to-four degrees to the northwest. The gravel contains 75-80% quartzite clasts derived from the Truchas Peaks area. The remaining clasts are granite, amphibolite, and schist that are mostly eroded from the Santa Fe Range. Pennsylvanian sedimentary rocks appear very rarely among the clasts and are derived from the east or southeast. Younger strata capping high ridges to the east are essentially 100% quartzite clasts.

FIGURE S1.1. View looking east towards the Sangre de Cristo Mountains. Town of Truchas (center) is on the Truchas surface, which is inset into the Entrañas surface (left).

This scenic view appears often in the 1988 Robert Redford movie *Milagro Beanfield War* that was adapted from the classic John Nichols novel and mostly filmed in Truchas. The towns of Truchas and Cordova, about 6 miles farther to the southwest, are the population centers for descendants of colonists of the Nuestra Señora del Rosario, San Fernando y Santiago Land Grant, which was established by Spain in 1754. The land grant encloses 14,786 acres and is owned by 290 land-grant members. About 2100 acres are irrigated to support livestock and timber harvesting produces income in the eastern and southern parts of the grant.

Return to vehicles and continue south.

13.3 The road is crossing the Truchas surface. This surface is eroded on Tesuque Formation from here to the west, and on Precambrian granitic rocks east of Truchas. A veneer of quartzite boulders, as much as 2 m across, is present across most of the surface. Looking back to the northeast there are views of a forested ridgeline that rises above the Rio de Truchas. This ridge also rises nearly 100 m above the Entrañas surface and consists of almost entirely quartzite gravel of the Tesuque Formation resting nonconformably on Proterozoic biotite-quartz monzonite and coarse-grained peraluminous granite. The ridgeline is interrupted by several beheaded valleys that were north flowing tributaries to the ancestral Rio Quemado on the Entrañas surface before piracy and incision occurred to the south in the current vicinity of the Truchas surface (Smith et al., 2004). **1.1**

13.5 T-intersection in the town of Truchas. Turn right
[55] (west) to continue on NM-76. 0.2

14.1 Road-cut on right exposes coarse Tesuque Formation gravel that is compositionally similar to the deposits exposed in roadcuts below the Oso and Entrañas surfaces, although granitic and sedimentary clasts are slightly more abundant at this location. Extending beyond 3 km to the south, at 9:00 to 11:00, are a series of broad, concordant ridges developed on the lower western flank of the Santa Fe Range. Called the Borrego surface by Smith and Pazzaglia (1995), this geomorphic feature can be described as a late Miocene-Pliocene pediment approximately 8-10 km wide that appears to rise in elevation to the south (Fig. S1.2). **0.6**

14.3 Through the trees and just below the road on the left (south) is an exposure of the Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff, erupted 1.61 million years ago at the time of formation of the Valles caldera in the Jemez Mountains. The fallout pumice and ash layers rest on gravel of the Cañada Ancha surface of Smith et al. (2004). The Cañada Ancha surface is a highly degraded geomorphic surface that marks an early Pleistocene, northeasterly course of the ancestral Rio Quemado. The Cañada Ancha surface projects upslope into the sky beneath the gallery on the left, marking where the drainage was captured by an east-flowing river that paralleled the modern Rio Quemado. **0.2**

15.3 A good view to the south. At 1:00, the Borrego surface is broken by a linear north-south trending valley that marks the topographic expression of an unnamed, east-down fault (see Fig. S1.2). Preferential erosion of the softer Tesuque Formation on the hangingwall of the fault (still preserved on the north end of the fault), together with a probable weakness of the Proterozoic bedrock in the immediate area of the fault zone due to increased fracturing and shearing, has resulted in the north-south trending valley. Approximately 28 km to the south, another east-down fault appears to have experienced vertical motion around ~36 Ma, based on unpublished apatite fission-track age data (Shari Kelley, pers. comm., 2003). The fault seen here offsets the Tesuque Formation so it post-dates this sediment (inferred to be late Oligocene or later). **1.0**

15.6 Views to the northwest of badlands eroded in the Tesuque Formation. Dips in the area north of the road range from nearly horizontal to as much as 5° to the northwest and appear to decrease upsection. Although the Tesuque strata are not as well exposed here as farther west, they do clearly coarsen upward from interbedded sand, gravel, and silt to an uppermost 50 m composed almost entirely of sandy gravel, with clasts up to 80 cm across. This upward-coarsening trend is evident throughout the Española Basin (e.g., Koning and Maldonado, 2001, Koning, 2002b, Koning 2003, Smith et al., 2004). This trend is probably due to increasing rates of rift tectonism since the early Miocene, which both progressively steepened the westward tilt of the Española Basin half graben and generated more topographic relief (Koning, 2002a, 2003); however, climatic changes around 11-12 Ma may also have influenced textural trends (Koning, 2002c). At all levels in these exposures, the gravel is a mix of quartzite and granitic clasts with sparse Paleozoic sedimentary clasts; the quartzite abundance increases upsection from about 45% to 80%. The valley of Cañada de los Tanos, south of the road, follows along the southwest striking contact of Tesuque Formation with underlying Proterozoic granite, amphibolite, and schist. Good views of the Borrego surface continue to the south (Fig. S1.2). **0.3**

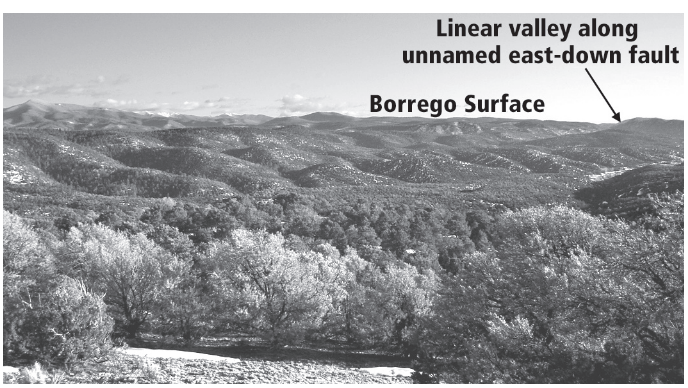


FIGURE S1.2. The area of low-sloping, broad, concordant ridges marks the Borrego surface developed on the western front of the Santa Fe Range (in front of and to the right of the higher mountains beneath the clouds). At extreme right is a linear north-south valley that marks the topographic expression of the unnamed, east-down fault noted in mile 15.3. View is to the south from mile 15.6.

16.3 Junction with road to village of Cordova. Continue
[56] **to right on NM-76.** Both the state highway and the county road to Cordova traverse erosional surfaces graded southeastward to a prominent gravel terrace along the Rio Quemado. This terrace continues westward into the Española Valley as a high, gravel-capped pediment named the Santa Cruz surface by Manley (1976a). About two kilometers south of this junction, the Tesuque Formation rests nonconformably on Proterozoic amphibolite and biotite schist, cut by garnetiferous peraluminous leucogranite pegmatites near Cordova (Smith et al., 2004). Bedding dips in the Tesuque Formation steepen southward from 5° NNE to 16° N over a distance of less than a kilometer, suggesting that the northern terminus of the Santa Fe Range is a roughly east-west striking monoclinal flexure formed by differential uplift of the Santa Fe Range. **0.7**

18.1 At 10:00, the fault noted in mile 15.3 is marked by a steepening of the hillslope (with the higher hills in the footwall of the fault). At 11:00, this fault juxtaposes Tesuque Formation on the east with Proterozoic bedrock on the west. In a classic example of stream superposition, the Rio Quemado has maintained a relatively straight course and cut through the Proterozoic bedrock of the fault footwall, rather than going only one kilometer to the north and staying in much softer Tesuque Formation. **1.8**

18.9 Peak at 10:00, south of the narrow gorge cut by the Rio Quemado, is locally known as Cerro de Chimayó. Along its eastern side is the north-south striking Chiquito fault (east-down), estimated to have 80 to 100 m of throw. The flat surface to the east of both the fault and peak is the Santa Cruz surface; 5-25 m of sandy gravel underlies the terrace tread and is interpreted to be early Pleistocene in age (Koning et al., 2002). Straight ahead in far distance is a prominent escarpment north of the Santa Cruz River, with superb exposures of the Tesuque Formation (Fig. S1.3). Strata in the escarpment strike northeast and commonly dip 3-9° to the northwest, with dips decreasing up-section (Koning, 2003; see Minipaper by Koning). **0.8**

19.6 At 5:00, on the right side of road, is a 7-8 m-thick interval of reddish fluvial channel and overbank deposits. The channels are composed of very thin to thin beds of

GEOLOGY OF THE ESCARPMENT NORTH OF THE SANTA CRUZ RIVER, EASTERN ESPAÑOLA BASIN, AND INFERENCES REGARDING RIFT TECTONISM IN THE MIOCENE

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One of the best exposures of the Tesuque Formation in the Española Basin is the 200 - 300 m-tall escarpment north of the Santa Cruz River and west of longitude 105°53'W (Fig. S1.3). Geologic mapping efforts here in the summer of 2002 yielded important observations of sedimentologic trends in the Tesuque Formation, which in turn allows inferences to be made regarding the nature and rates of rift tectonic activity in the Miocene (Koning, 2003). On the escarpment, eight lithostratigraphic units were differentiated in the Tesuque Formation based on provenance, texture, and general sedimentologic characteristics. Relatively good age control is obtained from fossil assemblages and tephras that are found in most units (except the oldest ones); these indicate that the strata along the escarpment probably have an age range of 30(?) to 9 Ma (Koning, 2003; Galusha and Blick, 1971; Izett and Obradovich, 2001).

The units reflect two general depositional environments. The first environment was a west- to northwest-sloping alluvial slope (see Smith, 2000, for discussion of alluvial slopes) that flanked the western margin of the Sangre de Cristo Mountains, over which flowed numerous streams with headwaters south of the Truchas Peaks. This alluvial slope environment is represented by units associated with lithosome A of Cavazza (1986). These units are characterized by medium to thick, tabular to broadly lenticular beds of silty sandstone interbedded with various proportions of coarser channel deposits of pebbly sandstone, sandstone, and pebble-conglomerate. The gravel of lithosome A is generally dominated by granite, with subordinate quartzite, and the sand fraction has abundant pinkish potassium feldspar. Lithosome A was further subdivided according to texture. Finer units (silty very fine to medium sandstone and siltstone with less than 5-7% coarser sand and gravel channel deposits) are interpreted to generally represent the distal alluvial slope. Coarser units, composed of slightly muddy very-fine to very-coarse sandstone with greater than 5-7% gravelly sand channel deposits, are interpreted to generally represent the medial and proximal alluvial slope.

The second environment was a south- to southwest-flowing fluvial system on a basin floor. This environment is represented by units associated with lithosome B of Cavazza (1986), which are characterized by siltstone, claystone, and fine sandstone floodplain deposits interbedded with subordinate, relatively broad channel deposits of sandstone and conglomerate. Sourced in the Sangre de Cristo Mountains north of Truchas Peaks and east of the Picuris-Pecos fault, the gravel of lithosome B consists of a hetereolithic clast assemblage dominated by Paleozoic sandstone, siltstone, and limestone. Subordinate clast types in this area include quartzite, granite, and felsic to intermediate volcanic clasts. The sand fraction has a grayish color (in contrast to the pinker sand of lithosome A) due to a relative abundance of lithic grains containing volcanic detritus and greenish quartz grains derived from weathering of greenish Paleozoic sandstones.

Galusha and Blick (1971) subdivided the Tesuque Formation into the Nambé, Skull Ridge, and Pojoaque Members. These members were mapped in the Cundiyo quadrangle to the south (Koning et al., 2002) and can be differentiated locally in the lower slopes of the escarpment west of Chimayó . However, it becomes increasingly difficult to map these members eastward along the escarpment because the diagnostic lithostratigraphic features associated with their respective contacts become less obvious in that direction.

Along the escarpment, strata of the Tesuque Formation generally strike northeast and unconformably overlie crystalline Proterozoic rocks. Near the mountain front, the older (upper Oligocene to lower Miocene) strata of the Tesuque Formation dip 6-10° to the northwest. As one moves up-section (i.e., to the northwest), stratal dips decrease to about 2-4°. However, major structures, such as those discussed below, can locally cause stratal dips to increase up to 47° (but generally to 8-22°).

