# Geologic Map of the Turquoise Hill Quadrangle, Santa Fe County, New Mexico.

By

**Daniel J. Koning and R. Bruce Hallett**

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**New Mexico Bureau of Geology and Mineral Resources**
***Open-file Digital Geologic Map OF-GM 41***

Scale 1:24,000

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

# GEOLOGIC MAP OF THE TURQUOISE HILL 7.5-MINUTE QUADRANGLE, SANTA FE COUNTY, NEW MEXICO

**By**

**Daniel J. Koning[1] and R. Bruce Hallett[2]**

**Revision: December, 2012**

*1 (danchikoning@yahoo.com).* Daniel J. Koning mapped and described late Cenozoic strata (including the Tesuque Formation, Ancha Formation, and Quaternary sediment deposits) and constructed the cross-sections.

2 Golder Associates Inc., (bruce_hallett@golder.com). R. Bruce Hallett described the basalt flows on the Caja del Rio Plateau and mapped and described the Espinaso Formation, Galisteo Formation, and Tertiary intrusive rocks.

# 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on this geologic quadrangle map are based on reconnaissance field geologic mapping, compilation of published and unpublished work, and photogeologic interpretation.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.

# DESCRIPTION OF MAP UNITS

Grain sizes follow the Udden-Wentworth scale for clastic sediments (Udden, 1914; Wentworth, 1922) and are based on field estimates. The term “clast(s)” refers to the grain size fraction greater than 2 mm in diameter. Gravel percentages are estimated by volume in the field. Sand is classified according to Pettijohn et al. (1987). Colors of unconsolidated sediment are based on visual comparison of dry samples to the Munsell Soil Color Charts (Munsell Color, 1994). Colors of the Tertiary intrusives and Paleogene sediment are based on visual comparison of samples with the Munsell Rock Color Chart (Munsell Color, 1991). To maintain consistency with recent mapping efforts in adjacent quadrangles, the classification of volcanic and plutonic rocks follows IUGS classification (Streckeisen, 1979) based on mineral composition in hand sample and thin section. Geochemical nomenclature equivalents, following the classification of Cox et al. (1979) are also provided. Major-element analyses were performed at the New Mexico Tech X-ray fluorescence (XFR) laboratory by Chris McKee.

Surficial units are only delineated on the map if estimated to be at least 1 m thick. The term “colluvium” is reserved for sediment interpreted to be mainly transported by gravitational processes (such as topple, creep, slumping) but unconfined surface flow is also involved to some extent. Sheetflood and sheetwash sediment is mainly transported by unconfined surface flow. Because of poor exposure, colluvium and sheetflood-sheetwash sediment are not mapped where overlying the Ancha Formation or Tuerto gravel except adjacent to the Tsinat Mesa basalt. Age assignments for surficial deposits are based chiefly on height above modern valley floors and the degree of soil development and should be considered as estimates. Soil horizon designations and descriptive terms follow those of the Soil Survey Staff (1992) and Birkeland et al. (1991). Stages of pedogenic calcium carbonate follow morphogenetic classification of Gile et al. (1966).

## QUATERNARY COLLUVIUM, SLOPEWASH, AND EOLIAN DEPOSITS

af

**artificial fill (present)** — Sand, silt, and clay reworked and deposited by man in conjunction with highway construction.

Qc

**Colluvium (modern or middle(?) Pleistocene to Holocene)** — Yellowish brown (10YR 5/4-6), brownish yellow (10YR 6/6), brown (10YR4-5/3), and olive brown (2.5Y 4/3), sandy gravel with various proportions of silt and clay. Color varies according to source rock type. Gravel clasts are generally angular to subangular and range in size from pebbles to boulders. Sediment is poorly sorted and commonly lacks bedding. Both clast- and matrix-supported. Soils developed on colluvium may possess calcic horizons with stage II to III carbonate morphology. Generally poorly consolidated but may be somewhat cohesive where calcium carbonate soil horizons have formed. Estimated to be 1-3 m thick.

**Qc**
**Map unit**

**Colluvium overlies an older map unit** (*i.e.*, **Ku**, **QTasr**, **QTbtf**, **QTbtf, QTbtt, Tc, Tsdh, Te, Tm,** and **Tmh**). The underlying unit is inferred by clasts within the colluvium and adjacent outcrops.

Qsw

**Sheetflood and slopewash deposits (Modern or Holocene)** — Yellowish brown (10YR 5/4) to light yellowish brown (10YR 6/4), pebbly and silty sand. Sand is very fine- to very coarse-grained and vaguely bedded. Sediment is poorly sorted and loose. The maximum observed soil development is marked by horizon(s) with stage I carbonate morphology. Very thin bedding and lack of cobbles and boulders characterize the sediment. Estimated to be 1-2 m thick.

Qsw
QTbtf

**Sheetwash overlies QTbtf**. The underlying unit is inferred by composition of sand grains within the sheetwash sediment and adjacent outcrops.

Qesd

**Eolian sand dunes (upper(?) Holocene)** — Light yellowish brown (10YR 6/4) to yellowish brown (10YR 5/4), silty very fine- to medium-grained sand. Sand is loose, moderately to well sorted, arkosic, and subrounded. Dune form is irregular, linear, or parabolic. Parabolic dunes generally occur around a scoured "blow-out." Exposures were not available to permit an examination of soils. The dunes are generally stabilized by grass or yucca. Native American pottery shards are found on top of some dunes. The dunes are generally 1 to 2 m tall.

# QUATERNARY ALLUVIAL DEPOSITS

Qam

**Stream alluvium (Modern)** — Generally light brown (7.5YR 6/4) to light yellowish brown (10YR 6/4), gravelly sand. Sand is mostly medium- to very coarse-grained and is poorly to moderately sorted, arkosic, and subangular to subrounded. Sediment is either massive or contains very thin to thin, lenticular or tabular beds. Gravel clasts are mostly pebbles with subordinate cobbles. There is generally very low to low vegetation density on active stream alluvium except for areas of high groundwater or perennial flow; in these areas, trees and shrubs can be dense. Sediment is loose and inferred to have been transported by water within the past 50 years.

Stream alluvium is locally divided into two subunits:

Qamg

**Stream alluvium in recent gullies (Modern)** — Stream alluvium is present within recently incised gullies or trenches up to 8 m deep. Alluvium is generally less than 1 m thick.

Qamf

**Stream alluvium at gully-mouths (Modern)** — Stream alluvium that generally occurs as a fan-shaped deposit (in plan view) at the mouth of a recently incised gully. The sediment is generally less than 2 m thick.

Qaf

**Arroyo-mouth-fan deposits (upper Pleistocene(?) to Holocene)** — Light yellowish brown (10YR 6/4), sandy gravel interbedded with silt and silty sand. Present at the mouths of tributary arroyos. Color and composition may vary according to changes in the parent material. Poorly to well sorted and unconsolidated. Sandy gravel is generally clast-supported and in lenticular, thin to very thin beds. There are generally more pebbles than cobbles. Gravel clasts are subangular to rounded. Sand is arkosic and subangular to subrounded. Silt or silty sand may be massive or tabular and thin to medium-bedded. The top 0.5-2.0 m of sediment exhibits weak soil development (stage I- to I carbonate morphology) and is probably Holocene in age, which is consistent with Dethier et al. (1988) and Pazzaglia (1989). Underlying this Holocene sediment is Pleistocene sediment whose top locally displays a buried soil whose calcic horizon(s) have up to stage III carbonate morphology. Probably interfingers with Qay except for the lowermost and uppermost part of the deposit.

Qay

**Younger alluvium (uppermost Pleistocene to Holocene)** — Commonly a light yellowish brown (10YR 6/4) to brown (10YR 5/3), silty-clayey sand to clay-silt interbedded with pebbly sand and sandy pebbles. Located in or near the bottom of valleys. Color and composition may vary according to lithology of upland drainages. Sand is very fine- to very coarse-grained, poorly to well sorted, arkosic, and subrounded to subangular. Gravel clasts are subrounded to subangular and mostly granitic in composition. The silty-clayey sand and clay-silt are generally massive to very thinly- or thinly- bedded. Gravelly sediment is generally present in very thin to thin, tabular or lenticular beds. Gravel commonly occupies less than 50% of the total sediment volume; larger drainages have more gravel than smaller drainages. The clay-silt has loose to hard consistence (probably increasing with clay content) and the sand is generally loose. In Arroyo de Los Chamisos, several weakly developed, buried soils (i.e. no noticeable calcic horizons and weak Bw horizons) have developed in *Qay*. In the southeast portion of the quadrangle, *Qay* may overlie an older alluvial unit. These two units are separated by a scour surface. The top of the older unit exhibits a buried soil having stage II to IV carbonate morphology and Bt horizon(s) with few to many, faint to distinct, clay films on ped faces; common, distinct, clay films on ped pores, and few to common, faint, clay bridges. The underlying older unit is probably upper to middle Pleistocene in age based on degree of development of the buried soil. *Qay* is inset into the Ancha Formation below *Qao* terraces and interfingers with Qaf.

The unit may be divided into 2 subunits based on landscape position (i.e., height above stream base level) and inset relationships:

Qay2

**Younger subunit (middle to upper Holocene)** — Occupies the valley bottom or terraces that are within 2 m (6 ft) of valley bottoms. Surfaces typically have a poorly developed top soil exhibiting calcic horizon(s) with weak stage I carbonate horizon(s). This soil is locally overlain by approximately 10 to 30 cm of historic to modern alluvium exhibiting very little soil development. The surface overlying *Qay2* may serve as a floodplain during modern floods. Charcoal (sample T-367) was collected 3.6 m below the ground surface and returned a radiocarbon age of 4160 ± 40 yr BP using standard AMS (Beta Analytic Inc., 2000) (Table 1). This date and the stratigraphic position of the sample support a middle to upper Holocene age for *Qay2* and are compatible with its weak soil development. Exposed thickness is up to 5 m (16 ft).

Qay1

**Older subunit (uppermost Pleistocene to middle Holocene)** — Terrace deposits that consist of silt or sand with subordinate pebbles. The soil on the surface is generally marked by calcic horizon(s) with stage I carbonate morphology. The treads are commonly 2-4 m (6-13 ft) above the valley bottom but they converge towards the valley bottom in an upstream direction. *Qay2* is inset into *Qay1*, so *Qay1* must be older than about 4200 yr BP and is probably uppermost Pleistocene to middle Holocene in age. This age range is compatible with the degree of soil development on this unit (e.g., Pazzaglia, 1989). Base is not exposed but thickness probably ranges from 2-6 m (3-20 ft).

Qao

**Older alluvium (Pleistocene)** — Pale brown (10YR 6/3), light yellowish brown (10YR 6/4), strong brown (7.5YR 5/6) to reddish yellow (7.5YR 6/6), gravelly sand and sandy gravel that underlie terraces above the present-day valley bottom. Terrace treads above the valley bottom generally diverge in a downstream direction (Figure 2). Sand is generally unconsolidated and poorly to moderately sorted, arkosic, and subrounded to subangular. Gravel clasts are poorly to moderately sorted and subrounded (although granitic fine pebbles tend to be subangular). A pumice lapilli bed in a terrace deposit along lower Bonzanza Creek was dated by $^{40}Ar/^{39}Ar$ and yielded an age of 1.25 ± 0.06 Ma (sample T-318, Table 1; Peters, 2000a).

Along lower Arroyo Hondo and Arroyo de los Chamisos, four terrace deposits composed of *Qao* are identified and correlated:

Qao4

**Terrace deposit 4 (upper Pleistocene)** — A fill terrace whose tread is 3-9 m (10-30 ft) above the modern stream in the north-central portion of the quadrangle, but this height increases to 25-28 m (80-95 ft) near La Cienega (Figure 1). The strath of this terrace at La Cienega has developed on Espinaso Formation and is approximately 24 m (77-80 ft) above the modern stream. Observed cobble: pebble ratios are 3:7 to 3:2 (estimated by volume). *Qao4* may correlate to a terrace to the west on the Tetilla Peak quadrangle (Sawyer et al., 2001) whose tread is approximately 25 m (80-84 ft) above the Santa Fe River. This terrace in turn is tentatively correlated to *Qta4* of Smith and Kuhle (1998) (Sawyer et al., 2001). Unit *Qta4* is overlain by eolian sand and silt that contain the ~60 ka El Cajete pumice (Smith and Kuhle, 1998). This correlation suggests an upper Pleistocene age for *Qao4* that predates 60 ka. Terrace deposit thickness is difficult to measure but is probably 6-8 m (20-25 ft).

Qao3

**Terrace deposit 3 (middle to upper Pleistocene)** — A fill terrace whose tread is 6-14 m (20-45 ft) above the modern stream in the north-central portion of the quadrangle, but this height increases to approximately 37 m (120 ft) northeast of La Cienega (Figure 1). Probably represents a separate filling event than the one that formed *Qao4*. Cobbles are subequal to pebbles or exceed pebbles (estimated by volume). *Qao3* may correlate to a terrace deposit to the west on the Tetilla Peak quadrangle (Sawyer et al., 2001) whose tread is approximately 40 m (130 ft) above the Santa Fe River. This terrace in turn is tentatively correlated to *Qta3* of Smith and Kuhle (1998) (Sawyer et al., 2001). Unit *Qta3* predates 60 ka so if this correlation were correct then *Qao3* would also be pre-60 ka in age. Terrace deposit thickness is difficult to measure but is probably less than 8 m (25 ft).

Qao2

**Terrace deposit 2 (middle Pleistocene)** — Probably a strath terrace associated with a relatively thin deposit. The tread overlies sandy gravel and is generally 21-24 m (70-80 ft) above the modern stream (Figure 1). The ratio between cobbles and pebbles is approximately 1:1 (estimated by volume). The soil developed on *Qao2* has a stage III carbonate morphology. *Qao* is inferred to be middle Pleistocene in age based on comparison to the terrace stratigraphy and associated soil development in the Red River Valley near Taos (Pazzaglia, 1989) and in the western Espanola Basin along the Rio Grande and Rio Chama (Dethier et al., 1988). Terrace deposit is less than 2 m thick where exposed in a road cut along Highway 599 (NE1/4, NE1/4, Section 23, T16N, R8E).

Qao1

**Terrace deposit(?) 1 (lower Pleistocene)** — A broad strath terrace corresponding to the Airport surface of Spiegel and Baldwin (1963). It is generally 27-38 m (90-125 ft) above the modern stream, and is developed on top of thick gravel of the Ancha Formation in the northern part of the quadrangle (Figure 2). The strath of this unit lies 2-6 m (6-20 ft) below the interpreted top of Ancha Formation aggradation (i.e. Plains surface of Spiegel and Baldwin, 1963). It is assumed that there is a thin veneer of alluvium associated with the terrace but this alluvium has not been positively identified in the field. The soil developed on the tread has a stage III to IV carbonate morphology and is generally classified as the Pueblo - Paraje soil complex (Charles Hibner of the U.S.D.A.-N.R.C.S., pers. comm., 2000). Since this unit is only slightly below the top of the Ancha Formation, it is interpreted to reflect the initiation of regional incision that occurred 1.2 – 1.5 Ma (see age discussion in Ancha Formation).

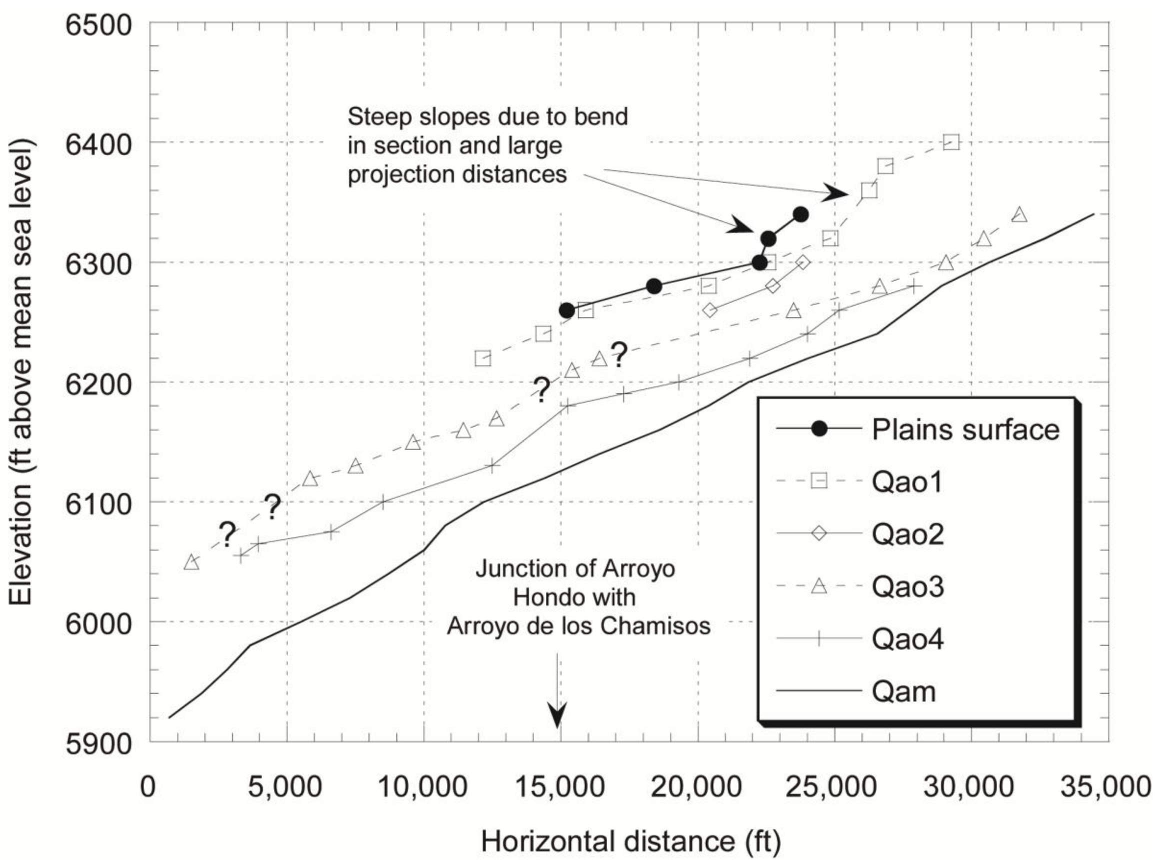


**Figure 1.** Longitudinal profiles of treads developed on *Qao* terrace deposits. The elevations of the treads were projected orthogonally onto a vertical plane that followed Cienega Creek from La Cienega northeastward to its junction with Arroyo Hondo, then northeastward up Arroyo Hondo to its junction with Arroyo de los Chamisos, and then northeastward up Arroyo de los Chamisos to near the center of Section 13, T16N, R8E. The Plains surface interpreted near the airport is also projected onto this line together with the modern stream thalweg.

## SANTA FE GROUP

As used here, the Santa Fe Group represents basin fill deposits that were deposited in the Rio Grande rift during the late Oligocene and late Cenozoic, excluding the Espinaso Formation, younger terrace alluvium, and alluvium related to present drainages. The name "Santa Fe" was first applied to poorly consolidated sediments north of Santa Fe and between Santa Fe and Galisteo Creek (Hayden, 1873). The term "Santa Fe Formation" was first used near Española for sediment containing Miocene fauna (Denny, 1940; Galusha and Blick, 1971). Spiegel and Baldwin (1963) elevated the term "Santa Fe" to group status and considered the Santa Fe Group to include the sedimentary rocks and volcanic rocks related to the Rio Grande trough, within an age range of middle(?)

Miocene to Pleistocene(?). They placed the lower limit above the latitic and basanitic flows exposed in the La Cienega area.

In this quadrangle, the Santa Fe Group consists of the Ancha and Tesuque Formations. The Ancha Formation (Pliocene to lower Pleistocene) overlies the Tesuque Formation (upper Oligocene to middle Miocene) across an angular unconformity. The Ancha Formation is browner and appreciably coarser than the Tesuque Formation. The Tesuque is a wedge-shaped unit that pinches out in the south-central portion of the quadrangle and thickens to the north. Its thickness at the north edge of the map is as much as 900 m (3000 ft) (cross-section C-C'; Grauch et al., 2009). Near La Cienega, the Espinaso-Tesuque contact is not exposed, but a discrepancy in very sparse bedding attitudes between the Espinaso and Tesuque formations may suggest an angular unconformity at this location. Well data and cross section construction indicates that lowest strata of the Tesuque Formation in the La Cienega area (*Tte*, described below) are interbedded with Cieneguilla basanite flows (*Tc*), both of which fill paleovalleys eroded into the Espinaso Formation. Near the southern boundary of the quadrangle, the top of the Espinaso Formation is interpreted to have been eroded prior to Tesuque Formation deposition because of drill-hole data near Gallina Arroyo (see Cross-sections C-C' and C-C'); here, the Tesuque may exist as thin deposits, overlain by Ancha Formation, at the bottom of paleo-valleys developed on top of the Espinaso Formation. It is inferred that much of the crenulations of the Te/Tt subsurface contact is due to paleo-topography from this ca. 28-26 Ma erosion event.

QTaas

**Ancha Formation, alluvial slope deposits (Pliocene to lower Pleistocene)** — Common colors range from brownish yellow (10YR 6/6), yellowish brown (10YR 5/4-6), light yellowish brown (10YR 6/4), and reddish yellow (7.5YR 6/6). It is generally a silty sand with varying amounts of gravel (pebbles with minor cobbles) derived from the Sangre de Cristo Mountains. To a lesser extent, there are also strong brown (7.5YR 5/6), clayey sand beds as well as gravelly medium- to coarse-grained sand beds. The sand is predominately very fine- to fine-grained, poorly to well sorted, arkosic, and subangular to subrounded. Clasts are generally 85-95% reddish granite with the remainder being amphibolite, gabbro, diorite, quartzite, and gneiss. Minor Tertiary intrusive clasts from the Cerrillos Hills are observed at some places within 1.6 km (1 mi) of the mapped Ancha -Tuerto gravel contact. The Ancha

Formation gravel is generally clast supported and subrounded. Sedimentary structures are rare. Bedding is vague, generally tabular, and generally medium or thick. The exposed sediment is unconsolidated except for minor indurated or semi-indurated, very thin- to medium-thick, wavy, calcium carbonate beds generally located in the lower Ancha Formation. Cementation of the lower Ancha Formation becomes more pervasive southeast of this quadrangle. A veneer of sheetwash or colluvium commonly covers the Ancha Formation; good exposures tend to be limited to road cuts or arroyo cuts. Although present, buried soils are not common and generally consist of calcic horizon(s), with stage II to III calcium carbonate morphology, overlain by Bt horizon(s). Clay films and soil structure are commonly well developed. The soil developed on the Plains surface -- an interpreted complex, diachronous, aggradational surface of the Ancha Formation (Spiegel and Baldwin, 1963) -- has been classified as Panky loam (Charles Hibner of the U.S.D.A. - N.R.C.S., pers. comm., 1999). In the type section for the Panky Series (1,500 ft east and 300 ft north of the southwest corner of Section 26, T17N, R8E), Panky loam contains 36 cm of soil horizons with illuviated clay (Bt or Btk) underlain by 180 cm of calcic and siliceous horizons (Bk or Bkq). Where observed on this quadrangle, Bt horizons are 0-25 cm thick and calcic horizons, possessing a stage II to III carbonate morphology, are up to 70 cm thick. Petrocalcic nodules in colluvium suggest that the soil on the Plains surface may locally have calcic horizons exhibiting stage IV calcium carbonate morphology.

The texture and clast composition of this unit varies across the quadrangle. South of Interstate 25 and north of Gallina Arroyo, the upper Ancha Formation is generally a clayey to silty sand; this sediment coarsens near the eastern quadrangle boundary so that a gravel erosional lag is common on the surface. The sand south of Interstate 25 is mostly very fine- to fine-grained. Here, there are minor pebble lenses and minor coarse- to very coarse-grained sand beds. South of Interstate 25, quartzite clasts are generally absent in the upper Ancha Formation, except for near Gallina arroyo (where they comprise less than 3% of the clasts). Compared to the central portion of the quadrangle, there is more medium- to very coarse-grained sand and gravel in the vicinity of Gallina Arroyo. Adjacent to the southeast side of Bonanza Hill, the Ancha Formation generally consists of very thinly- to thinly-bedded, fine- to coarse-grained sand and pebbly sand.

The contact between the Ancha Formation and the underlying Tesuque Formation is an angular unconformity where exposed at the basin margins (e.g., Spiegel and Baldwin, 1963, and 2.4-3.4 km (1.5-2.1 mi) northeast of La Cienega) and this is probably true in the subsurface of this quadrangle as well. There is evidence that the Ancha Formation once extended over the Tsinat Mesa basalt flows (*QTbtf*) in this quadrangle. In colluvium overlying the upper basalt flow, fine- to coarse-grained sand composed of potassium feldspar and quartz, derived from the Sangre de Cristo Mountains, are mixed in various proportions with basaltic sand grains. Between the upper and lower mapped basalt flows, fluvially rounded, quartzite pebbles have been found. Much of the Ancha Formation over the upper basalt flow has since been removed by erosion. The Ancha Formation probably interfingers with the Tuerto Gravel below their mapped contact in the southwest portion of the quadrangle.

The maximum age of the Ancha Formation is interpreted to be near the middle of the Pliocene based on: (1) a zircon fission-track date of 2.7 Ma from a pumice bed near the base of the unit in Canada Ancha north of the map (UTM coord.: N: 3,956,893 E: 399,807; Manley and Naeser, 1977; Kim Manley, pers. comm., 2002); (2) a significant thickness of Ancha sediment, estimated to be at least 25 m-thick, underlies the lowest Tsinat Mesa basalt flow at Cieneguilla. The age of this flow is very likely 2.3-2.8 Ma (see Tbsf unit description below). The minimum age of the Ancha Formation is constrained by three dated tephra beds in the upper Ancha Formation (Table 1). Samples T-264 and T-40 returned $^{40}Ar/^{39}Ar$ ages of 1.48 ± 0.02 Ma and 1.63 ± 0.02 Ma, and probably correlate to Cerro Toledo Tephra and lower Bandelier Tuff (also called the Guaje Pumice Bed), respectively (Peters, 2000a). Tephra sampled from an inset terrace deposit of Qao along lower Bonanza Creek (sample T-318, Table 1) is correlated to the upper Bandelier Tuff on the basis of the $^{40}Ar/^{39}Ar$ age of its youngest sanidine crystals (1.25 ± 0.06 Ma) (Peters, 2000a). Thus, Ancha deposition on the quadrangle generally ceased in the lower Pleistocene, probably between 1.2-1.5 Ma, due to regional incision of the drainages.

Based on drill-hole and geophysical data used to construct the cross-sections, the Ancha Formation on this quadrangle is estimated to be 24-90 m (80-300 ft) thick and to average 50-60 m (160-200 ft). In the extreme southeast corner of this quadrangle and the southern Seton Village quadrangle, seismic refraction studies have modeled two layers that exhibit seismic velocities of approximately 440 m/s (1450 ft/s) and 1800 m/s (5900 ft/s) (line RE-9; Biehler, 1999b). These are probably unsaturated and saturated Ancha Formation, respectively (Sean Biehler, pers. comm., 1999). These two layers have a cumulative thickness of 45 m (150 ft). The base of the Ancha Formation exhibits significant relief and so the thickness of the formation can be expected to vary (cross-sections A-A'and C-C'; Spiegel, 1975; American Groundwater Consultants, 1985; Lazarus, 1985; College of Santa Fe, 1994).

QTasr

**Ancha Formation deposited by the Santa Fe River (Pliocene to lower Pleistocene)** — Generally a sandy gravel with subequal proportions of pebbles to cobbles (estimated by volume). Boulders comprise about 2-5% of the total sediment volume. Rounded quartzite clasts compose 1-15% of the upper Ancha Formation gravel; otherwise, gravel composition is similar to that of *QTaas*. The remaining sediment is a clayey or muddy, arkosic sand with less than 50% pebbles. See discussion under *QTaas* for the age and stratigraphic relations of the Ancha Formation.

**Significant strata included in the Ancha Formation (refer to Explanation of Map Symbols for identifying tephra and ashes):**

**Pumice lapilli beds (lower Pleistocene)** — White and massive pumice lapilli. Pumice may be overlain by 50 cm of fluvially reworked, pumiceous fine-lapilli and sand. Exposures are approximately 9-15 m (30-50 ft) below the extrapolated Plains surface (i.e., the approximate upper extent of aggradation of the Ancha Formation). The pumice has been tentatively correlated with Cerro Toledo Tephra by Izett et al. (1981); this correlation is supported by a recent $^{40}Ar/^{39}Ar$ date of 1.48 ± 0.02 Ma (sample T-264, Table 1; Peters, 2000a). However, immediately to the east of the quadrangle (UTM coord: 3,953,468 N, 404,422 E), a pumice in a similar stratigraphic position has been dated at 1.607 ± 0.020 Ma (Winick, 1999) and correlated to the lower Bandelier Tuff (also referred to as the Guaje Bumice Bed). Thus, this unit probably includes beds of both Cerro Toledo Tephra and lower Bandelier Tuff (Guaje Pumice Bed); these could not be confidently differentiated in the field. The pumice is generally 60 to 100 cm thick but Spiegel and Baldwin (1963) report a thickness of 6 m (20 ft) in SE1/4 NE1/4 Section 18, T16N R9E.

**White ashy sand (lower Pleistocene)** — Very pale brown (10YR 8/2), fine- to very coarse-grained sand. Beds are medium-bedded and tabular. Found within the upper Ancha Formation in the north-central portion of the quadrangle. Where exposed, this ashy sand overlies a reddish yellow (7.5YR) to strong brown (7.5YR) clayey sand, which has a 10-20 cm-thick Bt soil horizon near its top that is yellowish red (5YR) in color. This ashy sand is interpreted to be reworked lower Bandelier Tuff (Guaje Pumice Bed), as indicated by a $^{40}Ar/^{39}Ar$ age of 1.63 ± 0.02 Ma (sample T-40, Table 1; Peters, 2000a). This unit is approximately 50-150 cm thick.

QTat

**Tufa (lower Pleistocene)** — White, indurated tufa found within ~6 m (20 ft) of the top of the Ancha Formation just east of an old railroad grade in the northeast portion of the quadrangle (SE1/4 NE1/4 of Section 29, T16N, R9E). Its stratigraphic position high in the Ancha section suggests it is lower Pleistocene in age.

QTav

**Volcaniclastic lithofacies of the Ancha Formation (upper Pliocene)** — Light gray (10YR 7/1-2), gray (10YR 6/1), to light brownish gray (10YR 6/2), or brownish yellow (10YR 6/6), yellowish brown (10YR 5/4-6), brown (10YR 5/3), pale brown (10YR 6/3), to light yellowish brown (10YR 6/4), volcaniclastic muddy sand, sand, and fine pebbles that are interbedded in arkosic sediment of the Ancha Formation. Outcrops are generally massive but may be vaguely, very thinly to medium-bedded, or planar laminated with minor cross-laminations; unconsolidated to consolidated. Clasts are composed of subangular to subrounded, poorly to well sorted, basaltic to andesitic tephra and pumice that is both matrix- and clast-supported. Locally, clasts have been altered, which has made them soft and created bluish yellow, yellow, to greenish brown colors. Sand is poorly to moderately sorted, subrounded to subangular, and a lithic wacke or lithic arenite. Generally found in the northwest quadrant of the map, outcrops are suggestive of discontinuous channel fills that appear to lie in a similar stratigraphic position. The volcaniclastic sediment may be mixed with granitic sand and pebbles. The basaltic to andesitic tephra and pumice are interpreted to have initially erupted from the Cerros del Rio volcanic field (perhaps by hydromagmatic processes), was transported eastward by wind, and then deposited as ash-fall deposits. Later, most of this volcaniclastic sediment was probably reworked by fluvial and hyperconcentrated flow processes to form channel fills. However, a few ash-fall lapilli beds in this unit are very evenly, thinly- and very thinly- bedded, particularly near the Caja del Rio Plateau, and these were not reworked. This unit projects slightly below the lower Tsinat Mesa basalt flows (*Tbf*) and is probably close in age to these rocks (2.3-2.8 Ma). These deposits may be up to 4 m thick.

QTt

**Tuerto gravel (Pliocene to lower(?) Pleistocene)** — Yellowish brown (10YR 5/4-6), light yellowish brown (10YR 6/4), very pale brown (10YR 7/3-4), or brownish yellow (10YR 6/6), silty sand interbedded with yellowish brown (10YR) to light yellowish brown (10YR 6/4), gravelly sand and sandy gravel. This poorly to moderately sorted sediment is primarily derived from hypabyssal intrusive rocks of the Cerrillos Hills, Turquoise Hill, Bonanza Hill, and Cerro de la Cruz. It is very similar lithologically to Tuerto gravel underlying the Ortiz surface to the south (Steve Maynard, pers. comm., 2000). This sediment probably interfingers with the Ancha Formation near their respective contact in the southwestern portion of the quadrangle. The sand is commonly very fine- to fine-grained, moderately to poorly sorted, subrounded to subangular, and a lithic-rich arkose. The silty sand is massive or very thinly to thinly bedded, and mixed with 1-10% pebbles that occur in discrete, very thin beds. The gravelly sediment is estimated to occupy 10-25% of the total sediment volume (the proportion increases towards bedrock hills). Gravel consists of subangular pebbles and cobbles. Gravel commonly occurs in: (1) thin to medium, lenticular (laterally continuous over 10s of meters), generally unconsolidated beds dominated by pebbles, or (2) thick, extensive, indurated beds with subequal cobbles and pebbles. The gravel is generally clast-supported and may be cross-stratified.

The thickness of the Tuerto gravel ranges from 1 m near bedrock hills to perhaps 45-60 m (150-200 ft) in the lower Alamo Creek area. Its lower contact rests nonconformably on Oligocene intrusive rocks and metasediments. The geomorphic and hydrologic factors that induced incision and abandonment of the Plains surface (Spiegel and Baldwin, 1963) on top of the Ancha Formation would likewise probably have induced incision of the Tuerto gravel. If so, the top of the Tuerto gravel would be similar to the Plains surface in age. The Plains surface projects westward to about the 6200 ft elevation contour immediately south and southwest of Turquoise Hill. Near Cerro de la Cruz, the original top of the Tuerto gravel was probably located at the slope deflection seen near the 6180 ft elevation contour. The slope deflection is hypothesized to be the result of talus from Cerro de la Cruz prograding out over this abandoned surface and acting as an armor when the surrounding, unarmored sediment was later eroded. Below ~15 m (50 ft) from the interpreted original top of the Tuerto gravel, thin to thick beds of sand and gravel may be completely indurated by calcium carbonate. Within about 6 m (20 ft) of the interpreted original top of the Tuerto gravel, there are four buried soils that define sediment units 1-2 m thick. The soils consist of Bt horizon(s) underlain by Bk horizon(s) with stage II to III calcium carbonate morphology. The Bt horizon(s) have common to many, distinct to prominent clay films on ped faces and pores. Buried soils are also found more than 6 m (20 ft) below the interpreted original top of the Tuerto gravel but are sparse.

Sample T-231, a right mandible of the prairie dog genus *Cynomys*, was found 5 to 6 m below the interpreted top of the Tuerto gravel (Table 1) (Gary Morgan, pers. comm., 2000). *Cynomys* first appears in the late Blancan land mammal "age" (late Pliocene, about 2.5 Ma or slightly younger) and survives into the Holocene (Gary Morgan, pers. comm., 2000). The jawbone is most closely identified with the two described late Pliocene species of *Cynomys*, either *C. hibbardi* or *C. vetus*, but due to insufficient work on this genus, the species identification is not conclusive (Gary Morgan, pers. comm., 2000).

Yung and McCaffrey (1903) first used the term "Tuerto Gravel" for placer gravels along the Arroyo Tuerto between San Pedro Mountain and Hagan, but later Stearns (1953a) broadened its usage to include gravelly sediment overlying the Ortiz pediment surface. In the past, it has been mapped in the vicinity of Gallisteo-Tonque arroyos (Stearns, 1953a), San Pedro (Kelley and Northrop, 1975), and west of the Ortiz Mountains (Bachman, 1975). No type section has been described for the Tuerto gravel and conceptually it remains a somewhat vague unit. The term "Tuerto gravel" is used in this quadrangle because of the lithologic and age similarity between the sediment derived from the hypabyssal intrusions in the Cerrillos Hills area and the sediment derived from the Ortiz Mountains (Steve Maynard, pers. comm., 2000; Bachman, 1975).

Tte

**Tesuque Formation, lithosome E (upper Oligocene to lower Miocene)** — Brownish gray to light gray pebbly sandstone and sandy conglomerate, with minor clay, silt, and tuff in the matrix (the latter being trace-30%). Sparse exposures exhibit thin to thick, tabular beds that are internally massive (mostly) to horizontal planar laminated. The gravel is composed of latite, andesite, and tuffaceous-pumiceous sandstone eroded from the Espinaso Formation (*Te*), in addition to variable basaltic rocks eroded from the Cieneguilla basanite (*Tc*). Gravel includes pebbles through boulders (mostly cobbles in exposed outcrops). Clasts are subrounded to subangular, poorly to very poorly sorted, and generally matrix-supported. Measurement of clast imbrication indicates an easterly paloeflow direction. The sand fraction is very fine- to very coarse-grained (mostly fine- to very coarse-grained), subrounded to subangular, poorly sorted, and composed of volcanic-lithic arenite to wacke sandstone. To the east, in the subsurface, this unit is mostly a gray to brown (locally pink) sandstone, clayey-silty very fine- to very coarse-grained sandstone and pebbly sandstone. The proportion of basaltic detritus increases down-section, probably reflecting unroofing of the volcanic source area the west. A subunit of lithosome E is locally differentiated on the cross-sections (*Tteg*), which has greenish volcanic grains. In described wells, it is commonly observed that lithosome E grades upward into muddy volcaniclastic sand and then up into reddish brown sandy mud of lithosome S (*Tts*). In the subsurface, this unit interfingers eastward with arkosic sand of the Tesuque Formation derived from the Sangre de Cristo Mountains (subsurface units *Tts* and *Tta*). The lower part of the unit interfingers with at least four flows of the Cieneguilla basanite (see cross-sections). In general, the unit is interpreted to have been deposited on east-sloping alluvial fans flanking volcanic paleo-highlands near the western quadrangle border. However, lithosome E near Gallinas Arroyo, in addition to the lowest parts of this unit near La Cienega, was deposited in paleovalleys carved into the Espinaso Formation. Since lithosome E lies at the base of the Santa Fe Group, it probably is no younger than lower Miocene in the Santa Fe embayment. Lithosome E appears to be well-consolidated in boreholes, based on caliper logs (e.g., the recent Jail well by the NM State Penitentiary), and commonly is weathered and slightly muddy. Wells indicate a maximum thickness of 160-170 m.

## BASALT OF TSINAT MESA

Tsinat Mesa basalt forms the eastern rim of the Cerros del Rio volcanic field and is found in the northwest Turquoise Hill quadrangle. Here, it consists of basalt lava flows together with associated andesitic tuffs and basaltic tephra deposits erupted from cinder cone(s) at the northeast corner of the Tetilla Peak quadrangle. At least some of these deposits interfinger with the Ancha Formation on this quadrangle. A basaltic trachyandesite dike on the adjacent Tetilla Peak quadrangle yielded a $^{40}Ar/^{39}Ar$ radioisotopic date of 2.68 ± 0.03 Ma (Sawyer et al., 2002). In addition, similar basalt cinders and flows yielded K-Ar ages of 2.5 and 2.6 ± 0.3 Ma in the southwest corner of the Aqua Fria quadrangle, 2.5-3.0

km to the north (35° 39' N lat; 106° 07' W long; Bachman and Mehnert, 1978). Thus, the age range of the basalt on this quadrangle is very likely to be 2.3-2.8 Ma, which is compatible with recent work on the Cerros del Rio volcanic field (e.g. WoldeGabriel et al., 1996; Sawyer et al., 2002).

QTbtf

**Basalt flows of Tsinat Mesa (upper Pliocene to lowermost Pleistocene)** — Basalt flows on the Caja del Rio, may include subordinate tephra. Flows display minor flow banding with varying degrees of vesiculation. Flows are fine-grained, medium dark gray (N4) to dark gray (N3), trachybasalts with plagioclase phenocrysts and xenocrystic quartz. The flows are 3-5 m thick, generally overlie tephra, and cap low cliffs just west of the Sante Fe River.

QTbtt

**Basaltic tephra of Tsinat Mesa (upper Pliocene to lowermost Pleistocene)** — Primarily tephra deposits that are basaltic with subordinate andesitic compositions. The initial eruptive tephra units are 10-12 m thick and occasionally bedded with thin (1-3 cm) andesitic tuff. There possibly may be basalt flows included in this unit in the extreme northeast corner of the quadrangle.

## PALEOGENE LAVA FLOWS, INTRUSIONS, AND SEDIMENTARY ROCKS

In the southwestern and western portions of the map are outcrops of intermediate to mafic intrusions, flows, and volcaniclastic sediment. Minor outcrops of reddish brown sandstone of the Galisteo Formation are present near La Cienega but this unit, as well as the Espinaso Formation, probably underlies most of the quadrangle in the subsurface. Although Johnson (1903) first described the Espinaso Formation, it was named by Kirt Bryan (Charles Stearns, pers. comm., 2001) and the first detailed study was by Stearns (1953b). The Galisteo Formation was named by Hayden (1869) but studied in detail by Stearns (1943).

### LAVA FLOWS

Tc

**Cieneguilla basanite (upper Oligocene)** — Grayish black (N2), porphyritic, olivine-bearing, volcanic flows of basanite, nephelinite, and basalt. Flows are fine-grained and non-vesicular. Bedding textures and flow structures are poorly preserved. North of Cienega Creek, basalt flows are present as fractured blocks in isolated remnants. South of Cienega Creek, flows are in isolated outcrops and form the low-lying bluffs rising out of the creek bottom. Locally, flow tops display well-developed desert varnish and olivine glomerophenocrysts; however, no ultramafic nodules or xenocrysts were observed as reported by Sawyer et al. (2002) in the Tetilla Peak quadrangle. In thin section the 80-90% groundmass is dominated by clinopyroxene, followed by lesser amounts of skeletal olivine, subhedral plagioclase, and Fe-Ti oxides. Plagioclase crystals display a slightly trachytic flow texture. Whole-rock geochemical results plot the rock in the basanite field (Figure 3 and Table 2, samples 99RBH5 and 99RBH15). A small remnant of basanite forms the peak at Cerro de la Cruz. The small exposure is grayish black (N2) and fine-grained with microphenocrysts of reddish-brown olivine and nepheline in a holocrystalline matrix. Columnar jointing dips towards the center of Cerro de la Cruz, which indicates that the basanite was emplaced at a high level in the crust (i.e., hypabyssal) and suggests that Cerro de la Cruz possibly represents a vent. Spiegel (1975) interpreted that the Cieneguilla basanite or similar flows were interbedded with the lower Tesuque Formation based on well data. Unit is equivalent to Cieneguilla limburgite of Stearns (1953b), Sun and Baldwin (1958), and Spiegel and Baldwin (1963); also equivalent to Cieneguilla basanite of Sawyer et al. (2002). The Cieneguilla basanite has been dated at 25.1 ± 0.7 Ma using K-Ar radioisotopic analyses (Baldridge et al., 1980) and 26.08 ± 0.62 Ma using $^{40}Ar/^{39}Ar$ radioisotopic analyses (Table 1; Peters, 2000b). This value is similar to a K-Ar radioisotopic date of 25.1 ± 0.6 Ma (Kautz et al., 1981) and a $^{40}Ar/^{39}Ar$ radioisotopic date of 25.41 ± 0.32 Ma (Connell and Cather, 2001) obtained from an olivine tholeiite at Espinaso Ridge west of Cerrillos. At Cerro de la Cruz the Cieneguilla basanite is observed above, or intrudes into, the Espinaso Formation latitic breccia, and so should be younger than the Espinaso Formation. Total thickness of the Cieneguilla basanite is interpreted to be less than 30 m (100 ft) in the Turquoise Hill quadrangle, much thinner than the 220 m (720 ft) measured by Sun and Baldwin (1958) on the Tetilla Peak quadrangle.

## INTRUSIONS

Tm

**Quartz monzonite and monzonite porphyry (Oligocene**) — Light gray (N7), medium-grained intrusion of porphyritic monzonite exposed immediately north of La Cienega and light brownish gray (5YR), medium-grained, intrusive quartz monzonite of Turquoise Hill and Cerrillos Hills. At La Cienega, phenocrysts of orthoclase, plagioclase, and quartz are present amongst fine-grained, weathered feldspar. Biotite, plagioclase, magnetite, and a trace of clinopyroxene are present in the groundmass. A single whole-rock geochemical result plots the monzonite porphyry in the syeno-diorite field (Figure 4 and Table 2, sample 99RBH8). Outcrops of the monzonite are heavily fractured (~ 10 fractures/meter) and iron-stained. Sawyer et al. (2002) report this intrusion is centered on Cerro Seguro about 2 km (1.2 mi) to the west. A biotite from the monzonite intrusion at Cerro Seguro has recently been dated by $^{40}Ar/^{39}Ar$ at 29.40 ± 0.05 Ma (B. Sauer, unpublished data, 1999). The quartz monzonite at Turquoise Hill and Cerrillos Hills consists predominantly of plagioclase, in addition to 5-10% quartz and minor amounts of potassium feldspar, clinopyroxene, orthopyroxene, and biotite at Cerrillos Hills, and minor amounts of biotite at Turquoise Hill. Field relationships at Turquoise Hill indicate *Tm* may be cogenetic with *Tdi* given the lack of an intrusion breccia and a gradational contact 3-6 m wide. However, immediately to the west, Stearns (1953b) concluded that intrusions probably equivalent to *Tdi* cut across hornblende quartz latite (probably correlative to *Tm*) and are thus younger. *Tm* is correlative with *Tmi* of Sawyer et al. (2002), *Ti* of Sun and Baldwin (1958), and *T4* of Disbrow and Stoll (1957). Monzonite at Cerro Bonanza and other localities in Los Cerrillos have been dated at approximately 28-30 Ma (Maynard, 1995; B. Sauer, unpublished data, 1999).

Tmh

**Hornblende monzonite (Oligocene)** — Light gray (N7), hornblende-bearing monzonite intrusion at Bonanza Hill. Phenocrysts of subhedral hornblende, potassium feldspar and plagioclase are present. The groundmass is dominated by plagioclase, potassium feldspar, and quartz. Geochemically, the rock is classified as a granite. A single whole-rock geochemical result plots the hornblende monzonite in the granite field (Figure 4 and Table 2, sample 99RBH18). Probably correlative with unit *Ti1* of Disbrow and Stoll (1957) and unit *Tmh* of Sawyer et al. (2002).

Tsdh

**Hornblende syeno-diorite (Oligocene)** — Medium dark gray (N4), holocrystalline, hypidiomorphic-granular, hornblende diorite of Turquoise Hill and Cerrillos Hills. At Turquoise Hill, the observed mineral assemblage is plagioclase, clinopyroxene, minor quartz, and about 2% hornblende and magnetite. Compared to Turquoise Hill, this unit is coarser at Cerrillos Hills and consists of about 20% biotite, 75% plagioclase and quartz, and 5% magnetite. A single whole-rock geochemical result plots the hornblende diorite in the syeno-diorite field (Figure 4 and Table 2, samples 99RBH19and 99RBH22). It locally intrudes fine-grained Cretaceous sandstone and mudstone at Turquoise Hill. Contact metamorphism with adjacent Cretaceous sediments at Turquoise Hill is minor with an albite-epidote mineral assemblage.

Tah

**Hornblende andesite (Oligocene)** — Two small intrusive knobs at La Cienega. The light medium gray (N6) andesite contains porphyritic euhedral hornblende in a trachytic texture. Total thickness is about 4 m (13 ft). One outcrop continues as a dike about 500 m (1640 ft) to the northwest into the Tetilla Peak quadrangle. The exact age is uncertain but probably lies within the Oligocene.

## SEDIMENTARY ROCKS AND MINOR LAVA FLOWS

Te

**Espinaso Formation (Oligocene to lower Miocene(?))** — Andesite, latitic breccia and conglomerate, quartz latite flows, and ash-flow tuff exposed along Cienega Creek near La Cienega and at Cerro de la Cruz. East of the Cerrillos Hills, latitic conglomerate and coarse-grained sandstone are probably present in the subsurface based on outcrops to the south of the quadrangle (Larsen and Taylor, 1991). Andesite stratigraphically underlies the basal latitic breccia flows, is exposed only locally, and is at least 5 m (16 ft) thick (bottom contact not observed). Northeast of La Cienega (Section 32, T.16N., R.8E.), the andesite is fine- to medium-grained, brownish gray (5YR 4/1), has microphenocrysts of plagioclase, and was deposited prior to the intrusion of Tmi (Sawyer et al., 2002). Locally, the andesite is at least 5 m (16 ft) thick. Sun and Baldwin (1958) report a thickness of 180 m. A localized 1 m (3 ft)-thick, weathered volcanic ash occurs just north of Cienega Creek in Section 32, T16N, R8E. Overlying latitic breccia flows, 1-5 m (3-16 ft) thick, contain latite blocks, pebble-sized basanite, and ash flow tuff in a matrix of plagioclase, quartz crystals, and lithic fragments. Outcrop sections of the breccia are variably welded; the more distal and thicker portions of the breccia are crudely sorted and bedded with subrounded clasts, indicating a sedimentary origin. The quartz latite flows are light gray (N7), medium- to coarse-grained, and contain phenocrysts of quartz and plagioclase as well as microphenocrysts of biotite and hornblende. Geochemically, the quartz latite and latitic breccia plot in the trachyte and rhyolite fields (Figure 3 and Table 2, samples 99RBH20 and 99RBH21). Thickness of the quartz latite and latitic breccia flows is 60 m (200 ft); Sun and Baldwin (1958) report a thickness of 440 m (1444 ft) to the west. A densely welded, grayish red (10R 4/3), ash flow tuff occurs at Cerro de la Cruz and dips 8 - 12° to the southwest. The tuff has two units that are in conformable contact with one another. The lower unit is moderately welded and well sorted. Subordinate lithics include a hornblende-plagioclase (zoned) porphyry and monzonite porphyry. Geochemically, this rock is an andesite to trachyandesite (Figure 3 and Table 2, sample 99RBH16). The upper unit is strongly welded with larger lithics of similar composition. The upper contact is covered with basanite talus from unit *Tc* and the lower contact is not exposed. Total thickness of the tuff is estimated to be approximately 18 m (59 ft) and may be correlative with ignimbrites noted by Smith (1991) at Espinaso Ridge. Field relationships (particularly bedding orientation) indicate that the andesite, quartz latite, ash-flow tuff, and latitic breccia and conglomerate are tilted as a single unit. This relationship and lithologic similarities to the Espinaso Formation as described elsewhere (Erskine and Smith, 1993; Sun and Baldwin, 1958; Sawyer et al., 2002) form the basis for including both the flows and the conglomerate in the Espinaso Formation. The Espinaso Formation conformably overlies the Galisteo Formation to the south near Cerrillos (Lucas, 1982; Gorham and Ingersoll, 1979), and that relationship is probably the case over much of this quadrangle in the subsurface. However, near La Cienega the contact is an angular unconformity, probably because of proximity to intrusions related to Espinaso magmatism. Field observations near La Cienega indicate that the Espinaso Formation is overlain by the Tesuque Formation but the contact is not well-exposed.

The Espinaso Formation is generally thought to be Oligocene in age because of its conformable contact with the underlying Eocene Galisteo Formation and because it is intruded by Oligocene intrusives (Baldridge et al., 1980; Sauer, 1999; Maynard, 1995; Erskine and Smith, 1993). Near Espinaso Ridge, 22.5 km (14 mi) to the southwest of La Cienega, high-potassium andesite and basaltic andesite in the Espinaso Formation returned K-Ar dates of 34.3 ± 0.8 Ma and 34.6 ± 0.7 Ma (Kautz et al., 1981). A nepheline latite about 130 m below the top of the Espinaso Formation yielded a date of 26.9 ± 0.6 Ma (Kautz et al., 1981; Connell and Cather, 2001). Using mineralogical and chemical similarities, Sawyer et al. (2002) correlate the upper Espinaso latite flows with a Cerrillos augite monzonite that has been dated at 28-30 Ma (Maynard, 1995; Sauer, 1999; Baldridge et al., 1980). Baldridge et al. (1980) report a biotite K-Ar radioisotopic date of 19.5 ± 0.5 Ma and a feldspar radioisotopic date of 19.6 ± 0.6 Ma from a glassy latite flow in the upper Espinaso 1.5 km (0.9 mi) northeast of La Cienega. However, these dates are suspect because no other latitc rocks in the Espinaso Formation have returned ages less than 25 Ma. The radioisotopic dates support an Oligocene age for the Espinaso Formation and suggest the possibility that minor intermediate volcanism may locally have extended into the early Miocene. The Espinaso Formation is approximately 300-370 m (1000-1200 ft) thick near La Cienega but its thickness may be as great as 550 m (1800 ft) to the east (cross-section A-A') and is interpreted to be around 600 m (2000 ft) thick to the northeast (Yates La Mesa Unit #2 well in the Agua Fria quadrangle; Grant Enterprises Inc., 1998, and Grant, 1999).

Tg

**Galisteo Formation (Eocene)** — Pale reddish brown (10R 5/4) to moderate reddish brown, medium- to coarse-grained sandstone in addition to reddish conglomerate and mudstone. Unit referred to as Galisteo Formation in Sun and Baldwin (1958) and Spiegel and Baldwin (1963), but Lucas et al. (1997) differentiated the Diamond Tail Formation in what was formerly the lower Galisteo Formation. The Diamond Tail Formation is not interpreted in outcrop but likely is present in the subsurface. Sandstone is primarily cemented with clays, is friable, subangular to subrounded, and moderate to well sorted. This formation tends to be poorly exposed. It generally conformably underlies the Espinaso Formation (Sun and Baldwin, 1958), although this relationship is not observed near La Cienega (probably because of local intrusive activity in the Oligocene). Beds generally dip 7 - 15° to the southeast. The Galisteo Formation is commonly interpreted to be a synorogenic sedimentary deposit coeval with the Laramide orogeny in this part of New Mexico (Stearns, 1943, 1953a; Gorham, 1979; Gorham and

Ingersoll, 1979; Ingersoll et al., 1990; Abbott et al., 1995) and unconformably overlies Mesozoic strata (Stearns, 1943). Based on well data, the thickness of this unit is approximately 400-430 m (1300-1400 ft) on this quadrangle. This agrees with the measured thickness of 400 m by Sun and Baldwin (1958) along Cienega Creek.

## MAPPED MESOZOIC ROCKS

Ku **Undifferentiated Cretaceous strata** — Quartz-rich sandstones and minor shale and limestone located in the area of Turquoise Hill and Cerrillos Hills. All sediments have undergone minor contact metamorphism and are commonly associated with historic and active mining activities. Thickness is widely variable.

## UNITS DEPICTED IN CROSS-SECTIONS AND SUBCROP MAPS BUT NOT SHOWN ON GEOLOGIC MAP

Descriptions of Mesozoic and Paleozoic strata are based on drill cuttings and geophysical well logs of the Yates La Mesa Unit #3 and Gianardi #1 CKZ petroleum exploration wells in addition to surface descriptions given in Sawyer et al. (2002) and Bachman (1975). Unit thickness is obtained from the cross-sections in this work. Descriptions of the Tesuque Formation are largely based from well cuttings from Nuclear Dynamic boreholes, in addition to the Jail well and the CDX-OBS-A well near the Santa Fe Community College (John Hawley, 2006, unpublished consultant report).

**Qva** **Valley-floor alluvium (Quaternary)** — Sand, gravel, silt, and clay that underlie the floors of modern drainages. Generally non- to weakly consolidated. Includes map units *Qam*, *Qaf*, *Qay*, and *Qao* and their respective subdivisions.

**Tta** **Lithosome A of Tesuque Formation (lower to middle Miocene)** — Very fine- to very coarse-grained sandstone; minor silty-clayey sandstone and pebbly sandstone; sand size is mostly very fine- to medium-grained. Sand is arkosic, subangular to subrounded, poorly to well sorted, and lacks chert and Paleozoic detritus. Colors range from light yellowish brown to light brown to dull orange to dull reddish brown to pink. Pebbles are composed of granite. Unit deposited on an alluvial slope by streams draining granitic terrain. Moderately to well consolidated.

**Tts** **Lithosome S of Tesuque Formation (lower to middle Miocene)** — Reddish strata consisting of intercalated fine- and coarse-grained intervals; inferred to be deposited on a fluvial fan by an ancestral Santa Fe River. Color is mostly dull orange with lesser reddish brown, light reddish brown, pink, light brown, or reddish yellow. Fine-grained sediment likely was deposited on a fluvial floodplain and consists of very fine- to medium-grained sandstone (mostly very fine- to fine-grained), siltstone, and claystone. Coarse sediment was probably deposited in channel-fills and is composed of pebbly sandstone and lesser sandstone, where the sand size ranges from fine to very coarse (mostly medium to very coarse). Sand is subrounded to subangular and arkosic. Pebbles are subrounded to angular, very fine to medium in size, and composed of granite, quartz or quartzite, Paleozoic limestone, and Paleozoic sandstone-siltstone. The presence of Paleozoic sedimentary detritus (yellowish siltstone or limestone in addition to dark chert) in the pebble and sand fraction, in addition to granite and quartzite clasts, distinguishes this unit from lithosome A. In the sand fraction, Paleozoic detritus, chert, and quartzite grains occupy less than 10% of the total sand grains. Unit is variably cemented and moderately to well consolidated. This arkosic sediment is finer-grained, better sorted, and more consolidated than the Ancha Formation, and is marked by significantly lower hydraulic conductivity values (by an order of magnitude; Fleming, 1991). It can be subdivided according to texture as follows:

**Ttsc** **Coarser-grained Lithosome S of the Tesuque Formation (middle Miocene), differentiated in cross-sections only** — Fluvial deposits characterized by a predominance of medium- to very coarse-grained, arkosic sand and gravelly sand channel-fills, with subordinate fine-grained floodplain deposits. Tongues of this unit are inferred on the north end of cross-section C-C'.

**Ttsm** **Medium-grained Lithosome S of the Tesuque Formation (lower to middle Miocene), differentiated in cross-sections only** — Fluvial deposits characterized by clay, silt and very fine- to fine-grained sand intercalated with subequal medium- to very coarse-grained, arkosic sand and gravelly sand channel-fills. Up to 450 m-thick on this quadrangle.

**Ttsf** **Finer-grained Lithosome S of the Tesuque Formation (lower to middle Miocene), differentiated in cross-sections only** — Fluvial deposits characterized by clay, silt and very fine- to medium-grained sand intercalated with minor medium- to very coarse-grained, arkosic sandstone channel-fills (locally with very fine to fine pebbles); relatively clayey. Up to 450 m-thick on this quadrangle.

**Ttse** **Interfingering and lithosomes S and E of the Tesuque Formation (upper Oligocene to lower Miocene)** — This unit is characterized by intertongues and mixing of lithosome S and E. See descriptions of *Tts* and *Tte* above.

**Tteg** **Volcaniclastic sediment with greenish volcanic grains (upper Oligocene to lowest Miocene)** — Very fine- to very coarse-grained sandstone and claystone; minor pebbly sandstone (pebbles are very fine to medium in size). Colors range from dull reddish brown to grayish red to dull brown to grayish brown. Unit is recognized by variable amounts of medium- to very coarse-grained, subrounded, greenish sand grains (and minor very fine pebbles); these grains are composed of a granular to aphanetic mafic volcanic rock or reworked, monolithic, volcaniclastic sandstone. Other lithic grains include subrounded to subangular latite, basalt, and hornfels. Variable amounts of feldspar and quartz that are subrounded to subangular and moderately to well sorted. Wells indicate a thickness of 5-55 m.

**Ttasl** **Lower tongue of mixed lithosome A and S sediment (Upper Oligocene to lowest Miocene)** — Reddish brown clayey-silty fine sandstone and sandy claystone; minor pebbly sandstone. Sand is very fine- to very coarse-grained (mostly very fine- to medium-grained), moderately to well sorted, angular to subrounded, and arkosic (but with locally trace chert, sandstone, and siltstone grains). Trace to very minor pebbles that include quartzite and chert. Lower 30 m is clayey. ~120 m-thick.

**Tte+Tc** **Interbedded Cieneguilla basanite and lithosome E [sub-Ancha subcrop map only]** — See above descriptions for Cieneguilla basanite (Tc on map) and lithosome E (Tte).

**Tcvu** **Uppermost flow of the Cieneguilla Basanite in the La Cienega area (lower Oligocene)** — See description of the Cieneguilla basanite (*Tc*) above. Flow is relatively thin (3-6 m thick).

**Tcu** **Upper flow of the Cieneguilla Basanite in the La Cienega area (lower Oligocene)** — See description of the Cieneguilla basanite (*Tc*) above.

**Tcm** **Middle flow of the Cieneguilla Basanite in the La Cienega area (lower Oligocene)** — See description of the Cieneguilla basanite (*Tc*) above.

**Tcl** **Lower flow of the Cieneguilla Basanite in the La Cienega area (lower Oligocene)** — See description of the Cieneguilla basanite (*Tc*) above.

**Ti** **Undivided Tertiary intrusions (Oligocene)** — Probably monzonite to diorite in composition based on exposures near the Cerrillos Hills.

**Ti+Mzu** **Tertiary intrusions with minor Mesozoic strata** — See descriptions intrusions above (*i.e.*, *Ti*, *Tm*, *Tmh*, *Tsdh*, *Tah*) and Mesozoic strata below.

**Te+Ti** **Espinaso Formation with multiple intrusions (Oligocene)** — See descriptions of the Espinaso Formation (*Te*) and intrusions above (*i.e.*, *Ti*, *Tm*, *Tmh*, *Tsdh*, *Tah*).

**Tgd** **Undifferentiated Galisteo and Diamond Tail Formations** — Unit consists of the following stratigraphic sequence, presented in descending order. The upper subunit corresponds with the upper Galisteo Formation. It is composed of tan to white, cross-bedded to massive, sandstone and pebbly sandstone channel-fills (non- to strongly cemented) with subordinate overbank deposits of fine sandstone and red, rose, tan, and gray-green mudstone; the gravel are predominately quartzite and chert. The middle unit corresponds with the lower Galisteo Formation. It consists of pink to red, sandy conglomerate and arkosic sandstone channel-fills intercalated with mudstone, siltstone, and fine sandstone overbank deposits; the gravel contains mostly granite, with subordinate Paleozoic limestone and sandstone. The proportion of granite to Paleozoic sedimentary clasts in the middle unit increases up-section (Maynard et al., 2002). The lower unit correlates with the Diamond Tail Formation (Lucas et al., 1997). It consists of sandstone and pebbly sandstone, mudstone, minor conglomerate, and local limestone beds that unconformably underlie the Galisteo Formation. The mudstone is variegated gray to maroon to greenish gray, and generally lacks the brick red (moderate reddish brown) colors common in the overlying Galisteo Formation (Lucas et al., 1997). Clasts in Diamond Tail Formation conglomerate beds are well-sorted and consist of dominantly white and gray quartzite and chert (Lucas et al., 1997). The Diamond Tail Formation pinches out northwards and is not interpreted to be present in the La Cienega area.

**Mzu** **Undivided Mesozoic strata** — Includes the Mesozoic units listed below (*i.e*., *Km*, *Kd*, *Jms*, *Jt*, *Je*, and *Tru*).

**Km** **Mancos Shale (Upper Cretaceous)** — Generally medium to dark gray shale, calcareous shale, sandy shale, minor limestone beds, minor sandstone beds, and minor bentonite. 210-240 m (700-800 ft) thick.

**Kd** **Dakota Formation (Upper Cretaceous)** — Whitish to medium gray, fine- to coarse-grained calcareous sandstones with minor siltstone interbeds. Generally thickly bedded. Approximately 35-45 m (120-150) thick.

**Jms** **Morrison Formation (Upper Jurassic) and Summerville Formation (Middle Jurassic)** — