Geologic Map of the Cundiyo Quadrangle, Santa Fe County, New Mexico

By

D.J. Koning, M. Nyman, R. Horning, M. Eppes, and S. Rogers

May, 2002

New Mexico Bureau of Geology and Mineral Resources
Open-file Digital Geologic Map OF-GM 56

Scale 1:24,000

This work was supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program (STATEMAP) under USGS Cooperative Agreement 06HQPA0003 and the New Mexico Bureau of Geology and Mineral Resources.

New Mexico Bureau of Geology and Mineral Resources
801 Leroy Place, Socorro, New Mexico, 87801-4796

GEOLOGIC MAP OF THE CUNDIYO 7.5-MINUTE QUADRANGLE, SANTA FE COUNTY, NEW MEXICO

BY

DANIEL KONING, MATT NYMAN, ROBERT HORNING, MARTHA EPPES, AND STEPHEN ROGERS

May, 2002

LIST OF FIGURES

DESCRIPTION OF MAP UNITS

Grain sizes follow the Udden-Wentworth scale for clastic sediments (Udden, 1914; Wentworth, 1922) and are based on field estimates. Pebbles are subdivided as shown in Compton (1985). The term "clast(s)" refers to the grain size fraction greater than 2 mm in diameter. Clast percentages are based on percent volume and are based on counts of about 100 clasts at a given locality. Descriptions of bedding thickness follow Ingram (1954). Sandstone classified according to Pettijohn et al. (1987). Colors of sediment are based on visual comparison of dry samples to the Munsell Soil Color Charts (Munsell Color, 1994). Surficial units are only

delineated on the map if estimated to be at least 1 m thick. Soil horizon designations and descriptive terms follow those of the Soil Survey Staff (1992) and Birkeland (1999). Stages of pedogenic calcium carbonate morphology follow those of Gile et al. (1966) and Birkeland (1999).

Mapping of geologic features was accomplished using field traverses, close inspection of numerous outcrops across the quadrangle, and aerial photographs. Terrace correlations were made by comparison of mapped strath heights, lithologic characteristics, and deposit thickness. Map units are correlated in regards to time in **Figure 1**. The authors did not receive permission to enter Nambé Pueblo lands, so away from the Nambé Indian Reservation borders that area has not been field-checked. Consequently, mapping of much of the Tesuque Formation in the southeastern part of the quadrangle was conducted using only aerial photographs and Kelley (1978), and is unfortunately not as accurate as in the remainder of the quadrangle.

ANTHROPOGENIC DEPOSITS

af Artificial fill (Recent) -- Silt, sand, and gravel under highways or in landfills; loose or compacted.

QUATERNARY AEOLIAN DEPOSITS

Qey **Younger aeolian sand deposits (late Pleistocene to Holocene) –** Reddish yellow (7.5YR 6/6) sand and silt that mantles the northwest side of a hill 0.3 to 0.4 km east of La Puebla in the northwest corner of the map; massive or cross- laminated (tangential foresets 1-1.5 m-tall); lenticular grain flows are locally observed in exposures showing trough cross-stratification and are up to 1.5 m-long and 2 cm-tall. Sand is very fine- to fine-grained, well sorted, subangular to subrounded, and a lithic-bearing arkose. Deposit becomes redder and more oxidized near the surface; a calcic soil horizon is locally observed at 50-110 cm-depth that exhibits a stage I calcium carbonate morphology. Loose to weakly consolidated. 4-12 m-thick.

Qeo **Older aeolian sand deposits, Española Formation (middle to late Pleistocene) –** Light yellowish brown to light brown (10-7.5YR 6/4) silty very fine- to fine-grained sand that may cap topographic mesas and locally overlies 0.3 to 1.0 m of **Qaou** gravel. Sand is massive (probably due to bioturbation), well sorted, subangular to subrounded, and arkosic. Interpreted to be aeolian because of fine texture but may include minor alluvium. Locally overlies gravel of **Qaou,** with no evidence of a significant soil at the contact between the two units. Correlates to unit Qe of Koning (2002) and the Española Formation of Galusha and Blick (1971). The Española Formation is reported to contain Rancholabrean-age (approximately 10-300 ka; Tedford et al., 1987) fossils that include *Canis dirus*, *Equus*, *Bison*, and *?Camelops* (Galusha and Blick, 1971, p. 80-81). Deposits are loose and up to about 6 m-thick.

QUATERNARY ALLUVIUM

VALLEY FLOOR

Qam **Modern Alluvium (subject to annual deposition) –** Pink to very pale brown (7.5-10YR 7/3-4) gravelly sand in modern channels. Beds are laminated or very thin to thin, and planar to wedge-shaped to lenticular. Gravel include cobbles and pebbles; clasts are subrounded to subangular, poorly to moderately sorted, and consist of granite and calcium carbonate-indurated nodules of Tesuque Formation sandstone plus 0-3% quartzite, 0-3% greenish Paleozoic(?) sandstone and siltstone, and trace schist. Sand is very fine- to very coarse-grained, poorly to well sorted, subangular to subrounded, and arkosic. 1 to 2 cm-thick beds of very fine- to fine-grained sand may be found on the surface and were deposited during waning flow conditions. Specific color and composition of sediment is dependent on source area of a given drainage. Surface not vegetated and there is no soil development. Correlates to unit Qam of Koning (2002) and unit Qc of Borchert and Read (1998, revised 2002). Loose. Thickness not directly observed but estimated to be less than 3 m.

Qay2 **Youngest young alluvium (historical) –** Light yellowish brown to light brown (7.5YR-10YR 6/4) to pink (7.5 YR 7/4) gravelly sand, sandy gravel, silty sand, and minor silt that generally underlie floodplains of modern drainages. Beds are planar to lenticular and very thin to thin. Gravel is pebbles with up to 30% cobbles, generally clast-supported, subrounded to subangular, and poorly to moderately sorted. Clasts include granite with 0-3% greenish Paleozoic siltstone and sandstone, 0-5% quartzite, and 1-60% calcium carbonate-indurated nodules and sandstone from the Tesuque Formation. Sand is very fine- to very coarse-grained, moderately to well sorted, subangular to subrounded, and arkosic. Color and composition of sediment is dependent on source area of a given drainage. No soil development. Terrace tread of deposit is less than 2 m above the active channel. Strath of deposit is generally not seen. Compared to **Qay1**, surface of unit supports sparser plant growth, particularly in regards to grass and trees, but more abundant woody shrubs. Correlates to unit Qay2 of Koning (2002). Loose to very weakly consolidated. Estimated to be 1-2 m-thick.

Qayi **Inset young alluvium (uppermost Holocene) –** Light yellowish brown (10YR 6/4) or light brown to pink (7.5YR 6-7/4) sandy gravel, gravelly sand, and sand that underlie terraces whose tread is inset between that of **Qay1** and **Qay2**. Commonly planar or low-angle cross-stratified, very thinly to thinly bedded gravel, and very thinly bedded to laminated sand. Gravel is mostly pebbles with <10% cobbles, clast-supported, poorly to moderately sorted, and subrounded to subangular. Clasts include granite and calcium carbonate-indurated nodules and sandstone from the Tesuque Formation, along with trace to 5% quartzite and 0-5% greenish Paleozoic sandstone and siltstone. Sand is generally medium- to very coarse-grained, subangular to subrounded, poorly to well sorted, and arkosic. Color and composition of sediment is dependent on source area of a given drainage. Where strath is observed, it is scoured and overlies **Qay1**. Soil development is very weak, with only incipient development of a Bw horizon. Correlates with unit Qayi in the Española quadrangle (Koning, 2002). Unit is probably related to regional arroyo incision and stream complex response phenomena that episodically occurred over the last several hundred years (since 800 to 2,000 years ago

in the Rio Tesuque drainage; Miller and Wendorf, 1958). Loose and up to about 2 m-thick but thickness is highly variable.

Qay1 **Older young alluvium (middle to upper Holocene) –** Pink to very pale brown (7.5-10YR 7/3-4) gravel, sand, and silt that underlie the higher surfaces formed on valley bottom alluvial fill (below higher, discontinuous, Pleistocene terrace deposits). Sediment is massive, in very thin to medium beds (planar-bedded to lenticular to wedge-shaped), or in channels (up to 60 cm tall); sparse ripple marks locally present within a bed. Gravel is mostly pebbles with subordinate cobbles, clast-supported, subrounded, and moderately to poorly sorted. Clasts are generally granite and calcium carbonate-indurated nodules of Tesuque Formation with trace schist, 0-5% greenish Paleozoic siltstone and sandstone, and trace to 5% quartzite. Sand is very fine to very coarse, subangular to subrounded, and well to moderately sorted. Surface generally supportes junipers and grass. Soil development is weak: original stratification may still be present with only incipient development of calcium carbonate films (less than 1 mm-thick) that are generally limited to the undersides of clasts; locally, Bk horizons are present with weak stage I carbonate morphology; HCl effervescence generally increases with depth; there is some development of ped structure (commonly moderate, medium to coarse, subangular blocky), usually associated with a Bw horizon. One or more weak buried soils (grossly similar to the present surface soil) may be present. Basal contact is highly scoured with up to 1 m of observed relief. Correlates with unit Qay1 in the Española quadrangle to the west (Koning, 2002) and to unit Qal in the Tesuque quadrangle to the south (Borchert and Read, in preparation). A charcoal sample from unit Qal in the Tesuque quadrangle about 9 km to the south of this quadrangle returned a radiocarbon date of 2230 ± 250 ^{14}C yrs B.P. (Miller and Wendorf, 1958). Loose to weakly consolidated. Up to 7 m thick but thickness is highly variable.