Numerous faults offset the Tesuque Formation in the escarpment. However, three generally north-south-striking structures are particularly significant. Each is associated with normal faulting and monoclinal flexures (probably draped over normal faults at depth), The Chimayó structure has offset the western side of the Chimayó horst (the bedrock-cored topographic high present 1 to 2 km east-southeast of the old Chimayó plaza) and is crossed between miles 21.2 and 21.7 of the Day 3 Supplemental road log. This structure is down-to-the-west and manifested primarily as a monocline that is locally faulted. The Chimayó structure one to two kilometers north of Chimayó is estimated to have 90-170 m of west-down throw (includes both fault and monocline). This structure may have greater throw south of Chimayó (cross section in Koning et al., 2002). The eastern side of the Chimayó horst is bound by an east-down normal fault called the Chiquito fault (crossed at mile 21.2) that extends southward into Santa Cruz lake. Interpreted stratigraphic offset along the Chiquito fault is 80-100 m.

The third fault zone is a northward continuation of the White Operation Fault of Koning et al. (2002), which is crossed between miles 23.6 and 23.9 of the road log. This is generally a west-down structure; however, both east-down and west-down faults are present within the fault zone. The structure is manifested by a slight increase in stratal dips to 7-9° and normal faulting with about 30-40 m of interpreted throw.

Detailed sedimentologic study and mapping of the map units indicate two important trends. First, the Tesuque Formation gradually coarsens-upward since about 16 Ma, with a more pronounced, but still gradual, coarsening shortly after 12-14 Ma. This coarsening is consistent with that seen by Koning (2002a) to the southwest and Smith et al. (2004) to the east. Second, both lithosomes B and A have progressively prograded westward and northwestward since about 16 Ma (Koning, 2002c), which is also observed to the southwest (Koning 2002a and 2002b). The favored interpretation explaining these two trends is that rift tectonism (i.e., extension) increased after about 16 Ma. This resulted in increased rates of westward tilting of the hanging wall of the Española Basin half-graben and more accommodation space being formed near the western master faults (i.e., the Pajarito fault and the prominent down-to-the-east fault south of Black Mesa), which caused the drainages associated with lithosomes A and B to shift to the west. Examples of how tilting of half-grabens may affect depositional systems is provided in Leeder and Gawthorpe (1987), Alexander and Leeder (1987), Blair and Bilodeau (1988), Mack and Seager (1990), Cather et al. (1994), and Gawthorpe and Leeder (2000).

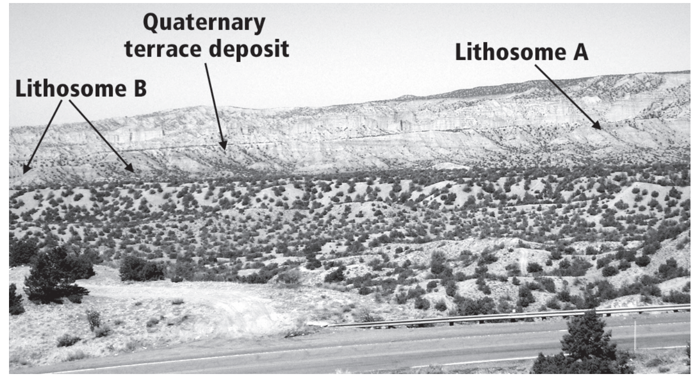

FIGURE S1.3. The ~300 m-tall escarpment north of the Santa Cruz River, as seen from STOP 2.

