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# Geologic Map of the Agua Fria Quadrangle, Santa Fe County, New Mexico

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Pamphlet to accompany
Scientific Investigations Map 2896

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# Contents

## DESCRIPTION OF MAP UNITS

[Sediments and lava flows exposed in the Agua Fria quadrangle (the map area), in the southern part of the Española basin (figs. 1 and 2), record alluvial, colluvial, and volcanic processes over the past 15–16 m.y. (million years). The mapped surficial deposits are known or estimated to be at least 1 m thick. The Santa Fe Group (units QTa, Ttu, and Ttl) and most of the surficial deposits (post-Santa Fe Group sediments) are poorly exposed. Thin (<50 cm), discontinuous sheetwash deposits (unit Qsw) locally mantle gently sloping map units. Limited exposures of the Ancha Formation (unit QTa) in the map area precluded mapping unit QTa as two separate map units consisting of fluvial deposits of the Santa Fe River and other alluvial deposits. We did not map deposits that are (1) of limited extent (less than about 25 m wide), (2) exposed in steep cuts, and (3) fill material (unit af) that was not observed on aerial photographs. Gravelly stream alluvium (units Qgi, Qgo3, Qgo2, and Qgo1) form small, poorly exposed deposits that are difficult to identify on aerial photographs; it is likely that some of these deposits are not shown on the map.

The surficial map units on this map are informal allostratigraphic units of the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983), whereas the other map units are informal or formal lithostratigraphic units. For this reason, subdivisions of stratigraphic units use time terms "late" and "early" where applied to surficial units, but use position terms "upper" and "lower" where applied to lithostratigraphic units.

The mapped distribution of units is based primarily on interpretation of 1:24,000-scale, color aerial photographs taken in 1990, and 1:40,000-scale, black-and-white aerial photographs taken in 1996. Most of the contacts on the map were transferred from the aerial photographs using a stereoplotter. The location of the Yates La Mesa No. 2 drill hole is based on coordinates reported by Bruce A. Black (Black Oil, Inc., written commun., 1985).

Age assignments for surficial deposits are based chiefly on the (1) relative degree of modification of their original surface morphology, (2) relative heights above modern stream channels, and (3) degree of soil development. Soil-horizon designations are based on those of the Soil Survey Staff (1999), Birkeland (1999), and Guthrie and Witty (1982). Some of the surficial deposits contain secondary calcium carbonate of pedogenic (soil) origin. Stages of secondary calcium carbonate morphology (referred to as stages I through III) in Bk, Bkb, Btkb, K, and Kb soil horizons are from Gile and others (1966) and Machette (1985).

Grain or particle sizes of surficial deposits are field estimates, based on the modified Wentworth scale (American Geological Institute, 1982). In descriptions of surficial map units, the term "clasts" refers to particles larger than 2 mm in diameter, whereas the term "matrix" refers to particles smaller than 2 mm in diameter. Many of the clasts in the map area were recycled chiefly from the Santa Fe Group (units QTa, Ttu, and Ttl); however, terrace deposits along the Santa Fe River (units Qty and Qti) probably also contain first-cycle (new) clasts derived from the Sangre de Cristo Mountains. In descriptions of clast composition of surficial map units, the term "granite" includes granite, quartz monzonite, granitic pegmatite, and probably granitic gneiss. The term "basalt" probably includes basaltic andesite.

Dry matrix colors of the surficial deposits, Santa Fe Group, and unit Tbt were determined by comparison with Munsell Soil Color Charts (Munsell Color, 1973). Colors of the surficial deposits generally are similar to those of the sediments and volcanic rock from which they were derived. The colors of the surficial deposits commonly are light brown (7.5YR 6/4) and pink (7.5YR7/4).

In this report, the terms "alluvium" and "alluvial" refer to material transported by running water confined to channels (stream alluvium) as well as by running water not confined to channels (sheetwash). The terms "colluvium" and "colluvial" refer to material transported on slopes chiefly by mass-wasting (gravity-driven) processes—such as creep, debris flow, and rock fall—aided by running water not confined to channels (sheetwash). Surficial map units that include debris-flow deposits probably also include hyperconcentrated flow deposits. These latter deposits are intermediate in character between stream-flow and debris-flow deposits. The terms "non-plastic" and "plastic" in the descriptions of units Qa and Qsw refer to the extent to which moist sediment changes shape continuously under the influence of an applied stress and to retain the impressed shape on the removal of the stress (Soil Survey Staff, 1951).

Spiegel and Baldwin (1963) identified and named three relict geomorphic surfaces in and near the map area. The extensive southwest-sloping geomorphic surface in the southern one-third of the map area is referred to as the Airport surface. The southwest- and locally west-sloping geomorphic surface in the northern two-thirds of the map area is referred to as the Divide surface. The extensive southwest-sloping geomorphic surface east, southeast, and south of the map area is referred to as the Plains surface. All

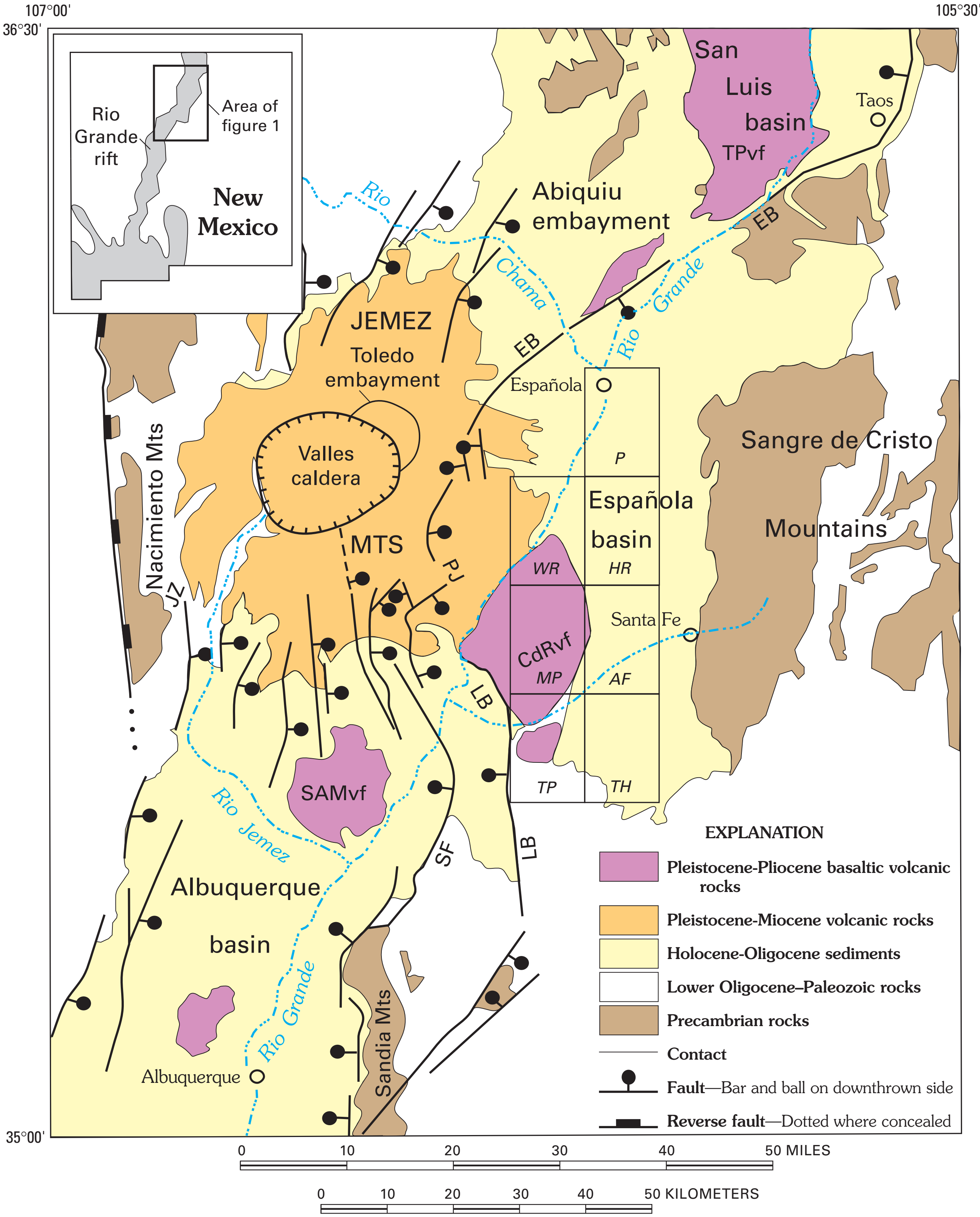


**Figure 1.** Location map and general geology of the Española basin, adjacent basins, and volcanic fields of the Rio Grande rift. Geology modified from Smith and others (2001, fig. 3). Approximate location of the Toledo caldera (Toledo embayment) is modified from Gardner and Goff (1996). Volcanic fields: CdRvf, Cerros del Rio volcanic field; SAMvf, Santa Ana Mesa volcanic field; TPvf, Taos Plateau volcanic field. Faults: EB, Embudo fault; JZ, Jemez fault; LB, La Bajada fault; PJ, Pajarito fault; SF, San Francisco fault. 7.5-minute topographic quadrangles: *AF*, Agua Fria; *E*, Española; *HR*, Horcado Ranch; *MP*, Montoso Peak; *SF*, Santa Fe; *TP*, Tetilla Peak; *TH*, Turquoise Hill; *WR*, White Rock Canyon.