POJOAQUE RIVER TERRACES

Qtp3 **Lower terrace deposit of Pojoaque River (upper Pleistocene) –** Light yellowish brown to yellowish brown (10YR 5-6/4) sandy gravel, sand, and silt that comprises axial and overbank facies; no good exposures of bedding. Unconformably overlies the Tesuque Formation with a scoured contact, and is inset below **Qtp2**. Axial facies is mostly mostly subrounded to rounded cobbles and boulders with subordinate pebbles; gravel is clast-supported, poorly to moderately sorted, and consists of granite and pegmatite with 1-6% amphibolite and trace to 1% quartzite; sand is fine- to very coarse-grained, subrounded to subangular, poorly to well sorted, and arkosic. Overbank facies includes massive silt and very fine- to fine-grained sand. Strath is 15-25 m above Pojoaque Creek. Correlates with Qtp2 in the Española quadrangle to the west Koning (2002). Age is younger than that of **Qtp2** on this quadrangle. Deposit is loose and 1-4(?) m-thick.

Qtp2 **Middle terrace deposit of Pojoaque River (middle to upper Pleistocene) –** Sandy pebbles and cobbles that are poorly exposed in this quadrangle. Tread may be covered by a veneer of silt and very fine-grained sand that is massive and possesses a soil with calcic horizon(s) having a stage III calcium carbonate morphology (soil may be up to 1.5 m-thick). Clast counts near the eastern Pojoaque Indian Reservation boundary yield: 1% biotite schist, 1-4% amphibolite, 95% granitic and pegmatitic clasts. The terrace strath is at a minimum of about 30 m above Pojoaque Creek, but progressively rises 30 m higher towards its southern margin. There is probably significant relief of the basal contact. Based on comparison with the terrace stratigraphy in the northern Tesuque quadrangle to the south (Borchert and Read, in preparation), this unit probably comprises several different cut-and-fill events over possibly as much as hundreds of thousands of years. However, on this quadrangle these cut-and-fill events occurred in relatively close elevational proximity with each other; consequently, it is extremely difficult to differentiate them given the poor exposure. Lowest exposed strath of unit correlates with Qgn5 to the south (Borchert and Read, in preparation) and to Qtpt1 in the Española quadrangle to the west (Koning, 2002), where it is better exposed and described. Qtpt1 is interpreted to be 120-150 ka by Koning (2002) based on comparison of this terrace height to chronologic data presented in Dethier and Reneau

(1995) and Dethier and McCoy (1993), in addition to geomorphic considerations. Loose and 18-25 m-thick.

Qtp1 **Upper terrace deposit of Pojoaque River (middle Pleistocene) –** Gravel, sand, and minor silt. Immediately south of the quadrangle boundary (UTM coordinates: 3,970,290 N, 411,760 E ± 30 m), is a white, powdery ash that lies about 3 m above the base of the deposit, preliminarily correlated to the Lava Creek B ash (about 620 ka; Sarna-Wojcicki et al., 1987)). Ash thickness is irregular but it is relatively continuous. The strath is approximately 42-55 m above the nearby East Cuyamungue Wash and Pojoaque River. Correlates with Qgn1 of Borchert and Read (1998, revised 2002) and possibly with Qtsc1 of Koning (2002). Loose and 3-12 m-thick.

SANTA CRUZ RIVER TERRACES

Qtsc3 **Lower terrace deposit of Santa Cruz River (uppermost Pleistocene) –** Light yellowish brown (10YR 6/4) to very pale brown (10YR 7/4) to pink (7.5YR 6/4) sandy gravel. Inset into the Tesuque Formation north of the Santa Cruz River. No clear bedding. Gravel consists of cobbles with subordinate pebbles and is clast supported, poorly sorted, subrounded to rounded, and composed of subequal quartzite and granitic clasts; a clast count in the extreme northwest corner of the quadrangle (UTM coordinates: 3,983,840 N, 410,280 E ± 20 m) gives 41% quartzite and 59% granitice clasts). Sand is mostly medium- to very coarse-grained, poorly sorted, subangular to subrounded, and arkosic. Strath of deposit is about 6-8 m above the valley floor. Correlates to Qtsc4 and Qtrg3 units on Española quadrangle to the west (Koning, 2002), which are latest Pleistocene (less than 30 ka) based on comparison of these respective strath heights with C-14 and amino-acid epimerization ratio chronologic data presented in Dethier and Reneau (1995). Loose and up to 6 m-thick.

Qtsc2 **Middle, thick terrace deposit of Santa Cruz River (middle to upper Pleistocene) –** Light yellowish brown to light brown (7.5-10YR 6/4) finer sand and mud associated

with overbank facies and varying proportions (but generally subordinate) of coarser sand and gravel associated with axial facies. Description is from that of equivalent deposits in the Española quadrangle 1.2-1.6 km to the west (Koning, 2002). Forms a thick, relatively extensive terrace deposit that is inset into the Tesuque Formation north of the Santa Cruz River. The axial facies has very thin to thick, lenticular to channel-shaped beds of sand and gravel, with the channels being up to 100 cm-deep; locally there are tangential, low angle cross-laminations or cross-beds (very thin) that are generally < 20 cm-tall. Gravel consists of approximately subequal cobbles and pebbles, is clast-supported, rounded to subrounded, and poorly to moderately sorted; clast count immediately north of Quarteles in the Española quadrangle to the west (UTM coordinates: 3,983,570 N and 408605 E ± 30 m) gives 19% quartzite plus 81% granite and pegmatitic quartz; sand is medium- to very coarse-grained, subrounded to subangular, poorly sorted, and an arkosic to lithic-rich arkosic. These axial facies are generally preserved near the top of the deposit. Overbank facies consists of silty very fine- to fine-grained sand and mud with 10% coarse to very coarse sand and pebbles (mostly granite with subordinate quartzite); massive; weakly consolidated to loose. A soil possessing calcic horizon(s) with stage III calcium carbonate morphology is locally preserved on the top of the deposit. Strath is 27-34 m above the Santa Cruz River. Unit correlates to Qtsc3 in the Española quadrangle to the west (Koning, 2002), which is interpreted to be around 120-150 ka based on C-14 and amino-acid epimerization ratio chronologic data for various Rio Grande terraces presented in Dethier and Reneau (1995) and Dethier and McCoy (1993). Based on its great thickness and relative height above modern stream grade, south of the Pojoaque River/Creek this unit very likely correlates to units **Qtp2** on this quadrangle and Qtpt1 of Koning (2002). Deposits are loose and 9-18 m-thick.

North of the Santa Cruz River, the basal 2-3 m of the terrace deposit is composed of a distinct grayish, quartzite-rich gravel. Gravel consists of cobbles with subordinate pebbles and is clast-supported, rounded to subrounded, poorly sorted, and composed of subequal quartzite and granitic clasts (granitic clasts include a sheared, grayish granite not common elsewhere). Clast count from a site northwest of Quarteles in the Española

quadrangle to the west (UTM coordinates: 3,983,740 N and 408,280 E ± 10) gives 8% sheared, grayish granite, 46% pinkish granite and pegmatitc clasts, and 45% quartzite (Koning, 2002).

Qtsc1 Upper terrace deposit of Santa Cruz River, associated with Santa Cruz pediment (upper Pliocene(?) to lower Pleistocene) – Brownish yellow to yellowish brown (10YR 5-6/6-8) and reddish yellow (7.5YR 6/8) sandy gravel. Where described southwest of Santa Cruz Reservoir, beds are vague, generally medium, and lenticular to channel-shaped. Gravel is clast-supported and composed of cobbles with subordinate pebbles and sparse boulders; clasts are poorly sorted, subrounded, and composed of 50-65% granite, 35-50% quartzite, 1% amphibolite, and 1% mica schist. Diameters of largest boulders range from 40-60 cm: 25-40 cm (a:b axes). Sand is mostly medium- to very coarse-grained, poorly to moderately sorted, subangular to subrounded, and arkosic. Most of sediment consists of channel facies (as previously described), but about 5% of sediment consists of thick beds of light yellowish brown (10YR 6/4), silty very fine- to medium-grained, massive sand and is interpreted as an overbank deposit. Gravel composition of deposits mapped south of Cundiyo is generally granitic, and deposits northeast of Santa Cruz Reservoir have a high abundance of quartzite clasts. Based on elevational similarities, Kelley (1979) correlates this unit to high terraces south of the Pojoaque River (units QTgp2 and QTgp3 of Koning and Maldonado, 2001; unit QTg of Borchert and Read, 1998, revised 2002). Both units QTgp2 and QTgp3 have interbedded pumice beds in their deposits, which have been dated at about 1.2 Ma and 1.5 Ma. In its upper 4 m, unit QTg contains a pumice bed correlated with the 1.6 Ma Guaje Pumice Bed of the Bandelier Tuff (Izett and Obradovich, 1994). Thus, it is reasonable to assume that unit Qtsc1 is approximately 1.2-1.6 Ma, or late Pliocene to early Pleistocene. Deposit is loose and 3 to 18 m-thick.

Qtscu Uncorrelated terrace deposit of Santa Cruz River south of Santa Cruz Reservoir (lower Pleistocene?) – A small terrace deposit that was not described and does not seem to correlate with the other Santa Cruz River terraces. Located between unit **Qtsc1** and

Qtsc2. Strath is located about 65 m above the Santa Cruz River. Approximately 6 m thick.

MISCELLANEOUS TERRACE DEPOSITS

Qaou **Undifferentiated high terrace deposits (middle(?) Pleistocene) –** Light yellowish brown to pale brown (10YR 63-4) sand and gravel. Unit is bioturbated or loose so that bedding is commonly not observed. Gravel consists of pebbles and cobbles; cobbles are subrounded quartzite and granite; pebbles consist of subangular granite, 5-15% quartzite, and subrounded calcium carbonate-indurated nodules and sandstone derived from the Tesuque Formation. Sand is very fine- to very coarse-grained, poorly to well sorted, subrounded to subangular, and arkosic. Deposits are interpreted to be alluvium because of the gravel abundance, although they may be aeolian in part. Locally overlain by unit **Qeo**, with no evidence of a significant soil at the contact between the two units. The terrace deposits of this unit are of varying heights above adjacent streams and likely have a range of ages. Loose and generally less than 5 m in thickness.

Qaoc **High terrace deposits near center of quadrangle (middle to upper Pleistocene) –** Light yellowish brown (10YR 6/4) silty sand, sand, and gravel that occupy a similar elevational range near the center of the quadrangle. Correlative in an approximate sense but strath formation and deposition may have occurred at somewhat different times between mapped localities. Beds are vague, very thin to medium, and lenticular. Gravel consists of pebbles that are clast-supported or matrix-supported, poorly to moderately sorted, subrounded to subangular, and composed of granitic clasts. Matrix-supported gravel are present where there is no bedding and is probably a result of bioturbation. Maximum measured gravel diameter is 10 cm. Sand is very fine- to very coarse-grained, poorly sorted, subangular to subrounded, and arkosic. Three well-developed soils are locally observed on the top of the deposit and appear to be responsible for preserving the terrace tread surface. Each of these three soils are

marked by having a Btk horizon or Bw horizon that is 20-45 cm-thick underlain by a Bk horizon that is 20-50 cm-thick; the calcic horizons commonly show stage II+ to III carbonate morphology. Generally 1-5 m-thick but locally up to 8 m.

MIOCENE SEDIMENTARY ROCKS

TESUQUE FORMATION

Generally pink, very pale brown, light brown, light yellowish brown, reddish yellow, and pale brown (most to least common) sandstone, siltstone, claystone, and pebble-conglomerate that underlie most of the quadrangle and collectively constitute an important aquifer for the region. We follow Cavazza (1986) in primarily subdividing the Tesuque Formation into two lithosomes based on lithologic composition and provenance (Lithosomes A and B). These two lithosomes are further subdivided according to gross textures plus biostratigraphic and age considerations: units **Ttbp**, **Ttbs**, and **Ttbn** of Lithosome B (order of units is youngest to oldest) and **Ttas**, **Ttan2**, **Ttan2i**, and **Ttan1** of Lithosome A (order of units is approximately youngest to oldest, unit **Ttan2i** is interbedded in unit **Ttan2**). Lithosome A comprises most of the Tesuque Formation on this quadrangle and consists of arkosic sandstone and granite-dominated conglomerate derived from granitic bedrock of the adjacent Sangre de Cristo Mountains. Compared to Lithosome B, Lithosome A sediment is generally more pinkish in color, has westward-directed paleoflow indicators, and the channel complexes are generally smaller and more narrow. Lithosome B is found only in the northwest and northern portions of the quadrangle. It consists of a heterolithic assemblage of gravel (greenish Paleozoic sandstone and siltstone, grayish Paleozoic limestone, Oligocene tuffs and other volcanic rocks, and Precambrian quartzite) because it is interpreted to be derived from across the Peñasco Embayment to the northeast (Cavazza, 1986). Lithosome B sediment is generally pale brown to very pale brown in color, has southwestward-directed paleoflow indicators (where measured in the northwestern corner of the quadrangle), and the channel complexes appear to be larger, broader, and more tabular than those of Lithosome A. The contact between Lithosome A and B is gradational and interbedded. We attempt to represent the contact using a series of closely spaced, large circles on the map (see accompanying Explanation of Map Symbols); these

circles were placed where the change between Lithosome A / B sediment was most pronounced. Whereas the width of the gradational zone is 1- 1.5 km west or northwest of the drawn contact, it is up to 4 km wide southeast of the drawn contact. In order to demonstrate the extent of interbedding southeast of the drawn contact, we plot locations of Lithosome B conglomerate beds where these were found more than 0.3 km southeast from the contact (we likely found only a small proportion of these conglomerates). Granitic conglomerate beds were not found more than 1 km northwest of the plotted contact.

On this quadrangle, Galusha and Blick (1971) have subdivided the Tesuque Formation into the Pojoaque, Skull Ridge and Nambé members. The Pojoaque – Skull Ridge contact is present in the extreme northwest corner of the quadrangle. It is projected northeastward across the Santa Cruz River from where Galusha and Blick (1971) describe the contact 1-2 km south of the Santa Cruz River and placed at the base of a channel sandstone (like what is found at Galusha and Blick's locality). However, strata do not appear to noticeably differ on either side of this contact north of the Santa Cruz River. The contact 1-2 km south of the Santa Cruz River was interpreted as a disconformity by Tedford and Barghoorn (1983) and Barghoorn (1981), but appears to be more conformable south of the Pojoaque River (Koning and Maldonado, 2001).

The common contact of the Skull Ridge - Nambé members is at the base of an ash bed called White Ash #1. The general lithologic characteristics of the upper Nambé Member versus the lower Skull Ridge Member is similar except that the Skull Ridge Member contains more tephra beds. Where White Ash #1 is not present (such as in the southernmost part of this quadrangle and northernmost part of the Tesuque quadrangle to the south), the two members are difficult to differentiate. Consequently, we feel that Cavazza's (1986) differentiation of Tesuque Formation strata is a more practical mapping tool in the field, and it more adequately reflects a lithostratigraphic subdivision scheme. Nonetheless, differentiating the Skull Ridge and Nambé members is useful when considering temporal issues, since White Ash #1 corresponds to a chronostratigraphic boundary and very closely marks a biostratigraphic boundary (between late Hemingfordian fauna and early Barstovian fauna; Galusha and Blick, 1971). Thus, we have further subdivided Lithosomes A and B into the Skull Ridge and Nambé members. In the

following map labels, the letters “a” and “b” designate these two lithosomes, and “s” and “n” designate the Skull Ridge and Nambé members, respectively.

We further subdivide the Nambé Member of Lithosome A into an upper and lower subunit (units **Ttan2** and **Ttan1**, respectively) based on lithologic differences and age considerations. Interbedded and included within the upper subunit is a coarse unit called **Ttan2i**. These two subunits generally correspond to Galusha and Blick’s (1971) lower conglomeratic sandstone and sand subunit and their upper fossiliferous subunit (except our upper subunit is thicker relative to the entire thickness of the Nambé Member of Lithosome A). Near the mountain front, the lower subunit is significantly coarser than the upper subunit and is generally tilted at least 5 degrees more than the upper subunit. In the field, there has been no verification of a contact demonstrating an angular unconformity between these two units. Rather, the contact appears to be gradational over 200-400 m stratigraphic distance and was drawn on the map as a dashed line in the approximate middle of this gradational zone.

The Pojoaque Member has likewise yielded abundant fossils that belong to the late Barstovian North American land-mammal age (Galusha and Blick, 1971; Tedford and Barghoorn, 1993), which spans from approximately 14.6 to 11.6 Ma (Tedford et al., 1987). Magnetostratigraphic work also supports the interpretation that the Pojoaque Member was deposited during the late Barstovian age (Barghoorn, 1981).

An extensive collection of fossils representing early Barstovian fauna (14.6-16.3 Ma) have been collected from the Skull Ridge Member (Galusha and Blick, 1971; Tedford and Barghoorn, 1993). These fossils together with magnetostratigraphic work (Barghoorn, 1981; Tedford and Barghoorn, 1993) indicate a 14.6-16.4 Ma age for the Tesuque Formation (14.6 and 16.4 Ma marking the respective boundaries of the early - late Barstovian and early Barstovian – late Hemingfordian North American land-mammal ages; Tedford et al., 1987). $^{40}Ar/^{39}Ar$ dates of five tephra beds (Izett and Obradovich, 2001; McIntosh and Quade, 1995) indicate a more narrow age range of about 14.6 to 15.9 Ma for the Skull Ridge Member (**Figure 2**). An ash bed 15-35 m below the Pojoaque – Skull Ridge contact west of this quadrangle (upper 285 Road Ash of Koning, 2002) yielded a $^{40}Ar/^{39}Ar$ date of 15.1 ± 0.06 Ma

(Izett and Obradovich, 2001). Tephrastratigraphic correlation by M. Perkins (University of Utah) indicates that White Ash #1 correlates to an ash erupted in Nevada, dated at 15.86 ± 0.03 (M. Perkins, personal communication to Andrika Kuhle, 1996 - reference listed in Kuhle, 1997). Since the White Ash #1 marks the base of the Skull Ridge Member, this suggests that the lower contact of the Skull Ridge Member is 15.9 Ma, which is more compatible with the $^{40}Ar/^{39}Ar$ date of 16.4 Ma (Izett and Obradovich, 2001) for the Nambé Member lower white ash estimated to be 200-220 m below (see Nambé Member lower white ash description).

Fossils of the upper Nambé Member are representative of late Hemingfordian fauna (Galusha and Blick, 1971; Tedford and Barghoorn, 1993). This is consistent with a $^{40}Ar/^{39}Ar$ date of 16.4 ± 0.13 Ma (Izett and Obradovich, 2001) obtained from the Nambé Member lower white ash within unit **Ttan2** (see tephra descriptions below). The lower Nambé Member (unit **Ttan1**) has a very poor fossil recovery. The only age control for the lower Nambé Member is (1) an K-Ar radiometric date of 24.9 ± 0.6 Ma (Baldridge et al., 1980) from an interbedded basalt near its base (unit **Tmov**) and (2) a $^{40}Ar/^{39}Ar$ radiometric date of 30.45 ± 0.16 Ma from a stratigraphically lower tephra in the Bishop's Lodge Member south of this quadrangle (Smith, 2000). The Bishops Lodge Member is now confidently mapped as being interbedded within the lower Nambé Member (Borchert and Read, 1998, revised 2002); Read et al., 2000; Smith, 2000), so the 30 Ma radiometric date from the Bishops Lodge Member also indicates that the Nambé Member was being deposited before that time.

Lithosome B

Ttbp **Pojoaque Member (middle Miocene) –** Pink (7.5YR 7/3-4) to light brown (7.5YR 6/4) to very pale brown (10YR 7/3-4), overbank siltstone and very fine- to fine-grained sandstone, with minor reddish brown (5YR 5/3-4) mudstone; these are interbedded with subordinate pale brown to light brownish gray (10YR 6/2-3) to very pale brown (10YR 7/3-4), very fine- to very coarse-grained, channel sandstone deposits. Fine-grained, overbank deposits are in thin to very thick, tabular beds; sand is subangular to subrounded, well sorted, and a feldspathic arenite. Channel

sandstone is in very thin to medium, planar to lenticular beds that collectively form channel complexes over 2 m thick. Channel sandstone beds are locally planar laminated, with minor cross-lamination up to 25 cm-tall that suggest southward paleo-flow; sand is subangular to subrounded, well sorted within a set of laminae but grain size varies widely, and is a lithic to feldspathic arenite (with greenish quartz grains in lithics probably derived from abrasion of greenish, Paleozoic sandstone of Lithosome B). Trace pebbles in channel sandstones consist of felsic tuff and limestone. White ashes locally are present and range 3-30 cm in thickness; ashes are generally altered. One significant gray (N7/) ash is shard-rich, silty-textured, not altered, and 50 cm thick (not shown on map; UTM coordinates: 3,983,730 N, 409,950 E ±30 m). 10-20% of beds are cemented by calcium carbonate or silica(?). Channel sandstone is loose to moderately consolidated; fine-grained overbank deposits are moderately consolidated. At least 40 m thick but upper contact not exposed on this quadrangle.

Lower contact of unit placed at the base of a 10 m-thick channel sand; sand is feldspathic (mostly) to lithic (subordinate) arenite with 1% muscovite grains, subangular, and well sorted. Other channel sands are present in the strata but this one best projects to the mapped Skull Ridge-Pojoaque Member contact in the Española quadrangle to the west (Koning, 2002); the contact also follows that of Galusha and Blick (1971), who presumably drew the contact using biostratigraphic constraints. There is no obvious change in sediment characteristics on either side of this contact.

Ttbs **Skull Ridge Member (middle Miocene) –** Very pale brown to pink (7.5-10YR 7/3-4) to pale brown (10YR 6/3), with minor pinkish gray (7.5Y 7/2) to light brown (7.5YR 6/4), sandstone, siltstone, and minor conglomerate and mudstone. Conglomerate and coarse to very coarse-grained sandstone are in very thin to thick, broadly lenticular to tabular beds; local planar laminations or tangential cross-stratification (up to 50 cm tall) are present and beds may fine upwards into finer sand or silt. Channel complexes may form discrete tabular beds up to 2-4 m thick

commonly indurated by calcium carbonate. Gravel consists of poorly sorted, subrounded to rounded pebbles. Clast count of two conglomerate beds east of La Puebla (UTM coordinates of western bed: 3,983,350 N and 411,150 E ± 10 m; UTM coordinates of eastern bed: 3,983,950 N and 412,380 E ± 30 m) gives 30-60% greenish Paleozoic siltstone and sandstone, 20-60% reworked calcium carbonate-cemented nodules reworked from the Tesuque Formation, 2-20% granite and other deep intrusive clasts, 2-12% quartzite, 3-8% Paleozoic limestone, 5-16% Oligocene tuffs and volcaniclastics, 0-17% miscellaneous quartz, and 0-2% unidentified. Beds of siltstone and very fine- to medium-grained sandstone are commonly medium to thick and tabular (with local ripple marks, internal planar horizontal- or cross-stratification up to 30-40 cm-tall, or massive). The sand is moderately to well sorted but mostly well sorted, subrounded to subangular, and commonly lithic-rich feldspathic arenite(?) (lithics probably from northeast). Unit erodes to form badlands topography, where exposure is generally good. Weakly to moderately consolidated. 220-250 m thick.

Ttbn **Nambé Member (Oligocene(?) to lower Miocene) –** Pink to very pale brown (7.5-10YR 7/3-4) to light brown (7.5YR 6/3-4) sandstone, siltstone, claystone, and minor conglomerate. Conglomerate beds are thin to thick, discontinuous, and associated with pale brown to light gray (10YR 6-7/2-3) sand. Gravel is generally subrounded pebbles with up to 20% cobbles. Approximate composition of the gravel is: 35-45% greenish Paleozoic(?) sandstone and siltstone; 25-35% fossiliferous, gray, Paleozoic limestone; 5-15% granite; 5-10% tuff; 1-5% intermediate to felsic volcanics; 5% angular petrocalcic soil horizon(?) rip-ups; and 1-5% quartzite. Sandstone and fine-grained beds are generally medium to thick and tabular. Sand is very fine- to very coarse-grained but most fine-grained, moderately to well sorted, subrounded to subangular, and a lithic-rich feldspathic arenite(?). Unit erodes to form badlands topography, where exposure is generally good. Weakly consolidated. Probably similar in thickness to unit **Ttan2** (described below), which is 400 m.

Lithosome A

Ttas **Skull Ridge Member (middle Miocene) –** Very pale brown to pink (7.5-10YR 7/3-4) to light brown (7.5YR 6/4) very fine- to medium-grained sandstone and siltstone, subordinate mudstone and coarse- to very coarse-grained sandstone, and sparse sandy pebble-conglomerate and pebbly sandstone beds. Conglomerate and pebbly sandstone are in very thin to medium, lenticular to tabular beds; low-angle cross-stratification locally present and beds are commonly well-cemented by calcium carbonate. Gravel is commonly clast supported, locally includes 5-10% cobbles, and is poorly to moderately sorted and subrounded to subangular. The sand in conglomerate beds is mostly medium- to coarse-grained, poorly to moderately sorted, and subrounded to subangular, and a feldspathic arenite. Clasts include 0.5-1% quartzite, trace biotite-schist, and 99% granite (incuding megacrysts of feldspar, and quartz). Fine sediment is in very thin to thick, tabular beds or else massive; beds locally are internally planar- to wavy-laminated or bioturbated. Sand is subrounded to subangular, moderately to well sorted, and a feldspathic arenite. Unit erodes to form badlands topography, where exposure is generally good. Weakly to moderately consolidated. 220-250 m thick. Kuhle (1997) and Kuhle and Smith (2001) describe this unit in much detail.

Ttan2 **Upper, fine-grained unit of Nambé Member (lower to middle Miocene) –** Pink to reddish yellow (7.5YR 7/3-4; 7.5YR 6/6) to light yellowish brown (10YR 6/4) to very pale brown (10YR 7/3-4) to minor light brown (7.5YR 6/4) very fine- to medium-grained sandstone and siltstone, with lesser light brown (7.5YR 6/4) to reddish brown (5YR 5/4) mudstone with siltstone, and <15% coarse- to very coarse-grained sandstone and pebble-conglomerate. Coarse sandstone and conglomerate beds are generally very thin to medium, lenticular to channel-shaped with internal planar-beds to cross-beds up to 15 cm-tall. Mudstones are thin to thick and tabular. Very fine- to medium-grained sandstone and siltstone are in thin to very thick, tabular beds that commonly form ledges; these strata may also be

massive and bioturbated. Beds of sandy pebble-conglomerate are clast-supported, may be indurated by calcium carbonate, and generally composed of granitic pebbles that are poorly sorted and subangular; sand in these beds is very pale brown to pink, fine- to very coarse-grained, subangular, well to moderately sorted, and a feldspathic arenite. Very sparse ash white ash beds up 35 cm-thick (including those described below); these are generally powdery and altered, internally massive, and have 0.5 to 1% fine sand-size mafics. Sparse, continuous, medium beds of light gray (10YR 7/1-2) to white (10YR 8/1) to very pale brown (10YR 8/2) freshwater limestone are locally present; these have crenulated to slightly wavy laminations or very thin to thin, wavy beds; paleoburrows locally observed; these limestone beds may be partly cemented by silica or mixed with minor ash. Very weakly to moderately consolidated; erodes to form badlands topography, where exposure is generally good. Approximately 400 m thick, including the interbedded unit **Ttan2i** (described below).

Ttan2i Coarse-grained unit interbedded in upper, fine-grained unit of Nambé Member (middle Miocene) -- Light yellowish brown (10YR 6/4) to very pale brown or pink (10-7.5YR 7/3-4 and 10YR 8/2) siltstone, mudstone, and very fine- to medium-grained sandstone with up to 50% channel deposits of sandy pebble-conglomerate and pebbly sandstone. Unit is overlain and underlain by finer strata of unit **Ttan2.** Channels complexes are up to 1.5 m thick and are represented by very thin to medium, planar or lenticular beds and ribbon-like channels up to 80 cm-thick; locally cross-stratified with foresets 60-70 cm-tall and locally calcium carbonate-indurated; gravel is pebbles with about 10-20% cobbles, is clast-supported, poorly to moderately sorted, subangular to subrounded, and granitic (and associated feldspar and quartz) with trace quartzite and schist. Sand in these channels is mostly medium- to very coarse-grained, subangular to subrounded, poorly to moderately sorted, and a feldspathic arenite. Sandstone and fine-grained deposits are in very thin to thick, tabular beds that are locally internally planar-laminated or massive. Up to 10% medium- to very coarse-grained sand may be scattered in fine

sediment. Unit commonly forms topographic highs because of its relative coarseness. Loose to weakly consolidated. East of Nambé, the unit lies 10-15 m above the lower white ash of the Nambé Member (described below), which has been dated at about 16.4 Ma by $^{40}Ar/^{39}Ar$ radiometric analyses (Izett and Obradovich, 2001). Thus, this unit appears to be younger than 16.4 Ma. Approximately 160 m thick.

Ttan1 **Lower, coarse-grained unit of Nambé Member (Oligocene to lower Miocene)**: Pinkish gray (7.5YR 6-7/2), pinkish white (5YR 8/2), yellowish red (5YR 5/6), reddish yellow (5-7.5YR 6/6), very pale brown (10YR 7/3), light yellowish brown to minor pale brown (10YR 6/3-4), and pink (7.5YR 7/3) pebbly sandstone, pebble-conglomerate, sandstone, and very minor mudstone. Unit forms the lower, coarse part of the Nambé Member; it generally forms topographic highs because of its relative coarseness. Coarse-grained beds are vague, discontinuous, and very thin to 50 cm-thick; bed shape is planar to lenticular, channel-shaped up to 120 cm-thick, or locally massive. Cross-stratification is locally up to 40 cm-tall. No grading in the beds. Gravel is mostly clast-supported, poorly to moderately sorted, locally indurated by calcium carbonate (particularly just above the lower contact with the bedrock) and composed of pebbles with up to 25% cobbles. Cobbles and very coarse pebbles are subrounded; very fine to coarse pebbles are subangular to minor subrounded. Gravel is granitic (including associated feldspar and quartz clasts) with up to 3% quartzite clasts, 0.5-3% biotite schist, and 0.5% gneiss and amphibolite. Sand may be slightly muddy and is very fine- to very coarse-grained but mostly medium- to very coarse-grained, poorly to moderately sorted, subangular, and a feldspathic arenite. Basal beds generally parallel the underlying nonconformity with the Precambrian bedrock, which locally has up to several meters of scoured-related relief (i.e. channel margins are observed). Sediment is loose to weakly consolidated. Approximately 460 m thick near the mountain front, but likely thickens westward in the subsurface.

It is interpreted that unit **Ttan1** fills a major, west-trending paleo-valley south of Cerro Piñon based on the spatial position of the lower contact. Here, there is trace to 20% yellowish Paleozoic(?) limestone, sandstone, and siltstone clasts (most abundant to the east); subequal pebbles and cobbles and sparse boulders; and cobbles are generally larger than to the immediate north. Clay bed marked on map (see Explanation of Map Symbols) is yellowish brown (10YR 5/4) to strong brown (7.5YR 5/6), sandy clay and clayey sand with 15-20% pebbles of granitic composition; soft and 1-3 m-thick. Other brown (7.5YR 7/4) clay or clayey sand beds may be found in this paleo-valley but they are minor.

TESUQUE FORMATION ASHES

Although Galusha and Blick (1971) identified 34 ashes in the Skull Ridge Member of the Tesuque Formation, we only mapped the more extensive ashes (Refer to Explanation of Map Symbols for identifying the respective ashes on the map)

Ash Eta/Zeta – Light gray (N7/), relatively non-altered, shard-rich, silty-textured ash that is internally planar laminated. Ash is underlain by pink to light brown to reddish yellow (7.5YR 6/4-6 and 7/4) siltstone and very fine- to fine-grained sandstone that are in medium to thick, tabular beds. Ash is overlain by light brown (7.5YR 6/4), very fine- to fine-grained, very weakly consolidated sandstone. Located 12-18 m above **Ash Gamma**. Although we interpret that this ash correlates to Galusha and Blick's (1971) Eta or Zeta ashes (separated by 5-6 m), we could not correlate to either specific one with confidence. Described using exposures near La Puebla (SE1/4 Section 4, T.20N., R.9.E). Commonly 30-50 cm thick.

Ash Gamma – Light gray to white (N7-8/), laminated ash. May be shard-rich and silty-textured, or reworked with 5-7% very fine- to fine-grained, detrital sand; internally planar laminated. Ash is overlain and underlain by pink to light brown (7.5YR 6-7/4) silty very fine- to fine-grained sandstone in medium, tabular beds. Ash is 12-18 m above **White Ash #4**. Commonly 20-60 cm thick.

White Ash #4 – White ash that lacks mafic minerals and has a silty texture with high shard content. Lower 10-30 cm is commonly ash-fall and generally massive. Upper part has very thin, slightly wavy, beds of reworked ash. Ash is overlain and underlain by very pale brown to pink to pinkish gray (10YR 7/3 to 7.5YR 7/2-3) siltstone and very fine- to fine-grained sandstone. Ash is 70-145 m above **White Ash #3**, with the greatest intervening stratigraphic distance south of Arroyo Seco (Kuhle, 1997; Kuhle and Smith, 2001). 70-170 cm thick.

Ash B – White to gray ash commonly in two beds. Where described 550-670 m south of the Santa Cruz River, the lower bed is white, massive, 20 cm thick, and reworked with very fine- to fine-grained, detrital sand. The upper ash is separated from the lower by 25-30 cm of siltstone. The upper ash is light gray, shard-rich, massive, 15 cm thick, and grades upwards into ashy siltstone. Where described, the ash is underlain by light yellowish brown siltstone and overlain by pinkish siltstone. Ash is 24-30 m below **White Ash #4**.

Ash F – White to gray (N6-8/), silty-textured, non-altered ash with abundant glass shards. Lacks mafic minerals and is locally planar- to wavy-laminated. Immediately overlain and underlain by very pale brown (10YR 7/3) siltstone. Near western quadrangle boundary south of Arroyo Seco (NW1/4 Section 21, T.20N., R.9.E.), ash lies 60 cm to a few meters below light gray (10YR 7/1), lithic-rich sandstone with scattered pebbles of northeastern provenance (i.e., Lithosome B). Ash is 18-25 m above **White Ash #3**, which is consistent with Kuhle (1997). 25-100 cm-thick.

White Ash #3 – White ash that is silty-textured, shard-rich, and has trace to 1% biotite crystals (very fine- to fine-grained sand-size). Very thin to medium, tabular bedded or else massive and bioturbated. Locally, the top 20 cm may be indurated by calcium carbonate. Ash is within pink (7.5YR 7/3-4) siltstone and very fine- to fine-grained sandstone that are in thin to thick, tabular beds or else massive. The ash is 15-20 m above **White Ash #2**, consistent with Kuhle (1997). Ash is 40 to 100 cm-thick near Arroyo Seco and White

Operation Wash. Near Santa Cruz River, ash thickness ranges from 0-200 cm but generally is 10-60 cm thick; here it may be reworked, very sandy, and pinch-out.

Ash 3Z is about 5 m above the mapped **White Ash #3**. It is light gray (10YR 7/1), silty-textured, shard-rich and within very pale brown (10YR 7/3), thin to thick, tabular beds of siltstone.

White Ash #2 – White with 1-3% biotite crystals. Ash is horizontally planar-laminated to massive to very thinly or thinly bedded; locally reworked with trough- and low angle-cross-stratification that may be up to about 6 cm-tall; some burrows present; hard and chalky-textured due to alteration Ash is at a distinct sedimentologic contact that makes the ash easy to identify: strata immediately above ash generally are massive to vaguely bedded (locally eroding to form a bulbous outcrop), very pale brown to pink (7.5YR-10YR 7/3) siltstone and very fine- to fine-grained sandstone, whereas strata below ash are generally light brown to light reddish brown (7.5YR-5YR 6/4) siltstone that form distinct, thin to medium, tabular beds. 10 to 150 cm thick; generally thinner, altered, and more reworked (with up 20-40% detrital very fine-grained sand and silt) to the north (particularly near the Santa Cruz River). Ash is 40-50 m above **White Ash #1**, which is consistent with Kuhle (1997).

Ashes 2A, 2B, and 2C are 3 to 8 m above mapped **White Ash #2.** These are light gray to gray (N7/ to N8/), shard-rich, silty- to very fine sand-textured ashes that are 20-100 cm-thick

White Ash #1 -- Ash is white and commonly altered; planar- to slightly wavy-laminated or very thin to thin, planar- to wavy-bedded. Ash has a gradational base and top. Near the northern boundary of the quadrangle, the ash is interbedded in pink to light brown (7.5YR 6-7/3-4) mudstone, siltstone, and very fine-grained sandstone. Near Arroyo Seco, ash is commonly underlain by pinkish gray (7.5YR 7/2) claystone and light brown (7.5YR 6/4) siltstone. Ash is overlain here by10-20 m of pinkish gray to pink (7.5YR 7/2-3) mudstone and light gray to light brownish gray (10YR 6-7/2), muddy very fine- to

fine-grained sandstone; these strata have very thin to thick, tabular beds. Near northern boundary of Nambé Pueblo, ash is underlain and overlain by very pale brown to pink (7.5-10YR 7/3-4) siltstone and very fine-grained sandstone in medium to thick, tabular beds (or else massive). Except for locally near its lower contact, ash is generally reworked and mixed with various proportions of detrital sand or mud. 20-120 cm thick.

Nambé White Ash – White ash that is massive to slightly wavy-laminated. Ash is relatively non-altered near the southern quadrangle boundary and north of the town of Nambé , but more altered near the northern quadrangle boundary. It is underlain and overlain by pink to light brown (7.5YR 7/3-4 and 6/4) siltstone and very fine- to medium-grained sandstone. Ash is about 30 m below **White Ash #1**. Identified as the Nambé White Ash stratum by Galusha and Blick (1971, p. 48, 2nd paragraph) and makes a good marker bed in the uppermost Nambé Member. 20-70 cm thick.

Nambé Member middle white ash – White ash that is relatively non-altered and interbedded in light brown to pink (7.5 YR 6-7/4), massive to bedded siltstone. Ash lies about 12 m below the **Nambé White Ash** in the southern portion of the quadrangle. Approximately 40-50 cm thick.

Nambé Member lower white ash – Located east of the town of Nambé and not accessible for detailed description, but appears relatively thick and continuous on aerial photographs. This ash bed is noted in Galusha and Blick (1971, p. 47-48, last and first paragraphs, respectively) as being prominent, well-exposed, repeated by faults, and underlying a layer of hard sandstone. Ash is estimated to lie 170-190 m below the Nambé White Ash and 10-15 m below the gravelly strata of unit **Ttan2i**. This ash was incorrectly referred to as the Nambé White Ash by Izett and Obradovich (2001); the ash was sampled and radiometrically dated by these workers, yielding a $^{40}Ar/^{39}Ar$ date of 16.4 ± 0.13 Ma.

OLIGOCENE TO EARLY MIOCENE VOLCANIC AND VOLCANICLASTIC ROCKS

Tmov Volcanic flows and volcaniclastic deposits (Oligocene to Early Miocene) – Olive (5Y 4-5/3) (weathered) to dark gray (2.5Y 4/1) and very dark gray (N3/) (non-weathered) basalt flow(s) overlying tuff and intermediate volcaniclastic rocks. Unit only exposed southwest of Cerro Piñon (NW1/4 of Section 8 and SE1/4 quarter of Section 6, T.19N., R.10E.). In outcrop, the basalt is 1-11 m thick. The top 2 m of the basalt is very weathered and weakly consolidated, and overlain by granite-bearing, clast-supported, sandy pebble-conglomerate or 1-3(?) m of brown (7.5YR 5/4) mudstone. Below the upper 2 m of the basalt, the flow is vesicular and more indurated, except that the basal 1 m is locally very weathered. The basalt overlies 2-3 m of red mudstone near the exposed Proterozoic basement of Cerro Piñon. This mudstone, in turn, overlies 1-3 m of granite-bearing, sandy pebble-conglomerate and arkosic sandstone underlain by Proterozoic basement of Cerro Piñon. Approximately 700 m south of where it onlaps the Proterozoic basement, the interval of arkosic sandstones and pebble-conglomerate beds overlie an unknown thickness (but probably less than 10 m) of volcaniclastic sediment containing clasts of intermediate volcanic rocks and tuff (**Figure 3**). This volcaniclastic interval is light gray to very pale brown (10YR 7-8/2), slightly clayey, very fine- to very coarse-grained sand with 1-3% very fine to medium pebbles; sand is subangular to subrounded, poorly sorted, and a lithic to feldspathic wacke; pebbles are comprised of 15-30% granite and 70-85% intermediate volcanic clasts and tuffs. We include the relatively thin volcaniclastic interval as a subunit in unit Tmov. It is not certain whether the intervening interval of granite-bearing pebble-conglomerate and arkosic sandstone (unit **Ttan1**) continues to separate the basalt and volcaniclastic interval in the subsurface to the west, but we speculate that it pinches out within unit **Tmov**. Also, a relatively thick interval of volcaniclastic detritus may overlie the basalt in the subsurface near the western quadrangle boundary, based on observations of deep cuttings in the Yates La Mesa #2 well west of Santa Fe (Daniel Koning, unpublished data; Cather, 1992; Grant Enterprises, 1998; Gary Smith, written communication, 2001), which may correlate to the Abiquiu Formation (Cather, 1992) in the subsurface of the Española quadrangle.

Unit **Tmov** is also present in the Castle and Wigzell #1 Kelly Federal well at 2330 to 2420 ft-depth, based on the senior author's description of the cuttings of this well (cuttings on file at New Mexico Library of Subsurface Data, New Mexico Bureau of Geology and Mineral Resources). Description of the well cuttings indicate that **Tmov** at this locality lacks the lower, intermediate-composition volcaniclastic interval and is overlain and underlain by coarse- to very coarse-grained, granite-bearing, pebbly arkosic sand (**Figure 3**). The upper 60 m of **Tmov** (2330-2390 ft depths) is composed of basaltic detritus mixed with progressively more granite-derived sediment as one moves up-section. Angular basaltic chips indicate a 12 m-thick basalt flow from 2390-2420 ft. The basalt is probably underlain by approximately 3 m of pebbly, granite-derived sand, which in turn is underlain by quartzose sandstone and then dark limestone and siltstone of probable Pennsylvanian age (unit **Penn**).

We correlate the basalt flow of this unit with the Cieneguilla basalts mapped near La Cienega southwest of Santa Fe (Koning and Hallett, 2000), outcrops of which are found near the mountain front in the Tesuque quadrangle to the south (Borchert and Read, 1998, revised 2002). Samples of the exposed basalt flow southwest of Cerro Piñon were collected and dated by K-Ar methods, yielding an age of 24.9 ± 0.6 Ma (Baldridge et al., 1980). This K-Ar date compares reasonably well with ages of 25-26 Ma obtained from similar basalts near La Cienega and Espinaso Ridge south of Santa Fe (Koning and Hallett, 2000; Kautz et al., 1981; Connell and Cather, 2001; Baldridge et al., 1980). The lower volcaniclastic interval probably correlates with the Bishop's Lodge member to the south in the Tesuque and Santa Fe quadrangles (Borchert and Read, 1998, revised 2002; Read et al., 2000; Smith, 2000). The Bishop's Lodge Member in turn has been correlated with the Espinaso Formation, and tephra from the Bishop's Lodge member has yielded a $^{40}Ar/^{39}Ar$ date of 30.45 ± 0.16 Ma (Smith, 2000). If the volcaniclastic unit in this quadrangle is also about 30 Ma, this implies that **Tmov** (which includes both the volcaniclastic interval and basalt flow) may span 5 m.y. of time.

PALEOZOIC SEDIMENTARY ROCKS

PM **Pennsylvanian and Missippian strata** – Gray limestone, yellowish to dark grayish siltstone, and quartzose sandstone. No good outcrop observed but unit is inferred by the presence of large, angular blocks of limestone in colluvium in the southeast corner of the quadrangle. Unit probably includes the Madera Formation, Sandia Formation, and the Arroyo Peñasco Group, based on mapping to the south (Borchert and Read, 1998, revised 2001). Unit partially penetrated by the Castle and Wigzell #1 Kelly Federal Well at a depth of 2430 to 2700 ft. bgs., indicating a minimum thickness there of 82 m (270 ft).

PROTEROZOIC IGNEOUS AND METAMORPHIC ROCKS

XYu **Undifferentiated Proterozoic igneous and metamorphic rocks (likely Mesoproterozoic to Paleoproterozoic) –** See the following descriptions in this section. This unit shown in Cross-section B-B' and on the first draft of the geologic map. On the map, this unit will be differentiated into the following units of this section in June-July, 2002.

Yg **Granite (likely Mesoproterozoic)** – Isolated exposures of quartz + plagioclase feldspar + potassium feldspar + muscovite granite along with medium-grained tonalite (unit **Xtm**). Commonly pinkish in color. Pegmatitic, porphyritic, and medium-grained textures present. Generally not foliated.

Yp **Pegmatite (likely Mesoproterozoic) –** Potassium feldspar + quartz + muscovite pegmatite. Large books of muscovite up to 5-cm in diameter. Occurs as dikes and pods cutting metasedimentary rocks and tonalites. Mapped where it forms the dominant rock type. Around and south of Cerro Piñon, plutonic rocks are predominantly pegmatite.

Ygp **Granite and Granitic Pegmatite (likely Mesoproterozoic)** –Distinct reddish weathered surface. Consists of potassium feldspar + quartz + muscovite + plagioclase feldspar + biotite. Varies in grain size from fine grained to pegmatitic. Forms the dominant

lithology in the vicinity of Santa Cruz reservoir. Potassium feldspar phenocrysts up to 25 cm long observed along east side of Santa Cruz Reservoir.

Xtg **Gneissic Tonalite (likely Paleoproterozoic) –** Fine- to coarse-grained igneous rock consisting of quartz + plagioclase + biotite + muscovite + potassium feldspar. Brownish to white weathered surface. Occurs as the major rock type in the northeastern portion of the quadrangle. Also occurs as meter-sized dikes, sills and pods within Proterozoic metasedimentary rocks and Proterozoic granites. Both non-foliated and foliated igneous rocks are included in this unit. Non-foliated tonalites are fine to coarse grained. Fabric in foliated tonalites defined by aligned biotite grains and interlayering of biotite-rich layers and quartz + feldspar layers. Locally, a south-plunging lineation is the major fabric element defined by elongate plagioclase feldspar porphyroclasts. Gneissic foliation cut by north- and northwest-striking, steeply dipping shear bands. Gneissic foliation also folded by shallow, south-plunging folds, probably the same as F3 folds in the metasedimentary rock. Unit is cross-cut by potassium feldspar + quartz + plagioclase feldspar pegmatite dikes and sills parallel to foliation

Xtf **Fine-grained tonalite (likely Paleoproterozoic) –** Intrusive rock consisting of plagioclase feldspar + quartz + biotite. Distinct reddish weathered surface.

Xtm **Medium-grained tonalite (likely Paleoproterozoic)** – Intrusive rock consisting of plagioclase feldspar + quartz + muscovite. Light colored in outcrop. Some areas show weak fracture cleavage. Foliation measurement within this unit is from screens of foliated metasedimentary rocks. Unit comprises the major plutonic rock in the southern region of the quadrangle.

Xtl **Layered tonalite (likely Paleoproterozoic) –** Interlayered reddish and white tonalite. Reddish tonalite consists of plagioclase feldspar + quartz + biotite + garnet + muscovite. White tonalite consists of plagioclase feldspar + quartz + muscovite + garnet.

Xpm **Mixed Plutonic and Metasedimentary Rocks (likely Paleoproterozoic)** – Complexly mixed unit consisting of metasedimentary rocks, foliated tonalite, biotite gneiss, fine-grained, equigranular tonalite, amphibolite and, pegmatite. Fine-grained tonalite both cross-cuts and intrudes parallel to foliation of metasedimentary rocks. Some outcrops show metasedimentary rocks grading into mass of medium grained tonalite. Screens of metasedimentary rocks within tonalite also observed. Unit is cut by potassium feldspar + quartz + plagioclase feldspar pegmatite dikes and sills parallel to foliation. Deformed pegmatite and foliated tonalite observed in several locations.

Xms **Metasedimentary Rocks (likely Paleoproterozoic)** – Biotite schist (commonly found as selvage near plutonic rocks), quartzite (non-foliated with minor plagioclase feldspar and biotite), muscovite schist (locally with magnetite porphyroblasts), biotite gneiss, and migmatite. The biotite gneiss consists of biotite + plagioclase feldspar + quartz, has distinct plagioclase feldspar augens, and well-developed lineation. The mafic layers of the migmatite contain aligned biotite (forming well-developed foliation) and the felsic layers consist of plagioclase feldspar + quartz. In the migmatite, ptygmatic folds are common; foliation parallels isoclinal folds and also deformed into open folds.

Unit is present throughout the quadrangle and typically observed as meter-scale discontinuous exposures cut by Proterozoic igneous rocks. Several map-scale bodies are shown south of State Route NM503. Unit is cross-cut by potassium feldspar + quartz + plagioclase feldspar pegmatite dikes and sills, which parallel foliation. This unit has a well-developed foliation (S2) that is axial planar to tight, isoclinal folds (F2). Fold hinges and lineation associated with S2 plunge south. Rare F1 fold hinges indicate the main foliation folds an early fabric (S1) that is parallel to compositional layering (S0). The main foliation is in turn folded into open, south-plunging folds (F3).

Xa **Amphibolite (likely Paleoproterozoic)** – Consists of amphibole + plagioclase feldspar. Massive and foliated varieties. Foliation defined by inter-layered amphibole and plagioclase feldspar-rich layers. Occurs as pods, dikes, and continuous layers within

metasedimentary and plutonic rocks. Several map-scale bodies are shown north of State Route NM503 in the vicinity of Santa Cruz Reservoir.

STRUCTURE

TESUQUE FORMATION

Tesuque Formation strata form a general westward-dipping homocline that is broken by numerous normal faults. Locally, deformation has created northward-trending monoclines, anticlines, and synclines. Beds of the upper Nambé Member and the Skull Ridge Member of both Lithosome A and B (units **Ttan2**, **Ttan2i**, **Ttas**, **Ttbn**, **Ttbs**) generally strike N30ºW to N30ºE) and dip less than 15º degrees to the west. Near the mountain front, strata of the lower Nambé Member (unit **Ttan1**) dips 15-30º to the west, and bedding strikes show much variability near Santa Cruz Reservoir.

Almost all of the observed faulting is normal; stratigraphic or slickenside evidence for significant strike-slip movement was not observed. Faults are generally down to the east with throws of up to 100 m. The two larger down-to-the-east faults are named the West Arroyo Seco fault and East Arroyo Seco fault; these are located north and northwest of the town of Nambé in the west-central portion of the quadrangle. A down-to-the-west fault zone extends north-northwest from near the center of the quadrangle to the northern boundary. This has been named the White Operation fault zone. It commonly consists of one or more fault strands within a 500 m–wide zone. The amount of throw along most of the White Operation fault is poorly constrained due to the lack of diagnostic strata in the upper Nambé Member (units **Ttan2** and **Ttbn**). About 2 km south of the northern quadrangle boundary, the fault displaces **White Ash #1** by only 10-15 m. However, within the upper 1 km of the northern quadrangle boundary the fault juxtaposes **White Ash #3** against the **Nambé White Ash**, indicating a throw of 70-80 m.

The most significant fold on the quadrangle is a monoclinal and anticlinal feature that extends north-south for about 4 km south of Chimayo. In the southernmost 1/3 of this structure

(NW1/4 Section 13, T.20N., R.9E.), strata east of the fold axis dip up to 3 degrees east, so we mapped the structure as an anticline there. However, the structure is a monocline over most of its length. Beds also steepen about 5 degrees in the vicinity of the down-to-the-east East Arroyo Seco fault, suggesting this fault breaks a monoclinal structure.

TESUQUE FORMATION-PROTEROZOIC BASEMENT CONTACT

We agree with Galusha and Blick (1971), Baltz (1978), and Kelley (1978) that there are no major rift-bounding faults along the present-day Sangre de Cristo mountain front. Rather, basal strata of the Tesuque Formation generally nonconformably overlie Proterozoic bedrock. The basal contact shows significant relief due to channel scouring and paleo-topography (1-150 m). Locally, faults correspond to the basin-fill mountain-front contact, but these are generally less than 1 km in length and are minor. Most faults displace the lower contact of the Tesuque Formation only a few meters. However, the fault north of, and continuing through, Santa Cruz Reservoir has offset the lower Tesuque Formation at least 100 m (the difference in elevation between the base of the Tesuque Formation west of Santa Cruz Reservoir and the lowest elevation of Tesuque Formation strata immediately northeast of Santa Cruz Reservoir).

It is unclear whether the valley where Cundiyo is located, and into which Nambé sediments were deposited, is of a structural or erosional origin. We have not recognized any major faults along the west side of this valley, aside from a small fault in the gully immediately west of the Cundiyo cemetrary. However, the valley appears to have an asymmetric cross-section, with the lower contact of the Tesuque Formation dipping to the west and projecting about 100 m below the top of the bedrock peaks west of the valley. Also, Paleozoic limestone is inferred in this valley but not located on Cerro Piñon to the northwest. This suggests that the valley may have formed as a half-graben, with a large-displacement normal fault on its western margin.

Considerable paleotopography was present during the early deposition of the Tesuque Formation, based on the location of the basal Tesuque Formation contact relative to the top of adjacent bedrock highs and considering the locations of mapped faults. The relief may range up to 100-150 m, with major peaks at Cerro Piñon and Lake Peak (northwest of Santa Cruz Reservoir), and a major west-trending paleo-valley located south of Cerro Piñon. In the Castle and Wigzell #1 Kelly Federal Well, the absence of the lower volcaniclastic interval of unit **Tmov** (correlative to the Bishop's Lodge Member) and the paucity of pre-**Tmov** Tesuque Formation deposits suggests these units pinch-out northwards against a paleo-topographic high in the middle part of the quadrangle (**Figure 2**). Moreover, unit **Ttan1** appears to onlap against a Proterozoic basement high in the vicinity of Santa Cruz Reservoir.

In the vicinity of Santa Cruz Reservoir, two noteworthy structural relationships occur in the basal Tesuque Formation strata. First, east of Santa Cruz Reservoir (NE1/4 SE1/4 section 7, T. 20 N., R.10 E.), the bottom contact is observed to be folded into an anticline, and immediately overlying strata are likewise folded into an anticline. This demonstrates that folding in the basement can also fold or bend overlying basin fill (as opposed to this deformation in the basin fill being accommodated solely by faulting). Second, faults immediately west of the Santa Cruz Reservoir (e.g., NE1/4 NW1/4 Section 8 T. 20 N., R. 10 E.) locally offset both the basal Tesuque Formation contact and lower Tesuque Formation strata, but strata about 10 m above the lower contact are not broken. This relationship suggests that local offsets along faults occurred shortly after the lowermost Nambé Member strata were deposited here. The age of these particular basal beds are probably 20-25 Ma, based on stratigraphic projection and correlation to the dated 25 Ma basalt in unit **Tmov** near Cerro Piñon. Thus, some minor faulting appears to have occurred here in the early Miocene.

INTERPRETATIONS OF DEPOSITIONAL ENVIRONMENT

Smith (2001) and Kuhle and Smith (2001) interpret that the Skull Ridge member of the Tesuque Formation was deposited in an alluvial slope environment. We extend this interpretation to Lithosome A strata of the Nambé Member as well, based on similar sedimentologic

characteristics. However, strata near the Lithosome A - Lithosome B boundary in the northwest corner of the quadrangle may record a transition from a distal westward sloping alluvial slope to a south-southwestward sloping, central basin floor or alluvial plain environment. The latter interpretation is consistent with subsurface data from four deep uranium drill-holes, located within 2 km west of the western quadrangle boundary, that penetrate the entire Skull Ridge Member (wells EB-33, EB-66, EB-101, EB-102; cuttings on archive at the New Mexico Bureau of Geology and Mineral Resources and described by the senior author). These cuttings are dominated by fine-grained sand, silt, and clay, with very sparse pebble beds of northeastern provenance (Lithosome B).

PRELIMINARY INTERPRETATIONS REGARDING LATE OLIGOCENE-EARLY MIOCENE RIFTING

Approximately 25 Ma, when unit **Tmov** was deposited in this quadrangle, there appears to have been relatively low rates of tectonic activity, if not tectonic quiescence, because volcaniclastic strata and basalt flows of this unit extend up to the present-day mountain front. This implies that the Española Basin had a relatively flat basin floor at this time, as opposed to having an asymmetric profile with a topographic low restricted to the west side of the basin due to high rates of displacement along a large master fault on the basin's west side. This is consistent with the presence of clay beds immediately above and below this unit adjacent to Cerro Piñon. It also is consistent with past interpretations that basalts south of this quadrangle (unit Ttnb of Borchert and Read, 1998, 2002 revision), correlative to those in **Tmov**, were deposited in a playa or relatively flat basin floor environment (Boyer, 1959).

The discrepancy of dips between the lower Nambé Member (unit **Ttan1**) versus overlying strata indicate either: (1) an episode of increased regional tectonism (manifested by westward tilting of the basin floor and faulting) followed much of the deposition of unit **Ttan1** prior to deposition of unit **Ttan2**, or (2) localized flexure near the present-day mountain front followed the deposition of both unit **Ttan1** and overlying strata. More work is needed to address the reason for this difference in dip magnitudes. However, interpretation of seismic reflection data (Biehler et al.,

1991) to the southwest, in the Horcado Ranch quadrangle, indicate: (1) that strata of the lower Nambé Member and the underlying unit **Tmov** are tilted approximately 5-8 degrees more than overlying strata of the Tesuque Formation (Koning and Maldonado, 2001, cross-section); (2) a large fault that generated 200 m of relief in interpreted Oligocene strata does not appear to offset strata correlative to the upper Nambé Member and Skull Ridge Member; (3) the strata interpreted by the senior author to be correlative to the Nambé Member appear to thicken signicantly across the Pojoaque and Las Dos fault zones. This is consistent with the hypothesis that significant tectonic activity, marked by tilting of the half-graben and faulting, occurred after the deposition of much of unit **Ttan1** and prior to the deposition the upper Nambé Member.

ACKNOWLEGMENTS

We thank the Pojoaque Pueblo and the Cundiyo Land Grant for allowing access onto their lands. Crayton Robinson kindly allowed us to traverse across his property. Gary Smith of the University of New Mexico and Sean Connell provided information and advice.

REFERENCES

Baldridge, W.S., Damon, P.E., Shafiqullah, M., and Bridwell, R.J., 1980, Evolution of the central Rio Grande rift, New Mexico -- New Potassium-Argon ages: Earth and Planetary Science Letters, vol. 51, p. 309-321.

Baltz, E.H., 1978, Resume of Rio Grande depression in north-central New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 163, p. 210-228.

Barghoorn, S., 1981, Magnetic-polarity stratigraphy of the Miocene type Tesuque Formation, Santa Fe Group, in the Española Valley, New Mexico: Geological Society of America Bulletin, v. 92, p. 1027-1041.

Biehler, S., Ferguson, J., Baldridge, W.S., Jiracek, G.R., Aldern, J.L., Martinez, M., Fernandez, R., Romo, J., Gilpin, B., Braile, L.W., Hersey, D.R., Luyendyk, B.P., and Aiken, C.L., 1991,

A geophysical model of the Española Basin, Rio Grande rift, New Mexico: Geophysics, v. 56, no. 3, p. 340-353.

Birkeland, P.W., 1999, Soils and geomorphology: New York, Oxford University Press, 430 p.

Borchert, C., and Read, A.S., 1998, revised 2002, Geology of the Tesuque 7.5-min. quadrangle, Santa Fe County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file Geologic Map OF-GM 47, scale 1:24,000.

Boyer, W.W., 1959, Playa deposit in the Bishop's Lodge Member of the Tesuque Formation, Santa Fe County, New Mexico: Journal of Sedimentary Petrology, vol. 29, n. 1, p. 64-72.

Cather, S.M., 1992, Suggested revisions to the Tertiary tectonic history of north-central New Mexico: New Mexico Geological Society Guidebook, 43rd Field Conference, p. 109-122.

Dethier, D.P., and McCoy, W.D., 1993, Aminostratigraphic relations and age of Quaternary deposits, northern Española Basin, New Mexico: Quaternary Research, v. 39, p. 222-230.

Dethier, D.P., and Reneau, S.L., 1995, Quaternary History of the western Española Basin, New Mexico: New Mexico Geological Society, 46th Field Conference Guidebook, Geology of the Santa Fe Region, p. 289-298.

Cavazza, W., 1986, Miocene sediment dispersal in the central Española Basin, Rio Grande rift, New Mexico, USA: Sedimentary Geology, v. 51, p. 119-135.

Compton, R.R., 1985, Geology in the field: New York, John Wiley & Sons, Inc., 398 p.

Connell, S.D., and Cather, S.M., 2001, Stratigraphy of the lower Santa Fe Group, Hagen Embayment, north-central New Mexico: preliminary results: New Mexico Bureau of Mines and Mineral Resources Open File Report, v. 454B, p. H49-H56.

Galusha, T., and Blick, J.C., 1971, Stratigraphy of the Santa Fe Group, New Mexico: Bulletin of the American Museum of Natural History, v. 144, 127 p.

Gile, L.H., Peterson, F.F., and Grossman, R.B., 1966, Morphological and genetic sequences of carbonate accumulation in desert soils: Soil Science, v. 101, p. 347-360.

Grant Enterprises, Inc., 1998, Subsurface geology and related hydrologic conditions, Santa Fe embayment and contiguous areas, New Mexico (P.R. Grant, principle investigator): Office of the New Mexico State Engineer Technical Division, Hydrology Bureau, Technical Report 97-5, 53 p.

Ingram, R.L., 1954, Terminology for the thickness of stratification and parting units in sedimentary rocks: Geological Society of America Bulletin, v. 65, p. 937-938, table 2.

Izett, G.A., and Obradovich, J.D., 2001, 40Ar/39Ar ages of Miocene tuffs in basin-fill deposits (Santa Fe Group, New Mexico, and Troublesome Formation, Colorado) of the Rio Grande rift system: The Mountain Geologist, v. 38, no. 2, p. 77-86.

Izett, G.A., and Obradovich, J.D., 1994, 40Ar/39Ar constraints of the Jaramillo Normal Subchron and the Matuyama-Bruhnes geomagnetic boundary: Journal of Geophysical Research, B, v. 99, p. 2925-2934.

Kautz, P.F., Ingersoll, R.V., Baldridge, W.S., Damon, P.E., and Shafiqullah, M., 1981, Geology of the Espinaso Formation (Oligocene), north-central New Mexico: Geological Society of America Bulletin, vol. 92, Part I (p. 980-983) and Part II (p. 2318-2400).

Kelley, V.C., 1978, Geology of the Española Basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Geologic Map GM-48, scale 1:125,000.

Kelley, V.C., 1979, Geomorphology of the Española Basin, New Mexico: New Mexico Geological Society Guidebook, 30th Field Conference, Santa Fe Country, p.281-288.

Koning, D.J., and Hallett, R.B., 2000, Geology of the Turquoise Hill 7.5-min. quadrangle, Santa Fe County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file Geologic Map OF-GM 41, scale 1:24,000.

Koning, D.J., and Maldonado, F., 2001, Geologic map of the Horcado Ranch quadrangle, Santa Fe County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file Geologic Map OF-GM-54, scale 1:24,000.

Koning, D.J., 2002, Geologic map of the Española 7.5-minute quadrangle, Santa Fe and Arriba counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file Geologic Map XXXXX, scale 1:24,000.

Kuhle, A., 1997, Sedimentology of Miocene alluvial-slope deposits, Española Basin, Rio Grande rift: an outcrop analogue for subsurface heterogeneity [M.S. thesis]: Albuquerque, University of New Mexico: 205 p.

Kuhle, A., and Smith, G.A., 2001, Alluvial-slope deposition of the Skull Ridge Member of the Tesuque Formation, Española Basin, New Mexico: New Mexico Geology, p. 30-37.

McIntosh, W.C., and Quade, J., 1995, $^{40}Ar/^{39}Ar$ geochronology of tephra layers in the Santa Fe Group, Española Basin, New Mexico: New Mexico Geological Society Guidebook, 46th Field Conference, Geology of the Santa Fe Region, p. 279-284.

Miller, J.P., and Wendorf, F., 1958, Alluvial chronology of the Tesuque Valley, New Mexico: Journal of Geology, v. 66, p. 177-194.

Munsell Color, 1994 edition, Munsell soil color charts: New Windsor, N.Y., Kollmorgen Corp., Macbeth Division.

Pettijohn, F.J., Potter, P.E., and Siever, R., 1987, Sand and sandstone: Springer-Verlag, New York, 553 p.

Read, A.S., Rogers, J., Ralser, S., Smith, G., Koning, D.J., and Bauer, P.W., 2000, Geology of the Santa Fe 7.5-min. quadrangle, Santa Fe County, Mew Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file Geologic Map OF-GM 32, scale 1:12,000.

Sarna-Wojcicki, A.M., Morrison, S.D., Meyer, C.E., and Hillhouse, J.W., 1987, Correlation of upper Cenozoic tephra layers between sediments of the western United States and comparison with biostratigraphic and magnetostratigraphic data: Geological Society of America Bulletin, v. 98, p. 207-223.

Smith, G.A., 2000, Oligocene onset of Santa Fe Group sedimentation near Santa Fe, New Mexico (abstr): New Mexico Geology, p. 43.

Smith, G.A., 2001, Recognition and significance of streamflow-dominated piedmont facies in extensional basins: Basin Research: v. 12, p. 399-411.

Soil Survey Staff, 1992, Keys to Soil Taxonomy: U.S. Department of Agriculture, SMSS Technical Monograph no. 19, 5th edition, 541 p.

Tedford, R.H., Skinner, M.F., Fields, R.W., Rensberger, J.M., Whistler, D.P., Galusha, T., Taylor, B.E., Macdonald, J.R., and Webb, S.D., 1987, Faunal succession and biochronology of the Arikareean through Hemphillian interval (late Oligocene through earliest Pliocene epochs) in North America, *in* Woodburne, M.O., ed., Cenozoic mammals of North America, geochronology and biostratigraphy: Berkely, University of California Press, p. 153-210.

Tedford, R.H., and Barghoorn, S.F., 1993, Neogene stratigraphy and mammalian biochronology of the Española Basin, northern New Mexico: Vertebrate paleontology in New Mexico, New Mexico Museum of Natural History and Science, Bulletin 2, p. 159-168.

Udden, J.A., 1914, The mechanical composition of clastic sediments: Bulletin of the Geological Society of America, v. 25, p. 655-744.

Wentworth, C.K., 1922, A scale of grade and class terms for clastic sediments: Journal of Geology, v. 30, p. 377-392.

COMMENTS TO MAP USERS

A geologic map displays information on the distribution, nature, orientation, and age relationships of rock and deposits and the occurrence of structural features. Geologic and fault contacts are irregular surfaces that form boundaries between different types or ages of units. Data depicted on this geologic quadrangle map are based on reconnaissance field geologic mapping, compilation of published and unpublished work, and photogeologic interpretation. Locations of contacts are not surveyed, but are plotted by interpretation of the position of a given contact onto a topographic base map; therefore, the accuracy of contact locations depends on the scale of mapping and the interpretation of the geologist(s). Any enlargement of this map could cause misunderstanding in the detail of mapping and may result in erroneous interpretations. Site-specific conditions should be verified by detailed surface mapping or subsurface exploration. Topographic and cultural changes associated with recent development may not be shown.

The map has not been reviewed according to New Mexico Bureau of Mines and Mineral Resources standards. Revision of the map is likely because of the on-going nature of work in the region. The contents of the report and map should not be considered final and complete until reviewed and published by the New Mexico Bureau of Mines and Mineral Resources. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the State of New Mexico, or the U.S. Government. Cross-sections are constructed based upon the interpretations of the authors made from geologic mapping, and available geophysical (regional gravity and aeromagnetic surveys), and subsurface (drillhole) data.

Cross-sections should be used as an aid to understanding the general geologic framework of the map area, and not be the sole source of information for use in locating or designing wells, buildings, roads, or other man-made structures.