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sand (with much reddish clay coatings on the sand grains) and gravel with clast imbrication indicating a southwest paleo-flow direction. A clast count of the gravel gives 34% granite, 25% yellowish to grayish Paleozoic limestone, 9% grayish to yellowish Paleozoic sandstone and siltstone, 14% quartzite, and minor biotite-schist, amphibolite, and quartz. This reddish sediment is somewhat similar to sediment near Santa Fe categorized as lithosome S (Read et al., 2000; Read and Koning, 2004), and may have been derived from drainages with similar provenance (east of the Picuris-Pecos fault). This reddish sediment is interbedded within the more abundant lithosome A alluvial slope sediment that is discussed in mile 19.9. Strata here strike 040-060° and dip 8-10° NW. **0.7**

19.7 STOP 2. Tesuque Formation Escarpment

[57] **Carefully pull off the road on available shoulders. Be cautious in walking alongside this curvy road because of frequent fast traffic.** This stop provides a view of the prominent escarpment north of the Santa Cruz River, which offers excellent exposures of the Tesuque Formation. **0.1**

At 1:00 to 2:00, at a distance of ~ 2 km, tilted Tesuque Formation deposits are unconformably overlain by Quaternary sandy gravel deposits (Fig. S1.3). The Tesuque Formation under the gravel deposits to the left belongs to lithosome B of Cavazza (1986), and was deposited by a relatively large stream system that generally flowed south-southwest. The sediment of lithosome B is marked by laterally extensive sandy to pebbly channel deposits and significant floodplain deposits of clay, silt, and fine sand. The clast composition of lithosome B under these terraces is approximately similar to that of the Dixon member at miles 6.3 to 7.3, and the two localities were very likely part of the same depositional system (although the lithosome B sediment here may be older than the Dixon member seen between miles 6.3 to 7.3). These lithosome B deposits interfinger to the north-northeast with lithosome A alluvial slope sediment derived from the Santa Fe Range. This interfingering relationsip suggests that the lithosome B stream had a south to slightly southeast paleo-direction at this particular locality and time of deposition. To the southwest are good views of Cerro de Chimayó and another gorge cut by the Rio Quemado (Fig. S1.4). Similar to the gorge noted at mile 18.1, this gorge is probably due to stream superimposition. Mapping by Robert Horning (in Koning et al., 2002) indicates that the Proterozoic here is composed of amphibolite and schist that have been intruded by multiple, coarse-grained granitic rocks.

Return to vehicles and continue south.

19.9 Road-cuts on right side of road provide good examples of lithosome A sediment. First used by Cavazza (1986) for arkosic and granite-rich sediment to the west-southwest, lithosome A here is marked by relatively abundant (25-60%) pebbly sandstone and sandy pebble-conglomerate channel deposits interbedded within poorly sorted, clayey-silty, very fine to very coarse sandstone deposits that are pink, light brown, very pale brown, or light yellowish brown in color. The latter, muddier sediment has been referred to as extra-channel sediment by Koning (2003) and commonly is present as thick, tabular beds that are internally massive and have been locally

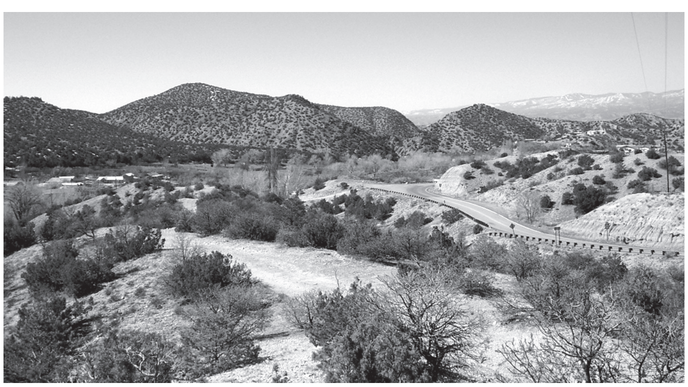

FIGURE S1.4. The topographic highs in the center of the photo are underlain by Proterozoic crystalline rock that includes pink granite, dark amphibolite, and a light granodiorite or tonalite that is locally foliated. Peak on the left is Cerro de Chimayó. In the foreground is the lower Tesuque Formation. The Tesuque Formation laps southward onto these topographic highs, which indicates that these highs were present during the early deposition of the Tesuque Formation in this area (probably late Oligocene to early Miocene). Locally, colluvium is present between the bedrock and the Tesuque Formation fluvial sediment. By the middle to late Miocene these topographic highs were buried by basin fill.

scoured by overlying coarser channels. The sand of lithosome A has abundant pinkish potassium feldspar, and the gravel consists of granite with minor quartz and quartzite (4-12% and 5-16%, respectively, in this area). Paleocurrent data and clast composition indicate that the granite-rich sediment was derived from the northwest part of the Santa Fe Range and deposited by west- to northwest-flowing streams on an alluvial slope (see Smith, 2000, and Kuhle and Smith, 2001 for discussion of alluvial slopes). These outcrops are interpreted to be representative of the medial or possibly proximal areas of the alluvial slope (Koning, 2003). Distal alluvial slope facies are present to the west (see comments associated with miles 23.9-25.6 of this road log). These locally have been described and subdivided in detail at the outcrop scale (Gaud, 2002; Kuhle and Smith, 2001; Kuhle, 1997) and differentiated in 1:24000-scale mapping (Koning, 2003). Strata here strike 026-072° and dip 9-13° NW. **0.2**

20.0 **Junction of NM-76 with NM-503** (which goes
[58] through the town of Rio Chiquito ~0.2 km to the south)**; continue straight on NM-76. 0.1**

21.2 Cross the Chiquito fault zone. Although no exposures of it are visible from the road, the fault can be observed 0.3 to 0.5 km to the south, where it locally juxtaposes reddish lithosome S(?) against browner lithosome A sediment. Between here and mile 21.7, stratal dips of the Tesuque Formation increase to 15 to 26° west due to a north-south mountain-front structure. This structure, called the Chimayó structure by Koning (2003), continues at least to the top of the escarpment to the north and to Cerro Piñon to the south. In its northern extent, the structure is a west-facing monoclinal-drape broken by a significant west-down normal fault along the steep mountain front at Chimayó (Koning, 2003) (Fig. S1.5). North of Chimayó 1 to 2 km, the Chimayó structure is estimated to have 90-170 m of throw (value includes both fault(s) and monocline). About 8 km to the south of Chimayo, a cross-section by Koning et al. (2002) suggests a possible structural relief on the scale of 1000 m. In that area, there is no west-down fault exposed at the surface and the top of the monoclinal drape is not preserved due to erosion. Even though faults and monoclines do coincide with much of the lower western front of the Santa Fe Range (west of the Borrego surface), the gross structure of the Española Basin southeast of the Abiquiu embayment is still probably that of a west-tilted half-graben (Cordell, 1979; Manley, 1979a; and Biehler et al., 1991). **1.2**

21.7 **Intersection of NM-76 with NM-520; continue**
[59] **straight on NM-76**. Chimayó is a small town whose historic center lies immediately southwest of this intersection. Thousands of pilgrims walk to the Santurario de Chimayó (0.9 miles to the south) from throughout northern New Mexico during Easter weekend. The church is built on sediment ascribed to have miraculous healing powers that pilgrims can scoop from the floor. Aside from the church, Chimayó is best known for its weaving products and for the Chimayó green chili—a unique, small, and relatively mild chili grown locally.

FIGURE S1.5. Looking north-northeast to the topographic high underlain by Proterozoic bedrock north of Cerro de Chimayó (see Fig. S1.4). The Santa Cruz River near the Santuario de Chimayó lies in the foreground. The gorge in the mountain front marks the Rio Quemado, probably formed due to stream superimposition. Note the pronounced change in slope on the western (left) side of the topographic high north of the Rio Quemado. Here, the upper slope forms a relatively broad surface dipping 8-15° W-NW. This slope value is similar to the general stratal dips of the Tesuque Formation and may represent an exhumed erosional surface developed in the middle(?) Miocene. The lower slope steepens significantly to 20-30° and coincides with a prominent west-down fault of the Chimayó structure

The book *Sabino's Map* by Don Usner (1995) provides colorful recollections of the area's early days. **0.5**

22.3 Highway NM-76 follows the Santa Cruz River west ward between Chimayó and Española, and generally passes over late Holocene alluvium. In bluffs about 0.5 km to the north and 1 km to the south, Lithosomes A and B are present in an interfingering relationship. This sediment belongs to the Nambé Member of the Tesuque Formation, as established by Galusha and Blick (1971). Between here and mile 23.6, several faults project across the highway from outcrops north and south of the valley (Koning, 2003; Koning et al., 2002). **0.6**

23.6 The White Operation fault zone underlies Quaternary alluvium in this vicinity (Koning et al., 2002; Koning, 2003). This structure is manifested by a slight increase in stratal dips and exposures of several strands of normal faults (generally west-down). In the badlands to the north, there is an estimated 30 m of down-to-west throw across this structural zone; 1.4 km to the southwest, there is approximately 70-to-80 m of throw based on the juxtaposition of certain ash beds. Across the Santa Cruz River 1.9 km to the south (9:00), one can see an ash bed near the top of the ridge. This is White Ash #2 of the Skull Ridge Member (see Galusha and Blick, 1971). Like White Ash #4 (mile 23.9 and mile 24.9), this ash serves as a wonderful stratigraphic marker, largely because of a sedimentologic change that occurs across it (see Kuhle and Smith, 2001). An $^{40}Ar/^{39}Ar$ date of 15.5 Ma has been obtained from White Ash # 2 (Izett and Obradovich, 2001). The ashy bed 35-40 m below White Ash #2 is White Ash #1, the base of which serves as the contact between the Skull Ridge and Nambé Members of the Tesuque Formation (Galusha and Blick, 1971). A couple of meters above this ash is the late Hemingfordian - early Barstovian North American Land Mammal age boundary (Galusha and Blick, 1971; Tedford and Barghoorn, 1993; Tedford et al., 1987). North of the highway, White Ash #1 does not occur so the contact between the Skull Ridge and Nambé Members cannot be adequately mapped there. **1.3**

23.9 The prominent white ash on top of the bluffs 1 km to the south (about 10:00) is White Ash #4 of the Skull Ridge Member of the Tesuque Formation. In this area, White Ash #4 is underlain by medium to thick, tabular beds of siltstone and very fine to fine sandstone with minor sandy channels of lithosome B, and overlain by more arkosic fine sand of the basin floor - distal alluvial slope transition (see Koning, 2003). This ash is probably the most laterally extensive of the ashes in the Tesuque Formation, is relatively thick (70 to 250 cm), and serves as a useful stratigraphic marker bed. It has been dated at 15.45 Ma and 15.3 Ma using $^{40}Ar/^{39}Ar$ methods (McIntosh and Quade, 1995, and Izett and Obradovich, 2001, respectively). The White Operation fault lies between White Ash #4 here and White Ash #2 noted at mile 23.6. **0.3**

24.9 A short distance ahead (0.1 miles) on right side of road, is a 50-65 cm-thick fine white ash that is interbedded within pinkish, well-consolidated siltstone and very fine-grained sandstone. **It is dangerous to closely inspect this outcrop because the shoulder of the road is virtually non-existent here.** This ash is tentatively correlated to the White Ash #4 of the Skull Ridge Member. The ash is truncated on its western end by a west-down fault. The fine-grained nature of the Tesuque Formation in this area represents basin floor facies and transitional basin floor-distal alluvial slope facies, and contrasts with the coarser, more proximal alluvial slope facies seen in mile 19.9. Here and to the west, bluffs of Tesuque Formation adjacent to the road on the north are unconformably overlain by a Quaternary sand and gravel deposit up to 18 m thick. The basal 2-4 m is composed of grayish, clast-supported cobbles with abundant quartzite (about subequal to granite in abundance). The overlying sediment is generally fine-grained, but has about 25-35% coarse channel deposits with a clast assemblage dominated by granite. The age of this terrace deposit is interpreted to be ~120-150 ka, based on correlation with terraces west of the Rio Grande whose ages have been constrained by carbon-14 and amino-acid epimerization ratio chronologic data (Dethier and McCoy, 1993; Dethier and Reneau, 1995; Koning and Manley, 2003). **1.0**

25.3 Over the next 200 m, the road parallels the strike of bedding and outcrops on the right offer exposure of transitional basin-floor to distal alluvial-slope facies. Near the base of the slope, a sandy channel complex is interbedded in siltstone and very fine sandstone similar to that at mile 24.9. The sand is relatively arkosic and pink here (with an estimated

1:4 ratio of lithic grains to pinkish potassium feldspar) but has a higher proportion of Paleozoic(?) lithics (about subequal compared to pink potassium feldspar grains) and a grayer color 200-300 m to the southwest. This gradation of color and sand composition is characteristic of the eastern part of the basin floor facies where it grades eastward into distal alluvial slope facies of the Tesuque Formation (i.e., the transition between lithosomes B and A). This lateral gradation reflects input of arkosic sand from relatively small, west- to northwest-flowing, tributary alluvial slope drainages into the southwest-flowing lithosome B fluvial system. The contact between the Skull Ridge and Pojoaque Members of Galusha and Blick (1971) has been placed at the base of this channel complex by Koning et al. (2002), although exact correlation with the "type locality" of this contact 3.8 km to the southwest (in a roadcut at La Puebla, see Galusha and Blick, 1971) is not certain. **0.4**

25.6 To the right is a 30 cm-thick fine white ash. The ash is altered and interbedded within medium, tabular beds of siltstone associated with the transition between basin-floor to alluvial-slope facies. There are over 70 tephra beds in the Santa Fe Group basin fill. The presence of so many tephra beds, together with generally good exposure, makes the Española Basin an ideal locality for stratigraphic studies of basin fill in a rift half-graben setting. Fossils collected between here and Española are associated with the Late Barstovian North American Land Mammal Age (14.5-12 Ma; Tedford and Barghoorn, 1993; Tedford et al., 1987). **0.3**

25.7 Exposures of very fine-to-fine, arkosic sandstone and silty sandstone. Strata here generally strike 030-050° and dip 4° NW. With one exception (mile 27.8), between here and Española there are no significant faults observed in the Tesuque Formation near the highway. **0.1**

25.8 Approximately 6-10 m up the hill to the north is a relatively unaltered, light gray ash. **0.1**

26.2 Intersection with road to La Puebla; continue straight
[60] on NM-76. **0.4**

26.4 Crossing Arroyo Quarteles. About 1 km up this arroyo are good exposures demonstrating the westward lateral transition from distalmost lithosome A alluvial slope facies to lithosome B fluvial channels and floodplain deposits. West of here, the Tesuque Formation observed near the road is interpreted as lithosome B basin floor facies and has an interpreted age of 14-12 Ma. **0.2**

27.0 Sandy gravel associated with the terrace described at mile 24.9 caps the bluffs to the right of the road. In this area, the underlying basin floor facies are relatively sandy. **0.6**

27.7 Basin floor sediment here is generally composed of massive, arkosic, very fine to fine sand, with some channels of medium- to very coarse-grained sand and minor pebbles of lithosome B provenance. The finer sand may perhaps be eolian. **0.7**

27.8 Outcrop on right exhibits fault displacement of silty very fine- to fine-grained sandstone and mudstone. This fault is part of the west-down Road fault of Galusha and Blick (1971) which appears to change to an east-down sense of motion) about 5 km north of here (Koning and Manley, 2003). **0.1**

28.3 Junction with NM-106. Turn left (south) on NM-
[61] 106 and pass over late Holocene valley fill. **0.5**

28.5 Sikh Gurdwara on west side of road. Founded in 1972 based on Sikh spiritual principles, this community of greater then 300 Sikhs run businesses, raise families, and meditate in a spirit of togetherness. **0.2**

28.8 Intersection with East Sombrillo Road (County Road 40). Just 0.1 mile east on this road are good exposures of lithosome B fluvial basin floor sediment, which here is generally composed of channel-fill sand and pebbly sand with 5-7% floodplain deposits of clay to silt. The pebbles are mostly Paleozoic limestone, sandstone, and siltstone, but subordinate quartzite and intermediate to felsic volcanic clasts are also present. Other outcrops of lithosome B in the vicinity are also generally dominated by sand. Two minor west-down faults can be observed. This sediment is still part of the Pojoaque Member of the Tesuque Formation. About 0.2 miles down East Sombrillo Road is an interesting Sikh temple. **0.3**

30.0 Junction of NM-76 with US-285. **1.2**
[62] Turn left (southeast) on US-285 to travel to Santa Fe and further south or turn right to head back to Taos or to points further north.

END OF SUPPLEMENTAL ROAD LOG.