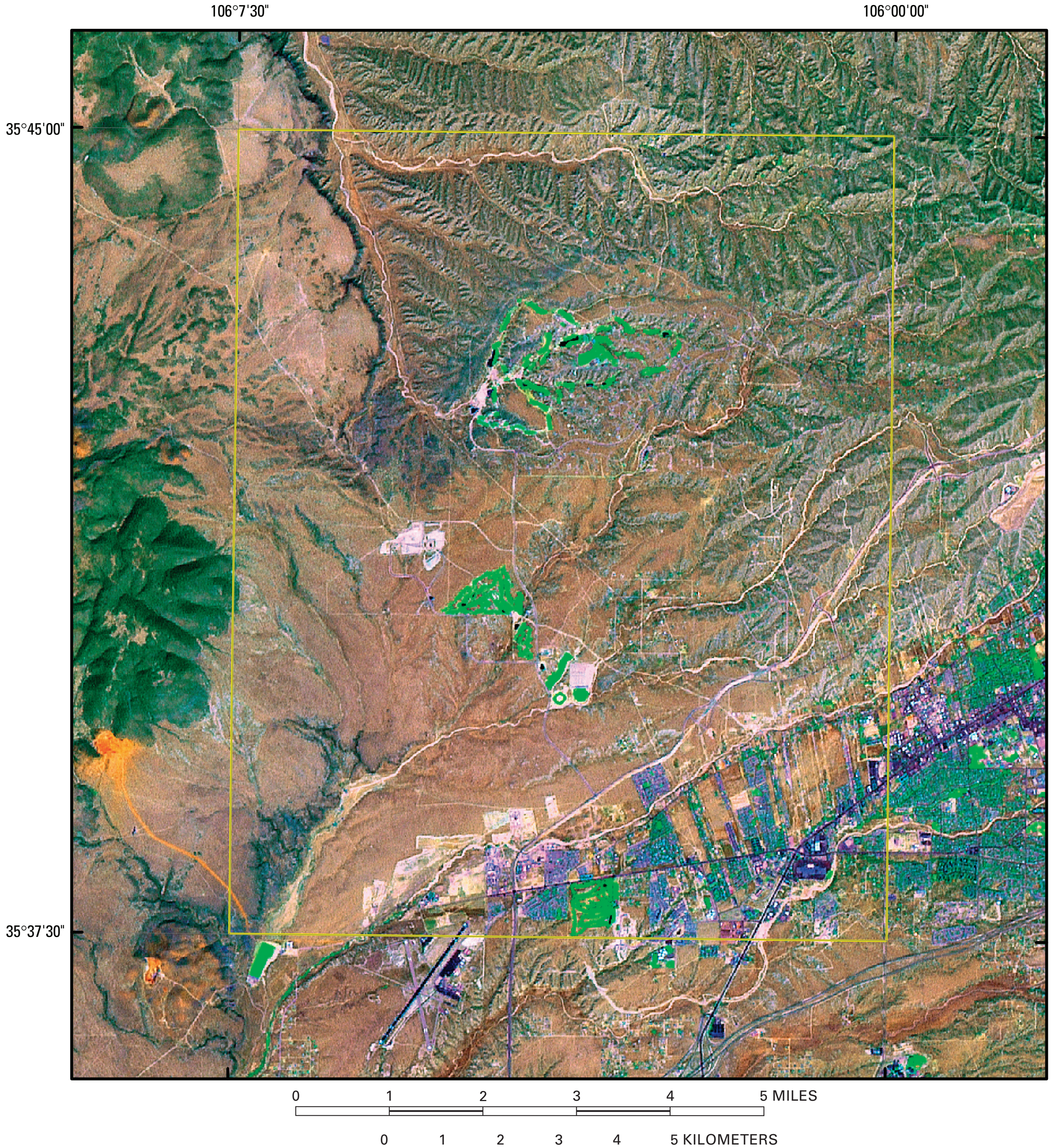


**Figure 2.** Landsat 7 satellite image (30-m band 7-4-2 merged with 15-m band 8) acquired on October 14, 1999, of greater Santa Fe, N. Mex., area (Sawyer and others, 2004), showing geologic features and contrasting land use. Volcanic rocks and sediments of the Cerros del Rio volcanic field are visible in the western part of the image, dissected Tesuque Formation in the northern and northeastern parts, and Ancha Formation and younger sediments in the central and southern parts. Light-green areas in the central part of the image are golf courses; many of the white areas are gravel pits, landfills, and construction sites; and the light-orange area and linear feature in the western part of the image are a cinder quarry and haulage road. Yellow rectangle is the boundary of the Agua Fria 7.5-minute quadrangle.

of these surfaces are formed on sediment of the Ancha Formation (unit QTa). The Airport surface is the youngest of the three geomorphic surfaces in the Santa Fe area and the Plains surface is considered to be the oldest (Spiegel and Baldwin, 1963). In the map area the Airport surface is locally as much as 15 m below the projected top of the Divide surface on the west side of Arroyo Calabasas and is locally as much as 20 m below the projected top of the Plains surface south of Cienega Creek near the eastern boundary of the Turquoise Hills quadrangle.

The satellite image (fig. 2) was obtained from processed Landsat 7 satellite imagery (30-m band 7-4-2 merged with 15-m band 8) created from two Landsat 7 scenes acquired on October 14, 1999 (Sawyer and others, 2004).

There are two versions of the Agua Fria quadrangle geologic map. One has a traditional topographic base from the USGS. The second has a screened shaded relief base generated from 10-m digital elevation model (DEM) data in the National Elevation Dataset; sun illumination is from the northwest at 45° above the horizon.

The geology was mapped from 1996 to 2004. The primary mapping responsibilities were as follows. R.R. Shroba mapped the surficial deposits and sediments of the Santa Fe Group. R.A. Thompson mapped the volcanic rocks. S.A. Minor mapped the faults and collected fault attitude and slickenline data. V.J.S. Grauch determined locations of some of the inferred faults based on analysis of aeromagnetic data. T.R. Brandt prepared the digital compilation of the geologic map and the shaded relief on one of the versions of this map.

Metric units are used in this report, except for depth measurements in the Yates La Mesa No. 2 drill hole, which were recorded in feet. A conversion table is provided for those more familiar with English units (table 1). Divisions of geologic time used in this report are provided in table 2]

**Table 1.** Factors for conversion of metric units to English units to two significant figures.

| Multiply | By | To obtain |
|---|---|---|
| centimeters (cm) | 0.39 | inches |
| meters (m) | 3.28 | feet |
| kilometers (km) | 0.62 | miles |

**Table 2.** Divisions of geologic time used in this report.

| Period | Epoch | | Age |
|---|---|---|---|
| | Holocene | | 0–10 ka |
| Quaternary | | late | 10–132 ka |
| | Pleistocene | middle | 132–788 ka |
| | | early | 788 ka–1.81 Ma |
| | Pliocene | | 1.81– 5.32 Ma |
| Tertiary | Miocene | | 5.32– 23.8 Ma |
| | Oligocene | | 23.8–33.6 Ma |

After Hansen (1991) with exceptions: 132,000 (late-middle Pleistocene) and 788,000 (middle-early Pleistocene) from Richmond and Fullerton (1986); 1.81 Ma (Pleistocene-Pliocene) from Lourens and others (1996); 5.32 Ma (Pliocene-Miocene), 23.8 (Miocene-Oligocene), and 33.6 Ma (Oligocene-Eocene) from Berggren and others (1995). Ages are expressed in ka for kilo-annum (thousand years) and Ma for mega-annum (million years).

## SURFICIAL DEPOSITS

### Artificial-Fill Deposits

af **Artificial fill (latest Holocene)**—Compacted fill material composed mainly of silt, sand, rock fragments, and locally trash. Mapped chiefly at or near roads and commercial and residential developments, in an inactive landfill in and along Arroyo de los Frijoles in the southern part of the map area, and in an active landfill south of Cañada Ancha in the western part of the map area. Both of the landfills contain organic (plastic products, vegetation, and so forth) and inorganic trash (metal, concrete, and so forth). The extent of the landfills, which is based on aerial photography flown in 1996, may change due to continued filling. Unit af locally includes small areas where the land surface was modified by earth-moving equipment. In these areas, the original geologic material cannot be recognized and locally is overlain by very thin, discontinuous deposits of artificial fill. Estimated thickness is 1 m to possibly more than 10 m in landfills

### Alluvial Deposits

Qa **Alluvium in stream channels and below low terraces (Holocene and late Pleistocene?)**—Mostly pebbly, medium to very coarse sand in active stream channels. Mostly poorly sorted, slightly pebbly, silty, very fine to medium sand, and minor amounts of slightly pebbly, medium to very coarse sand and lenses of sandy pebble gravel below low terraces. Matrix of these deposits is non-plastic to moderately plastic, and locally contains a minor amount of calcium carbonate. Deposits below low terraces are locally well exposed in recent stream cuts. Alluvial deposits that overlie lava flows near the western boundary of the map area consist of clast-supported, poorly sorted, non-bouldery and slightly bouldery, cobbly pebble gravel. Deposits of unit Qa are in channels of intermittent streams and form discontinuous terraces locally as much as 3.5 m above adjacent channels of intermittent streams. Clasts commonly consist of volcanic rock near the western boundary of the map area where they are derived chiefly from basaltic lava flows, and are mostly granite in other parts of the map area. Surface soils are absent in channel deposits; soils formed in terrace deposits have stage I carbonate morphology (Read and others, 2000). Unit Qa locally contains two, thin (15–55 cm), weakly developed, buried soils in the eastern part of the map area. These soils have cambic (Bwb) horizons as well as calcic (Bkb) horizons with stage I carbonate morphology that are formed in sandy deposits about 1 m thick. These soils and sediments locally overlie a buried soil that is similar to the surface soil formed in the top of unit Qty. Lenses of redeposited sand-size pumice and carbonate-cemented pumice fragments in clasts as large as 4 x 5 x 8 cm are exposed in a shallow excavation at site AF-42 in the west-central part of the map area (NW1/4 sec. 28, T. 17 N., R. 8 E.). Chemical correlation of the sand-size pumice (A.M. Sarna-Wojcicki, U.S. Geological Survey, written commun., 2004) suggests that it is 1.6-Ma Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff (Izett and Obradovich, 1994). It is likely that this pumice was eroded from pumice-bearing deposits in unit QTba. Unit Qa locally includes debris-flow deposits (unit Qdy) in areas of steep topography near the western boundary of the map area as well as thin, discontinuous, unmapped sheetwash deposits (unit Qsw) in other parts of the map area. Deposits of unit Qa are locally susceptible to stream flooding, sheet flooding, and deposition of debris flows. In addition, deposits composed of moderately well sorted silty sand are susceptible to gullying. Exposed thickness is 1.7–2.6 m; possibly as much as 10 m

Qty **Younger terrace alluvium (late Pleistocene?)**—Overbank and gravelly channel deposits that are locally well exposed in gravel pits along the Santa Fe River in the southern part of the map area. Overbank deposits are composed of slightly pebbly, slightly silty to silty, very fine to medium sand, about 40–100 cm thick. Channel deposits are greater than 7 m thick and consist of interstratified (1) sandy, slightly cobbly pebble gravel, (2) sandy pebble gravel, (3) pebbly coarse sand, (4) very fine to medium sand, and (5) silty very fine to fine sand. These deposits form beds and lenses and locally display fluvial cross beds. Along Arroyo de los Frijoles, sediments consist of medium to coarse sand and thin (10–20 cm) lenses of pebble gravel. These sediments are overlain by slightly pebbly, very fine to medium sand and thin (4–10 cm) lenses of sandy pebble gravel. Deposits of unit Qty underlie remnants of a discontinuous terrace about 2–3 m above the channel of the Santa Fe River and about 4 m above the channel of Arroyo de los Frijoles. Thin, unmapped deposits of sheetwash (unit Qsw) locally mantle unit Qty. Pebbles and small cobbles are commonly subangular to subrounded and consist chiefly of granite. Surface soils are formed in overbank deposits, have brown (7.5YR 5/4) and light-brown (7.5YR 6/4) Bw (cambic), Btj (juvenile argillic B), or Btk (argillic and calcic) horizons about 10–40 cm thick, and locally overlie pink (7.5YR 7/4) Bk (calcic) horizons with stage I carbonate morphology. These soil properties (Shroba and Birkeland, 1983; Machette and others, 1997; Nelson and Shroba, 1998; Birkeland and others, 2003) suggest that sediments of unit Qty were deposited during the last major glaciation (Pinedale) about 10–30 ka (Madole and others, 1998) or during the high stands of pluvial lake Estancia between about 12 and 24 ka (Allen and Anderson, 2000). Much of the sediment in unit Qty probably was deposited during a prolonged cool or cold and wet glacio-pluvial climate (Stone and others, 2001). Unit Qty is equivalent to terrace deposits (unit Qts2) mapped by Read and others (2000) in the adjacent Santa Fe quadrangle. Charcoal collected from a sample of organic-rich, fine-grained, overbank sediment of unit Qts2 yielded a radiocarbon age of 7,960±60 (Read and others, 2000). Some of the deposits in unit Qty may be of early Holocene age. Exposed thickness is 2–9 m; possibly as much as 10 m

Qti **Intermediate terrace alluvium (late? and middle Pleistocene)**—Overbank and gravelly channel deposits that are locally well exposed in gravel pits along the Santa Fe River in the southern part of the map area. Overbank deposits are composed of very slightly pebbly, silty, very fine to fine and very fine to medium sand, about 35–140 cm thick. Channel deposits consist of poorly sorted to moderately well sorted, clast-supported, interstratified (1) slightly cobbly pebble gravel, (2) sandy pebble gravel, (3) pebbly coarse sand, (4) thin (5–65 cm) lenses of slightly silty, very fine to very coarse sand, and (5) silty, very fine to fine sand. These deposits form beds and lenses and locally display fluvial cross beds and dark manganese stains. Deposits of unit Qti underlie discontinuous terrace remnants about 6 m above the channel of the Santa Fe River. Thin, unmapped deposits of sheetwash (unit Qsw) and possibly silty eolian sand locally mantle unit Qti. Pebbles and small cobbles are commonly subangular to subrounded and consist chiefly of granite. Surface soils are formed in overbank deposits and have brown (7.5YR 5/4) Bt and Btk horizons about 15–40 cm thick that locally overlie K horizons 55 cm thick with stage III carbonate morphology above Bk horizons with stage II carbonate morphology. These soil properties (Shroba and Birkeland, 1983; Nelson and Shroba, 1998; Birkeland and others, 2003), particularly the carbonate accumulation, suggest that sediments in unit Qti were deposited prior to the last major glaciation, probably during the Bull Lake glaciation about 120–160 ka (Nelson and Shroba, 1998). Unit Qti might be coeval in part with the lower lacustrine clay in the Estancia basin (Bachhuber, 1992). Much of the sediment in unit Qti probably was deposited during a prolonged cool or cold and wet glacio-pluvial climate (Stone and others, 2001). Exposed thickness 1–8.5 m; possibly as much as 10 m thick

Qsw **Sheetwash deposits (Holocene to middle? Pleistocene)**—Slightly pebbly to pebbly, slightly silty to silty, very fine to medium sand. These sediments are slightly to moderately plastic. Some of the silt- to fine sand-size fraction in these deposits may be of eolian origin. Surface soils locally have Bw, Bt, or Btk/K horizon morphology depending in part on the age of the deposit. Bt and Btk horizons have thin clay films on ped faces. Bt horizons are 20–70 cm thick; Btk horizons are 10–45 cm thick and have stage I–II carbonate morphology. K horizons are as much as 75 cm thick and have stage III carbonate morphology. These properties suggest that some of the more strongly developed soils are formed in deposits that may be about 120–160 ka (Shroba and Birkeland, 1983; Nelson and Shroba, 1998; Birkeland and others, 2003). The strongest soils formed in unit Qsw overlie gently sloping geomorphic surfaces cut on deposits of unit QTa. Although undifferentiated, younger deposits locally overlie older deposits of unit Qsw. Older sheetwash deposits are locally greater than 2 m thick and have upper surfaces marked by buried Bkb, Btkb, or Kb horizons greater than 30 cm thick. Presence of surface and buried soils formed on and in unit Qsw indicate periodic deposition followed by surface stability and soil development. The last major episode of deposition may have been associated with enhanced summer rainfall during the early Holocene (Reneau and others, 1996). Pebbles and small cobbles are commonly subangular to subrounded and consist of volcanic rocks in the western part of the map area where they are derived chiefly from basaltic lava flows, and are mostly granite in other parts of the map area. Deposits of unit Qsw on the south side of Alamo Creek in the northern part of the map area may locally include some small, unmapped deposits of unit Qgo1. Sediments in unit Qsw were deposited chiefly by non-channelized surface flow, but locally may include small, unmapped deposits of stream alluvium (unit Qa) and possibly eolian sand. Low-lying areas of unit Qsw are susceptible to sheet flooding due to unconfined overland flow, and locally to stream flooding and gullying. Disturbed surface of unit Qsw may be susceptible to minor wind erosion. Exposed thickness is 1.7–2.4 m; possibly as much as 5 m thick

Qgi **Intermediate gravelly stream alluvium (late? and middle Pleistocene)**—Fluvial deposits composed of sandy cobbly pebble gravel, pebbly sand, and a minor amount of slightly bouldery cobble gravel. Unit forms two small terrace remnants in Cañada Ancha near the northwest corner of the map area. Pebbles and small cobbles are angular to well rounded and consist chiefly of granite and quartzite along with subordinate amounts of basalt and quartz, and minor amounts of amphibolite and schist. Basalt boulders in unit Qgi are angular and are as much as 1 m in intermediate diameter. Soils not exposed on this unit. A thin mantle of colluvium (unit Qc) that consists chiefly of angular basaltic rock fragments overlies the western margin of the map unit. Top of unit Qgi is about 11 m above the stream channel in Cañada Ancha. Exposed thickness is about 7 m; possibly as much as 10 m thick

Qgo3 **Lower older gravelly stream alluvium (middle Pleistocene)**—Fluvial deposits along the channel of Alamo Creek and the stream channel in Cañada Ancha. Unit forms four small terrace remnants near the northeast corner of the map area and one small terrace remnant near the northwest corner of the map area. Deposits along Alamo Creek are composed of sandy, cobbly pebble gravel and slightly pebbly, very fine to medium sand that contains lenses of cobbly pebble gravel less than 1 m thick. Deposits in Cañada Ancha consist chiefly of cobbly pebble gravel. Pebbles and small cobbles are commonly subangular to well rounded in all five deposits. Along Alamo Creek, pebbles and small cobbles consist chiefly of granite and less than 20 percent quartzite. In Cañada Ancha they consist of about 40 percent granite, 15 percent quartzite, 15 percent basalt, 10 percent amphibolite, and 20 percent quartz plus pegmatite, schist, and gneiss. Much of the sand and gravel in unit Qgo3 probably was eroded from the Tesuque Formation (units Ttu and Ttl). The top of unit Qgo3 is about 24–27 m above the channel of Alamo Creek and about 21 m above the stream channel in Cañada Ancha. Exposed thickness along the channel of Alamo Creek is 1.6–6.5 m. Thickness in Cañada Ancha possibly as much as 10 m

Qgo2 **Higher older gravelly stream alluvium (middle Pleistocene)**—Fluvial deposits chiefly of cobbly pebble gravel form three small gravelly remnants in Cañada Ancha, near the northwest corner of the map area. Pebbles and small cobbles are commonly subangular to rounded and consist chiefly of granite and quartzite. Deposits contain little or no basaltic or andesitic clasts. The top of unit is about 32–40 m above the stream channel in Cañada Ancha. Exposed thickness is about 1.5–3 m; possibly as much as 10 m thick

Qgo1 **Oldest gravelly stream alluvium (early? Pleistocene)**—Fluvial deposits along Alamo Creek consist of slightly cobbly pebble gravel, pebble gravel, and pebbly coarse sand, and minor amounts of slightly pebbly very fine to medium sand and very fine to fine sand. Unit Qgo1 forms several small gravelly remnants near the northeast corner of the map area. Pebbles and small cobbles are commonly subangular to well rounded and consist of about 80 percent granite, 15 percent quartzite, 3 percent quartz, and 2 percent amphibolite. Some or much of the sand and gravel in unit Qgo1 probably was derived from the lower unit of the Tesuque Formation (unit Ttl). Unit Qgo1 may locally include gravelly lag deposits formed on and from gravelly deposits of unit Ttl. The top of unit Qgo1 is commonly about 40–50 m above the channel of Alamo Creek. Exposed thickness is 1.5–10 m

### Undivided Alluvial and Colluvial Deposits

Qfd **Fan alluvium and debris-flow deposits, undivided (Holocene to middle? Pleistocene)**—Deposits of bouldery cobble gravel, cobble gravel, pebble gravel, and pebbly sand in lenses and crudely stratified layers form colluvial aprons and fan-shaped landforms near the western boundary of the map area. Clasts are commonly angular and subangular and consist of rocks derived chiefly from basaltic and andesitic lava flows as well as minor amounts of subangular to rounded granite and quartzite eroded from units Tbta and Ttu. Basaltic and andesitic boulders deposited by debris flows are commonly 0.5–1.5 m in intermediate diameter. Sediments of unit Qfd were deposited by streams and debris flows. Exposed thickness is about 2–7 m; possibly as much as 15 m thick

### Colluvial Deposits

Qc **Colluvial deposits, undivided (Holocene to middle? Pleistocene)**—Deposits of non-sorted and non-stratified, mostly matrix-supported, sandy sediment and rock debris on steep slopes. Unit overlies unit Ttu below lava flows near the western boundary of the map area, and locally overlies unit Ttl near the northeast and southwest corners of the map area. Deposits range from sand and pebbly sand to bouldery rubble that has a sandy matrix. Bouldery deposits below lava flows armor and protect the underlying sediments from erosion. Unit Qc includes debris-slide, soil-creep, block-stream, debris-flow, and rock-fall deposits, as defined by Varnes (1978) and Cruden and Varnes (1996). Unit Qc may be susceptible to continued movement or reactivation due to natural and human-induced processes. Some of the basaltic blocks in unit Qc are as much as 3 m in intermediate diameter, whereas some of the sand in the unit probably was deposited as sheetwash and debris flows. Maximum thickness possibly 15 m

Qdy **Younger debris-flow deposits (Holocene and late Pleistocene?)**—Three lobate masses of bouldery basaltic debris deposited by sediment-charged flows near the northwest corner of the map area. Flow fronts are about 0.5–3 m high. Deposits are non-sorted or very poorly sorted and crudely stratified pebbles to boulders probably in a sandy matrix. Clasts are chiefly of basaltic composition, randomly oriented, and commonly as large as 1 m in intermediate diameter. They are derived chiefly from the upper unit of the basalt of Cañada Ancha (unit Tbu). Debris flows formed on or near steep slopes below basaltic lava flows and flowed down narrow washes. Unit Qdy contains minor stream-flow deposits, probably contains minor hyperconcentrated-flow deposits, and locally may contain rock-fall deposits at the base of steep slopes. Low-lying areas near the western boundary of the map area that are adjacent to stream channels in steep washes below cliffs are prone to periodic stream flooding and debris-flow deposition. The top of unit Qdy is less than about 6 m above the channels of east-flowing intermittent streams. Thickness probably about 0.5–5 m

Qdo **Older debris-flow deposits (late? and middle? Pleistocene)**—Three lobate masses of bouldery basaltic debris deposited by sediment-charged flows near the northwest corner of the map area. Deposits are non-sorted or very poorly sorted and crudely stratified pebbles to boulders probably in a sandy matrix. Clasts are chiefly of basaltic composition, randomly oriented, and as large as about 3 m in intermediate diameter. They are derived chiefly from the upper unit of the basalt of Cañada Ancha (unit Tbu). Unit Qdo probably contains minor stream-flow and hyperconcentrated-flow deposits and is locally mantled by thin sheetwash deposits (unit Qsw). The top of unit Qdo is about 13–27 m above the channel of an east-flowing intermittent stream. Thickness probably about 2–5 m

## LAVA FLOWS AND RELATED DEPOSITS OF THE CERROS DEL RIO VOLCANIC FIELD

The Cerros del Rio volcanic field is a predominantly basaltic to andesitic volcanic plateau along the southeast flank of the Jemez Mountains (fig. 1) of northern New Mexico. Lavas and related pyroclastic deposits of this field are locally exposed over 700 $km^2$ and reflect eruption of at least 120 $km^3$ of rift-related mafic magma, mainly between 2.7 and 1.1 Ma. Most of the lava flows are of Pliocene age and predate large-volume silicic caldera eruptions in the Jemez volcanic field; however, late-stage eruptions from the Cerros del Rio volcanic field postdate eruption of the Tshirege Member (1.2 Ma; Valles caldera) of the Bandelier Tuff in the Jemez volcanic field. Most of the eruptive centers in the Cerros del Rio volcanic field are central-vent volcanoes ranging from low-relief shield centers to remnants of steep-sided, breached cinder cones. These lavas have from 49 to 64 weight percent $SiO_2$ and exhibit a strong correlation between landform and whole-rock chemistry. Low-silica, subalkaline basaltic lavas erupted from broad shield volcanoes and formed thin (< 3–4 m) low-viscosity flows that traveled far; conversely, transitional to mildly alkaline basalts and basaltic andesites formed thick (as much as 30 m) discontinuous lavas flows that erupted from high-relief, steep-sided, dissected vents. Dacitic lavas are related to late-stage dome growth and eruption of thick (as much as 50 m), even more viscous blocky lava flows that issued from one well-defined vent area at Tetilla Peak about 8 km west-southwest of the map area (Sawyer and others, 2002) and locally in tributary canyons of the Rio Grande northwest of the map area (Dethier, 1997).

Volcanic deposits of the Cerros del Rio volcanic field are divided into a three-fold classification representing early, middle, and late phases of eruption that persisted from about 2.7 to 1.1 Ma (Thompson and others, in press). These subdivisions are based on 1:24,000-scale geologic mapping, stratigraphic studies, $^{40}Ar/^{39}Ar$ geochronology, and paleomagnetic and aeromagnetic data. Some geochemical data were used to identify rock lithologies within the stratigraphic subdivisions for the entire field and were incorporated in unit descriptions, where available, for volcanic deposits in the map area. Preliminary results of new $^{40}Ar/^{39}Ar$ age determinations are presented in unit descriptions. Volcanic units in the map area are believed to represent products of monogentic eruptive centers of the middle volcanic phase (about 2.6–2.1 Ma) of Thompson and others (in press). In places, map units represent the consolidation of deposits of limited extent and are based on similar lithologic character, stratigraphic position, inferred age, aeromagnetic and paleomagnetic signatures, and aerial extent of similar or related deposits. Map-unit nomenclature for the volcanic deposits in part reflects that proposed by Aubele (1978)

QTba **Basaltic and andesitic alluvium (middle? Pleistocene to late Pliocene?)**—Deposits of poorly sorted to moderately well sorted, clast-supported, pebbly cobble gravel and minor amounts of cobble gravel and pink (7.5YR 7/4), loose to slightly indurated, very slightly pebbly, silty, very fine to medium sand. Clasts are commonly subangular and consist of basalt, andesite, and basaltic andesite. Unit QTba locally contains carbonate-cemented white pumice fragments that are likely derived from the Bandelier Tuff (1.6- and 1.2-Ma eruptions, Izett and Obradovich, 1994). Unit overlies the upper and middle units of basalt of Cañada Ancha (units Tbu and Tbm, respectively) and locally overlies basaltic tephra (unit Tbt) in the western part of the map area. Exposed thickness is 2–4.5 m; possibly as much as 5 m thick

Tbt **Basaltic tephra (upper Pliocene)**—Coarse sand- to small pebble-size (0.5–15 mm) grains and clasts of basaltic tephra in lenses and layers about 15 cm to 5 m thick produced by hydromagmatic explosions that largely predate, but are partly contemporaneous with, the eruption of several early phase (2.6–2.7 Ma) basaltic lavas of the Cerro del Rio volcanic field (Thompson and others, in press). Within the Cerros del Rio volcanic field, these deposits are thickest along the Rio Grande in the White Rock quadrangle (fig. 1) about 8 km northwest of the map area (Aubele, 1978; Dethier, 1997) and generally thin toward the southeast in the northwestern part of the map area. Surge-and-fall deposits are moderately sorted and contain subangular to subrounded volcanic lapilli composed of basalt and basaltic andesite, ash, and cinders. Most of the deposits are reworked from primary ashfall (tephra) deposits and contain various amounts of sand-size quartz, feldspar, and locally scattered granite and siltstone clasts less than about 4 cm in diameter. These non-volcanic minerals and rock fragments were derived from the underlying Santa Fe Group. Some of the thicker beds of basaltic tephra are horizontally to subhorizontally bedded and moderately well sorted, and contain one or more upward-fining sequences. Poorly to well developed reverse grading is present locally. Basaltic tephra is black (2.5Y 2/0), but some grains are altered and are tan (10YR hue). Thickness is highly variable; typically 1–4 m, but locally as much as 12 m thick

Tbta **Basaltic tephra and Ancha Formation, undivided (upper Pliocene)**—Deposits of basaltic tephra (unit Tbt) about 15 cm to 5 m thick interstratified with sand, pebbly sand, and poorly sorted basaltic tephra-bearing sandstone of the Ancha Formation (unit QTa) about 1 cm to 4 m thick. Sediment in some of the basaltic tephra-bearing sandstone may have been deposited as hyperconcentrated flows. Unit underlies the lower and upper units of basalt of Arroyo Calabasas (units Tbcl and Tbcu, respectively), and the lower, middle, and upper units of basalt of Cañada Ancha (units Tbl, Tbm, and Tbu, respectively) near the western boundary of the map area. A thin (45 cm), buried soil formed in sandy sediment of the Ancha Formation (unit QTa) is locally exposed beneath a bed of basaltic tephra about 60 cm thick that is overlain by a thick lava flow (Tbm). The basaltic tephra and the underlying buried soil were baked by heat from the lava flow. The soil consists of a Btb horizon 10–25 cm thick that has well-expressed prismatic structure and light-red (2.5YR 6/6) clay films on ped faces. The underlying sandy Bkb horizon is 20–35 cm thick and contains tabular nodules as large as 8 x 10 x 18 cm at the base of the soil horizon that are well indurated by calcium carbonate. The calcium carbonate in these nodules and in the overlying basaltic tephra and the underlying sandy sediment may have precipitated from meteoric water percolating through fractures in the overlying lava flow. Maximum exposed thickness is about 34 m

Tcp **Andesite of Cerro Portillo (upper Pliocene)**—Medium-gray lava flows of Cerro Portillo volcano exposed on the western margin of the map area. Massive, blocky andesite lava flows (60 weight percent $SiO_2$, 7 weight percent $Na_2O+K_2O$, and <1 weight percent $TiO_2$) erupted from concealed vents west of the map area (fig. 1). On the adjacent Montoso Peak quadrangle (fig. 1) on the west side of the map area, these lava flows form broad surfaces on lava-flow sequences as much as 100 m thick. Lava flows contain ubiquitous phenocrysts of hornblende, plagioclase, clinopyroxene, Fe-Ti oxides, and minor olivine. Resorbed plagioclase xenocrysts are commonly associated with glomerocrysts of altered pyroxene. Inferred age of less than 2.3 Ma is based on age of unit Tbcu (2.3–2.4 Ma), which underlies unit Tcp. Exposed thickness in map area is 30 m

**Basalt of Cañada Ancha (upper Pliocene)**—Medium- to dark-gray lava flows exposed along the western margin of Cañada Ancha in the northwestern part of the map area. Comprises three informal map units produced by discrete eruptive events from unknown source vents presumed to underlie younger deposits west of the map area. The basalt of Cañada Ancha is overlain by the andesite of Ortiz Mountain (2.32 Ma) about 2 km west of the map area (Thompson and others, in press) and is inferred to be approximately contemporaneous with the basalt of Arroyo Calabasas

Tbu **Upper unit**—Basalt to basaltic andesite lava flows that cap an eastward-sloping surface on the west side of Cañada Ancha. Lava flows contain moderately abundant, equant olivine phenocrysts (1–2 mm in diameter), sparse clinopyroxene phenocrysts, and ubiquitous resorbed plagioclase xenocrysts (1–3 mm in diameter). Lava flows are lobate and discontinuous, and vary in thickness from 1.5 to 5 m. Flows have reversed magnetic polarity (M.R. Hudson, U.S. Geological Survey, written commun., 2004). Maximum exposed thickness is 8 m

Tbm **Middle unit**—Basalt to basaltic andesite lava flows that contain abundant olivine phenocrysts in a dense holocrystalline groundmass. Flows are widespread and continuous, locally thicker in areas where they filled topographic lows such as valleys or stream channels. Individual flows are as much as 12 m thick. Most lava flows have well-developed rubbly bases and highly elongated vesicle partings. Flows have reversed magnetic polarity (M.R. Hudson, written commun., 2004) and a preliminary whole-rock $^{40}Ar/^{39}Ar$ age of about 2.3–2.4 Ma (D.P. Miggins, U.S. Geological Survey, written commun., 2004). Maximum exposed thickness is 25 m

Tbl **Lower unit**—Basaltic lava flows near the southern end of Cañada Ancha are thin (1.5–2 m) and vesicular, and contain rounded to subrounded vesicles and sparse, small (< 1 mm) olivine phenocrysts in a fine-grained holocrystalline groundmass. Flows have reversed magnetic polarity (M.R. Hudson, written commun., 2004). Maximum exposed thickness is 10 m

**Basalt of Arroyo Calabasas (upper Pliocene)**—Medium- to dark-gray lava flows exposed along Arroyo Calabasas and three tributary arroyos in the southwestern part of the map area. Comprises two informal map units that represent discrete eruptive events from unknown vent areas, separated in time by as much as 350,000 yrs based on preliminary $^{40}Ar/^{39}Ar$ age determinations (D.P. Miggins, written commun., 2004), paleomagnetic polarity (M.R. Hudson, written commun., 2004), and regional aeromagnetic signature (Grauch and Bankey, 2003). Both map units are restricted to exposures along the eastern rim of the Caja del Rio Plateau in the western part of the map area and are inferred to underlie sheetwash deposits (unit Qsw) to the north and west. The upper and lower map units are exposed and juxtaposed along a prominent down-to-the-west normal fault in the southwestern part of the map area

Tbcu **Upper unit**—Basalt to basaltic andesite (50 weight percent $SiO_2$, 6.3 weight percent $Na_2O+K_2O$, and 1.5 weight percent $TiO_2$) lava flows that contain olivine and clinopyroxene phenocrysts in a fine-grained holocrystalline groundmass. Lava flows typically form discontinuous, overlapping lobes 2–3 m thick. Flows have reversed magnetic polarity and a preliminary whole-rock $^{40}Ar/^{39}Ar$ age of 2.3–2.4 Ma. Source areas are unknown, but inferred flow directions and aeromagnetic anomalies suggest a buried vent about 0.5–1 km north and west of the eastern rim of the Caja del Rio Plateau. Maximum exposed thickness is 12 m

Tbcl **Lower unit**—Basalt to basaltic andesite that contains sparse olivine phenocrysts in a fine-grained holocrystalline groundmass. Lava flows are typically discontinuous and thin, typically less than 1.5–2 m thick. In most places the map unit represents flow lobes of a single flow or eruptive event. Although the source area is unknown, normal magnetic polarity suggests a tentative correlation with late stage eruptions of the 2.68-Ma Basalt of Tsinat Mesa exposed about 1 km to the southwest on the Tetilla Peak quadrangle (Sawyer and others, 2002) (fig. 1). Maximum exposed thickness is 12 m

## SANTA FE GROUP

Sediments and minor sedimentary rocks of the Santa Fe Group (units QTa, Ttu, and Ttl) are locally well exposed in small stream cuts in the northern part of the map area. Spiegel and Baldwin (1963) and Koning and others (2002) measured stratigraphic sections of lava flows and underlying Santa Fe Group along the west side of Cañada Ancha, near the northwest corner of the map area. Aeromagnetic (Grauch and Bankey, 2003, plate 2) and drill-hole data (Myer and Smith, 2004) provide constraints on the thickness of Santa Fe Group in the map area. Total thickness of the Santa Fe Group (mostly Tesuque Formation) increases across the map area from about 750 m near the southeast corner, to 1,210 m at Yates La Mesa No. 2 drill hole near the center, to about 2,100 m near the northwest corner. The Santa Fe Group is about 3,000 m thick near the southwest corner of the Horcado Ranch quadrangle (Koning and Maldonado, 2001, cross section A-A′). Sediments of the Santa Fe Group thicken northwestward off the flank of a subsurface Proterozoic bedrock high (Grauch and Bankey, 2003; Johnson and others, 2004; Read and others, 2004; Koning and Maldonado, 2001). Saturated sediments and sedimentary rocks of the Santa Fe Group are a major source of water resources in the greater Santa Fe area (see, for example, Lewis and West, 1995; Johnson and Frost, 2004).

Sediments in unit QTa were deposited on an alluvial piedmont slope chiefly by streams flowing from the Sangre de Cristo Mountains. These streams were graded to the ancestral Rio Grande (Smith and others, 2001) prior to its post 2.6-Ma phase of downcutting and incision. As shown in figure 3, unit QTa is equivalent to the upper part of the Ancha Formation as mapped by Spiegel and Baldwin (1963) in the Agua Fria quadrangle, the Ancha Formation and the Tuerto Gravel as mapped by Koning and Hallett (2000) in the Turquoise Hill quadrangle, and in part to the Ancha Formation of Pliocene age in the Horcado Ranch quadrangle (Koning and Maldonado, 2001). Deposition of unit QTa corresponds in part to an episode of wetter than present-day climate conducive to the formation and maintenance of large, long-lived lakes in the Western United States between about 3.5 and 2.5 Ma (Forester, 1991). The oldest deposits of unit QTa may be about 3.5 m.y. old (Koning and others, 2002) or possibly as old as 5 m.y. (Gonzales and Dethier, 1991, fig. 3). These deposits may predate a significant climatic transition to cooler climate marked by periodic glaciation from 3.5 to 3.0 Ma (Pillans and Naish, 2004).

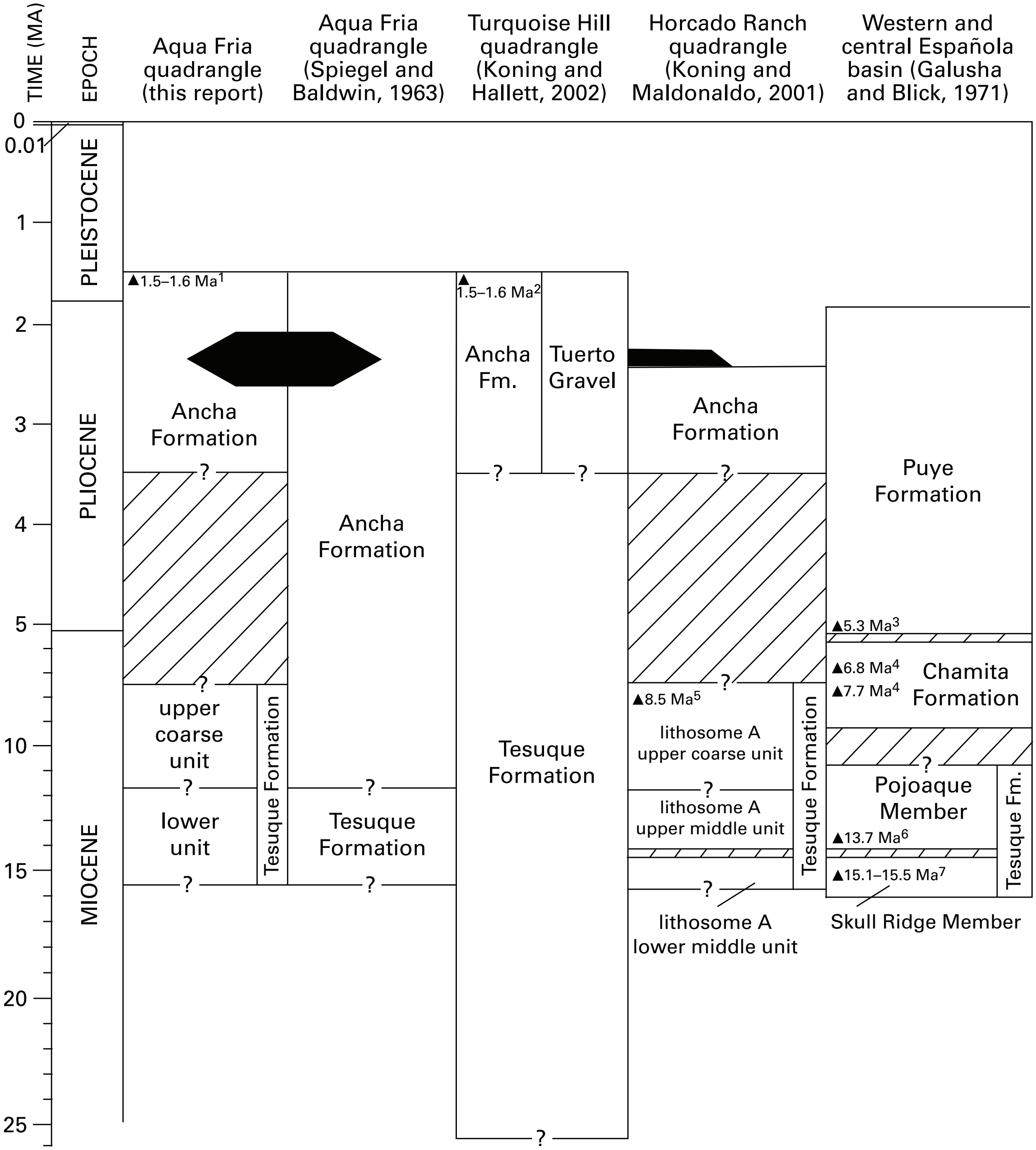


**Figure 3.** Generalized stratigraphic relations for sediments and rocks of the Santa Fe Group in and near the Agua Fria quadrangle. Younger deposits are not shown. The stratigraphic relations of some units are based on those of Koning and others (2002, fig. 5) and Tedford and Barghoorn (1993; fig. 2). Numbers next to triangles indicate ages of dated tephra. Sources of tephra ages are indicated by superscripts: [1], this report; [2], Koning and others (2002); [3], WoldeGabriel and others (2001); [4], McIntosh and Quade (1995); [5], Koning and Maldonado (2001) and Koning and others (2002); [6], Izett and Obradovich (2001); [7], McIntosh and Quade (1995) and Izett and Obradovich (2001). Black polygons are basaltic lava flows of the Cerros del Rio volcanic field. Age constraints for these flows are from Thompson and others (2005). Diagonal lines indicate missing section and associated unconformity.

Spiegel and Baldwin (1963) mapped deposits of our unit Ttu as part of the Ancha Formation and deposits of our unit Ttl as Tesuque Formation (fig. 3). In this report, unit Ttu is assigned to the Tesuque Formation because it is similar in character to the upper (coarser) part of the Pojoaque Member of the Tesuque Formation described by Galusha and Blick (1971) near Pojoaque. In the map area, units Ttu and Ttl are mapped as informal units, rather than as members (such as the Pojoaque and Skull Ridge) of the Tesuque Formation, because the contact between these members is difficult to identify and map south of the northern boundary of the Horcado Ranch quadrangle (Koning and Maldonado, 2001). Because of facies changes, correlation of our map units with stratigraphic units of Galusha and Blick (1971) in the central part of the Española basin are less certain than correlations with map units of Koning and Maldonado (2001) and Koning and Hallett (2000) in the adjacent Horcado Ranch and Turquoise Hill quadrangles (figs. 1 and 3).

In this report, units Ttu and Ttl are distinguished chiefly on the basis of differences in grain size and clast composition. Unit Ttu contains more granite and is coarser (contains more deposits of pebbly sand and pebble gravel) than the upper part of the lower unit (Ttl). Sediments in both of these units were deposited chiefly by streams that flowed from the Sangre de Cristo Mountains, probably on an alluvial slope underlain by a hanging-wall ramp (Cavazza, 1986, 1989) in the west-tilted Española half graben (Smith, 2000). The ramp probably sloped toward a down-to-the-east fault west of the Pajarito fault (Smith and others, 2001), west of the map area (fig. 1).

Unit Ttu (fig. 3) is lithologic and temporally equivalent to lithosome A, coarse upper unit of the Tesuque Formation (Koning and Maldonado, 2001) and to the coarse upper part of the Pojoaque Member of the Tesuque Formation (Galusha and Blick, 1971), and is temporally equivalent in part to the lower part of the Chamita Formation (Galusha and Blick, 1971). Pumice from near the exposed top of lithosome A, near the southwest corner of the Horcado Ranch quadrangle, yielded an $^{40}Ar/^{39}Ar$ age of 8.48±0.14 Ma (Koning and Maldonado, 2001; Koning and others, 2002). Some of the pebbly sand and gravel in unit Ttu may be due in part to major faulting and deepening of the Española basin at about 9 Ma (Aldrich and Dethier, 1990). Unit Ttu may represent the last phase of closed-basin deposition prior to through-flowing connection of the Española and Santo Domingo basins by the ancestral Rio Grande by 7 Ma (Smith and others, 2001).

The upper part of unit Ttl (fig. 3) is equivalent to lithosome A, upper middle unit of the Tesuque Formation (Koning and Maldonado, 2001), and in part to the finer lower part of the Pojoaque Member of the Tesuque Formation (Galusha and Blick, 1971). The lower part of unit Ttl is equivalent to lithosome A, lower middle unit of Tesuque Formation (Koning and Maldonado, 2001), and in part to the upper part of the Skull Ridge Member of the Tesuque Formation (Galusha and Blick, 1971). The lower middle part of the Pojoaque Member at or near its type section, about 17 km north of the map area, contains a thin (≤0.2 m) tephra that yielded a weighted-mean $^{40}Ar/^{39}Ar$ age of 13.7±0.18 Ma (Izett and Obradovich, 2001). The Skull Ridge Member of the Tesuque Formation is considered to be about 14.5–16 m.y. old based on its early Barstovian fossil assemblage (Tedford and Barghoorn, 1993), paleomagnetic studies (Barghoorn, 1981), and $^{40}Ar/^{39}Ar$ ages (15.1–15.5 Ma) of tephra (Izett and Obradovich, 2001; McIntosh and Quade, 1995). The Santa Fe Group is cut by faults that are locally, but poorly, exposed in the northern and eastern parts of the map area. Most of these faults strike north-northeast, dip either west or east, and exhibit normal or normal-oblique slip slickenlines. A few faults, however, display dominantly sinistral or dextral strike-slip striae (fig. 4). Although most mapped faults in the area are within unit Ttl (middle? Miocene), some faults in the north-central part of the map area cut sediments of unit QTa that may possibly be as young as early Pleistocene (~1.5–1.8 Ma)

QTa **Ancha Formation (lower Pleistocene and Pliocene)**—Comprises mainly sandy and gravelly stream deposits beneath west- to southwest-sloping geomorphic surfaces in and near the map area. The Ancha underlies the southwest- and locally west-sloping Divide geomorphic surface (Spiegel and Baldwin, 1963) north of the lower reaches of Arroyo de los Frijoles and Arroyo de las Trampas in the northern two-thirds of the map area. These deposits consist mostly of slightly cobbly pebble gravel, sandy pebble gravel, slightly pebbly very fine to medium and very fine to very coarse sand, and locally basaltic tephra-bearing sands and sandstone (table 3). Deposits are loose to weakly consolidated and form beds about 1–4 m thick and lenses about 3–50 cm thick. Bedding is tabular and indistinct. Gravelly deposits locally fill shallow channels about 1–1.5 m thick. The preceding deposits are commonly brown to reddish yellow (table 4).

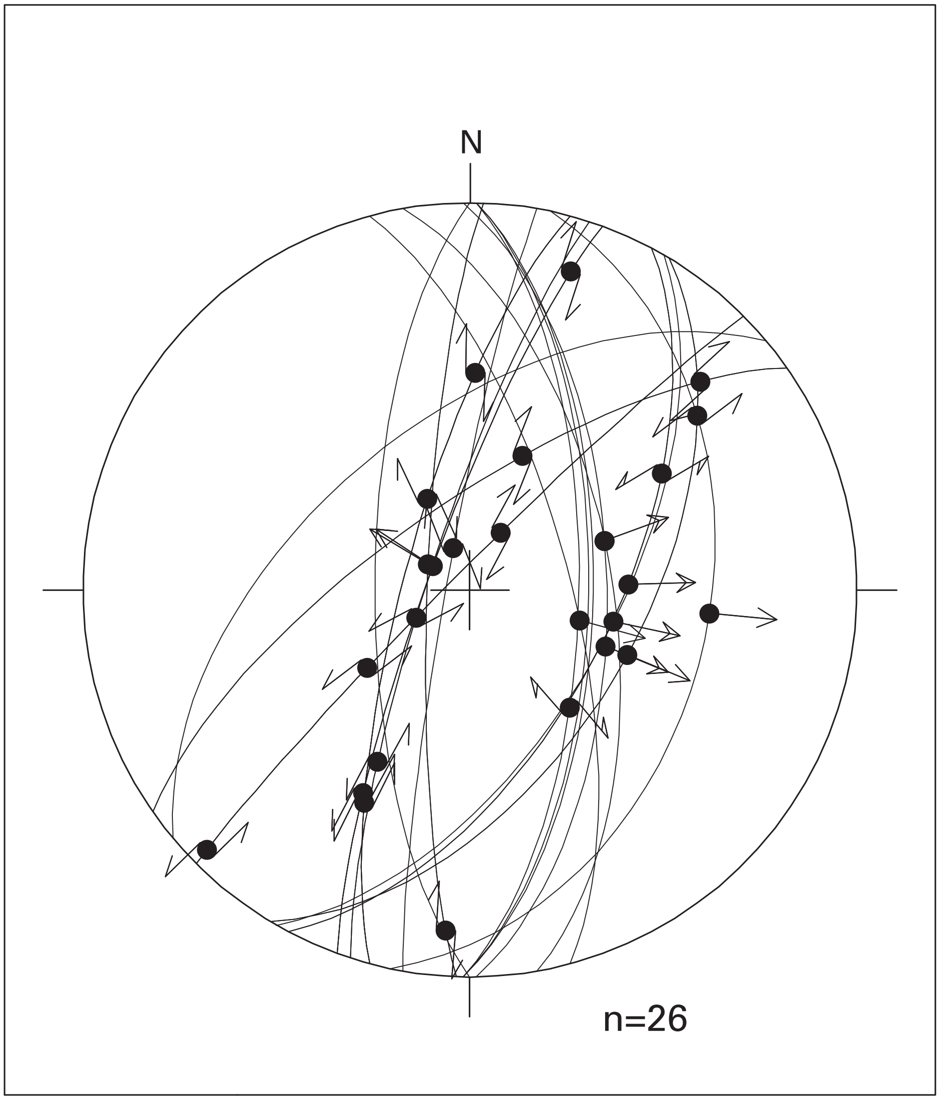


**Figure 4.** Equal-area, lower hemisphere stereographic plot of fault-slip data measured at exposures of mapped and unmapped (small-scale) faults within the map area. Locations of measurements made on mapped faults are shown on geologic map.

Buried soils are locally preserved in the upper part of the unit, suggesting multiple episodes of little or no deposition, surface stability, and soil development on the order of a few thousand to several tens of thousands of years (Machette and others, 1997; Nelson and Shroba, 1998; Birkeland and others, 2003). These soils have calcic (Btkb, Bkb, and Kb) horizons about 15–60 cm thick that display stage I to III carbonate morphology. Locally, these horizons are overlain by thin, eroded Btb horizons.

In the northwestern part of the map area, the upper 30 m or more of unit QTa contains thin beds and lenses of sand and sandstone that contain varying amounts of basaltic tephra. This tephra is probably equivalent in age to the basaltic tephra in units Tbt and Tbta (≲2.6–2.7 Ma). Sandy sediment rich in basaltic tephra is interstratified with granite-rich sandy sediment that contains minor to trace amounts of basaltic tephra. Sandstone contains minor to moderate amounts of basaltic tephra about 0.5–10 mm in diameter. The sandstone is weakly indurated and contains abundant quartz and feldspar ultimately derived from Proterozoic rocks in the Sangre de Cristo Mountains (fig. 1). It commonly ranges in size from very fine to medium sand to slightly pebbly very fine to very coarse sand, is commonly light brownish gray to pink (table 4), and forms lenses and small channels about 35 cm to 3 m thick. Pebbles and small cobbles are commonly

**Table 3.** Particle sizes of unconsolidated sediments and rocks of the Santa Fe Group.

[QTa, Ancha Formation; Ttu, upper coarse unit of the Tesuque Formation; Ttl, lower unit of the Tesuque Formation. Relative abundance: D, dominant; S-M, subordinate to minor; M, minor; --, not observed]

| Sediments and rocks | QTa | Ttu | Ttl |
|---|---|---|---|
| Slight cobbly pebble gravel | D | D | S-M |
| Pebble gravel | D | D | -- |
| Sandy pebble gravel | D | -- | -- |
| Pebbly sand | D | -- | -- |
| Slightly pebbly, very fine to medium sand | D | -- | -- |
| Slightly pebbly, medium to very coarse sand | D | D | S-M |
| Slightly silty to silty, very fine to medium sand | M | D | S-M |
| Non-silty to silty, very fine to very fine sand | -- | M | D |
| Sandy silt | M | M | -- |
| Clayey silt | -- | M | S-M |
| Silty clay | -- | -- | S-M |
| Sandy pebble conglomerate | -- | S | D |
| Non-pebbly to slightly pebbly sandstone | M | S | D |
| Siltstone | -- | -- | S-M |
| Claystone | -- | -- | S-M |

**Table 4.** Dry Munsell colors of unconsolidated sediments and sandstone of the Santa Fe Group.

[QTa, Ancha Formation; Ttu, upper coarse unit of the Tesuque Formation; Ttl, lower unit of the Tesuque Formation. --, not observed; X, color of matrix; X, color of clay films on sand grains]

| Color | | QTa | Ttu | Ttl |
|---|---|---|---|---|
| Light brownish gray | 10YR 6/2 | X | -- | -- |
| Pale brown | 10YR 6/3 | X | -- | -- |
| Pinkish gray | 7.5YR 6/2 | X | -- | -- |
| Brown | 7.5YR 5/4 | X | -- | -- |
| Light brown | 7.5YR 6/4 | X | X | X |
| Pink | 7.5YR 7/4 | X | X | X |
| Reddish yellow | 7.5YR 6/6 | X | -- | -- |
| Reddish yellow | 7.5YR 7/6 | -- | -- | X |
| Light reddish brown | 5YR 6/4 | -- | X | X |
| Pink | 5YR 7/4 | X | X | -- |
| Reddish yellow | 5YR 6/6 | X | -- | X |
| Red | 2.5YR 5/6 | -- | X | -- |

subangular to subrounded and consist of about 90–95 percent granite, 5–8 percent amphibolite, 0–1 percent quartz and chert, and 0–1 percent quartzite.

Fluvial deposits of the ancestral Santa Fe River underlie the southwest-sloping Airport geomorphic surface (Spiegel and Baldwin, 1963) north of Arroyo de los Chamisos and south of the lower reaches of Arroyo de los Frijoles and Arroyo de las Trampas in the southern one-third of the map area. These fluvial sediments commonly consist of slightly cobbly pebble gravel, pebble gravel, pebbly sand, and slightly pebbly medium to very coarse sand (table 3). They form beds about 1–3 m thick and lenses about 5–80 cm thick. Gravelly deposits commonly fill channels and commonly contain lenses of sand and pebbly sand. Sandy deposits commonly contain lenses of pebbly sand and sandy pebble gravel and are commonly light brownish gray to pink (table 4). Pebbles and small cobbles deposited by the ancestral Santa Fe River commonly are subangular to subrounded and consist of about 95 percent granite, 4 percent amphibolite, and 1 percent quartz, chert, and quartzite. Thin-bedded alluvial deposits underlie a southwest-sloping, slightly eroded geomorphic surface about 6 m above the adjacent Airport surface. These deposits are locally exposed south of Arroyo de los Chamisos near the southeast corner of the map area. They are composed of slightly cobbly pebble gravel, sandy pebble gravel, and slightly silty very fine to medium sand (table 3). The gravelly deposits contain abundant granules, accumulated in channels about 1–1.5 m thick, and commonly are inset into deposits of slightly pebbly slightly silty sand that contains thin lenses of pebble gravel. Sandy deposits have a 7.5YR hue and are commonly pink and reddish yellow (table 4). Pebbles and small cobbles commonly consist of about 90–95 percent granite, 5–8 percent amphibolite, and 0–2 percent quartz, chert, and quartzite. Thin (3–6 m) deposits of unit QTa underlie west-sloping remnants of the Divide surface that project to the concealed top of the Ancha Formation beneath lava flows and pyroclastic deposits of the Cerros del Rio volcanic field near the northwest corner of the map area.

Unit QTa ranges in thickness from about 60 m near the southern boundary of the map area (Koning and Hallett, 2000, cross section A-A′) to about 3–6 m in the northern part of the map area. Base of unit QTa is not exposed in the southern part of the map area; total thickness is about 3–60 m

Ttu **Upper coarse unit of the Tesuque Formation (upper and middle? Miocene)**—Mostly slightly cobbly pebble gravel, pebble gravel, slightly pebbly sand, and slightly silty to silty sand (table 3) in lenses and subordinate tabular beds about 30–100 cm thick. Sediments are unconsolidated to weakly consolidated; sandstone and conglomerate are cemented by fine-grained (micritic) calcium carbonate and locally by sparry calcite. Sand matrix is commonly light reddish brown and pink, but locally is light brown, pink, and red (table 4) where thin clay films and clay bridges coat sand grains. Gravel deposits are poorly sorted and clast supported. Deposits of sandy pebble gravel are moderately well sorted and matrix supported. Some of the sandy deposits are massive and matrix supported and may have been deposited by debris flows or hyperconcentrated flows. Clasts are commonly angular to subrounded and commonly consist of pebbles and less than 20 percent cobbles. Composition of these clasts is commonly about 95 percent granite, 3–4 percent metamorphic rocks, 1 percent quartz, and 0–1 percent quartzite. Sand is very fine to very coarse and consists chiefly of pink potassium feldspar and quartz. Unit Ttu contains pumice-rich lenses of unknown age that are exposed at two localities (sites AF-152 and AF-153) along the unpaved road next to the power line (SW1/4 sec. 3, T. 17 N., R. 8 E.) and in the adjacent Horcado Ranch quadrangle (Koning and Maldonado, 2001). Paleocurrent directions of channel features about 600 m northeast of the breached dam that retained Portales Pond in the northwestern part of the map area are about 275°–315° azimuth and indicate transport directions toward the west and northwest (Johnson and others, 2004). Base of unit is poorly exposed in map area. Thickness is possibly as much as 270 m

Ttl **Lower unit of the Tesuque Formation (middle? Miocene)**—Mostly non-silty to silty, very fine to fine sand, sandstone, and sandy pebble conglomerate in lenses and tabular beds about 10 cm to 4 m thick (table 3). Sandy and gravelly deposits are commonly 65 cm to 5 m thick; deposits rich in silt and clay are commonly 2–45 cm thick. In the northern part of the map area, the upper part of unit Ttl contains more weakly consolidated sandy deposits than the lower part. Cobbly conglomerate and thin, tabular, fine-over-coarse depositional couplets (probably sheet-flood deposits) are rare. Sandstone and conglomerate are weakly indurated to well cemented by fine-grained calcium carbonate and locally by calcite, and form ledges about 5 cm to 2 m thick. Sandstone beds and lenses commonly have fluvial cross beds. Sand matrix is commonly light brown, pink, and light reddish brown, but locally is reddish yellow where thin clay films and clay bridges coat sand grains (table 4). Deposits of slightly cobbly pebble gravel and sandy pebble conglomerate are poorly sorted and clast supported. Clasts are commonly subangular to subrounded pebbles and a minor amount of cobbles. Pebbles and small cobbles in the equivalent part of the Tesuque Formation in the adjacent Horcado Ranch quadrangle comprise about 25–90 percent granite, 3–35 percent quartzite, 3–35 percent Paleozoic sedimentary rocks, 4–5 percent amphibolite, and 0–1 percent chert (Koning and Maldonado, 2001). Lenses of slightly cobbly pebble gravel commonly are rich in quartzite clasts. Sand commonly is very fine to fine and medium to very coarse. Sandstone and very fine to fine (eolian?) sand commonly are rich in quartz. Other sandy sediments consist chiefly of pink potassium feldspar and quartz. Paleocurrent directions of channel features in the northern part of the map area are about 190°–350° azimuth and have an average transport direction toward the southwest (Johnson and others, 2004; and measurements by Shroba). Base of unit is not exposed in map area. Thickness is possibly about 400–600 m

**Silica-cemented rocks**—Three small resistant outcrops mapped as unit Ttl, near the northeast corner of the map area (shown on map by triangular symbol), consist of sandstone and conglomerate that are well cemented by secondary silica. Some of these rocks are red (7.5R 5/6), probably due to the alteration of iron-bearing minerals to hematite by fluids moving along or near the adjacent east-dipping fault. The cemented rocks were previously mapped as Paleozoic quartzite and conglomeratic quartzite (Spiegel and Baldwin, 1963), which is structurally problematic. The lack of intense fracturing and slickensides in these silica-cemented rocks suggests that the silica cementation may postdate faulting. There are several small outcrops of similar rocks near the southeast corner of the adjacent Horcado Ranch quadrangle (Borton, 1979; Koning and Maldonado, 2001). The outcrops within the map area commonly are composed of loose angular blocks as much as 3 m in diameter. Rocks on the ground surface near the outcrops are of similar composition. Silica-cemented sedimentary rocks are similar in grain size and bedding features to adjacent unaltered, weakly consolidated sediment of unit Ttl. The main difference between the cemented rocks and the adjacent sediment is that the rocks are richer in quartz and quartzite clasts and contain little or no granite or sedimentary rocks. Pebbles and small cobbles in the silica-cemented conglomerate commonly consist of about 85–90 percent quartzite and quartz, 10 percent chert, and trace to 5 percent schist and amphibolite (Koning and Maldonado, 2001). The close proximity of these outcrops and the associated blocks to a fault suggests that beds of relatively high permeability adjacent to the fault were preferentially cemented by silica precipitated from fluids moving along the west side of the fault (Koning and Maldonado, 2001)

# Chronologic, Stratigraphic, and Geomorphic Relationships of the Ancha Formation In and Near the Agua Fria Quadrangle

New $^{40}Ar/^{39}Ar$ ages and chemical correlation of reworked rhyolitic pumice on and near the top of the Ancha Formation (unit QTa) help to constrain the age of the uppermost part of the Ancha and thus provide maximum limits on the ages of the overlying Divide and Airport geomorphic surfaces. The pumice was erupted during early Pleistocene time from the Toledo caldera in the Jemez volcanic field about 30 km northwest of the map area. The Toledo caldera occupied an area within the Valles caldera and the adjacent Toledo embayment (fig. 1) (Gardner and Goff, 1996). At site AF-135, a buried soil with Btkb and Bkb horizons is formed in silty sand at the top of unit QTa. About 1.2 m of stratified, pumice-rich stream alluvium overlies the buried soil. This alluvium is overlain by about 2.4 m of slightly pebbly sand (unit Qsw) that has a Bt horizon 70 cm thick. Sanidine crystals from pumice near the base of the pumice-rich alluvium yielded an $^{40}Ar/^{39}Ar$ plateau age of 1.53±0.04 Ma (D.P. Miggins, written commun., 2004). A bed of stream-deposited pumice greater than 25 cm thick and about 8 m below the top of unit QTa is exposed at site AF-194. Sanidine crystals from this (lower) pumice yielded an $^{40}Ar/^{39}Ar$ plateau age of 1.56±0.03 Ma (D.P. Miggins, written commun., 2004). Pumice-bearing sediment of unknown age is poorly exposed just below the Divide geomorphic surface on or in unit QTa at site AF-197. The $^{40}Ar/^{39}Ar$ ages of pumice at sites AF-135 and AF-194 suggest that they formed during an early eruption (1.5 Ma) of the Cerro Toledo Rhyolite (Spell and others, 1996).

Chemical correlation based on the content of CaO and FeO (A.M. Sarna-Wojcicki, written commun., 2004) suggest that the pumice at sites AF-135 and AF-194 are equivalent to the Guaje Pumice of the Otowi Member of the Bandelier Tuff, which has a date of 1.61 Ma (Izett and Obradovich, 1994). The age of the youngest deposits in unit QTa is also constrained by rhyolitic tephra beneath the upper 4–18 m of fluvial deposits of the ancestral Santa Fe River, which underlie the Airport geomorphic surface in the northern part of the Turquoise Hill quadrangle (Koning and Hallett, 2000), south of the map area. These tephra yielded $^{40}Ar/^{39}Ar$ ages of 1.63±0.02 Ma, 1.61±0.02 Ma, and 1.48±0.02 Ma (Koning and others, 2002).

Collectively, these $^{40}Ar/^{39}Ar$ ages and chemical correlations indicate that the uppermost part of unit QTa is about 1.5–1.6 Ma (early Pleistocene) and both the Divide and Airport geomorphic surfaces are of Pleistocene age and are younger than about 1.5–1.6 Ma. Tephra with an $^{40}Ar/^{39}Ar$ age of 1.25±0.06 Ma, interpreted to be within inset terrace deposits below and younger than unit QTa, suggests that these geomorphic surfaces formed prior to 1.25 Ma (Koning and others, 2002).

Stratigraphic and geomorphic relationships in and near the map area also provide insights on the depositional and erosional history of the Ancha Formation (unit QTa). Deposition of the Ancha predates, was contemporaneous with, and postdates deposition of basaltic tephra and lava flows of the Cerros del Rio volcanic field. Eruption of this volcanic field must have had a profound effect on regional and local patterns of stream deposition. Fluvial deposits of unit QTa underlie, are interbedded with, and overlie 2.6- to 2.7-Ma basalt flows near the northwest corner of the Turquoise Hill quadrangle (Koning and Hallett, 2000) and underlie and overlie younger (2.3–2.4 Ma) basalt flows (Tbcu and Tbcl) near the southwest corner of the map area. Basaltic tephra, produced by hydromagmatic explosions, mostly predates but is partly contemporaneous with the eruption of early-phase (2.6–2.7 Ma) basaltic lavas of the Cerros del Rio volcanic field (Sawyer and others, 2002; Thompson and others, in press). The tephra of unit Tbt is interstratified with and underlies granite-rich deposits of unit QTa in the western part of the map area. Hydromagmatic explosions associated with the emplacement of basaltic magma suggest (1) the presence of high water table conditions, (2) that early-phase lavas buried a landscape of low relief that had experienced little prior stream incision (Cole and others, 2001; Bachman and Mehnert, 1978), and (3) little hydrologic or geomorphic influence due to deep incision near White Rock Canyon between about 2.5 and 3.7 Ma (Reneau and Dethier, 1996). Geologic and geomorphic relationships near the northwest corner of the Turquoise Hill quadrangle (Koning and Hallett, 2000) suggest about 10–15 m of incision of unit QTa by the ancestral Santa Fe River after 2.6–2.7 Ma. This incision may have begun by 2.5 Ma (Cole and others, 2001). Stream incision was followed by deposition of post-basalt fluvial deposits and other alluvial deposits (in and near the map area) that continued until slightly after the eruption and deposition of 1.5- to1.6-Ma rhyolitic pumice. The morphologic characteristics of buried soils in the upper part of unit QTa suggest multiple episodes of little or no deposition, which led to periods of surface stability and soil development on the order of a few thousand to several tens of thousands of years during the late Pliocene and the early part of the early Pleistocene. This same relationship (buried soils formed in basin-fill deposits of Pliocene and Pleistocene age) has been recognized by Koning and Hallett (2000) in the Tuerto Gravel just south of the map area and by Mack and others (1993) in the Camp Rice Formation in southern New Mexico. Some of the post-basalt stream incision may be related in part to (1) major down-to-the-west displacements on the La Bajada and San Francisco faults (fig. 1), (2) eastward tilting of the Santo Domingo basin, and (3) associated eastward migration of the Rio Grande (Dethier, 1999; Smith and others, 2001; Minor and others, in press).

## Stratigraphy of the Yates La Mesa No. 2 Drill Hole

One deep drill hole (Yates La Mesa No. 2) was drilled to evaluate potential petroleum resources in the Santa Fe area. Young Drilling Company completed the hole to a total depth of 7,710 ft (2,350 m) (Myer and Smith, 2004) near the center of the map area (SE1/4 sec. 24, T. 17 N., R. 8 E.). Interpretation of the gamma-ray log and cutting samples indicates that the drill hole started in and penetrated about 30 ft (9 m) of Ancha Formation, 3,936 ft (1,200 m) of Tesuque Formation, a 2,052 ft (625 m) interval of volcanic and volcaniclastic rocks, 1,516 ft (462 m) of Pennsylvanian sedimentary rocks, and bottomed in 176 ft (54 m) of Proterozoic granitic rock (Myer and Smith, 2004; D.A. Sawyer, oral commun., 2004). The upper 1,046 ft (318 m) of the volcanic interval consists of mafic rocks similar to the Cieneguilla Limburgite of Stearns (1953) (Myer and Smith, 2004), which was later mapped as the 25-Ma Cieneguilla Basanite by Koning and Hallett (2000). The lower 1,006 ft (307 m) of the interval resembles latitic lava flows and sedimentary deposits of the Oligocene Espinaso Formation (Myer and Smith, 2004).

Interpretation of the gamma-ray log for Yates La Mesa No. 2 (D.A. Sawyer, written commun., 2004) suggests that the Tesuque Formation comprises interstratified sand, mud (silt and clay), sandstone, siltstone, and mudstone. Sediments in the Tesuque at depths of 30–402 ft (9–123 m) and 3,108–3,760 ft (947–1,146 m) contain more sandy deposits than mud-rich deposits.

A seismic-refraction profile generated along a line about 2.4 km south of Yates La Mesa No. 2 imaged the base of the Tesuque Formation and the top of the underlying volcanic and volcaniclastic rocks at about 1.2 km. The profile suggests that the base of the Tesuque Formation slopes less than 1° northward toward Yates La Mesa No. 2 and less than 1° toward the northwest along the 6.4-km-long seismic line (Aldern, 1989, profile 1).

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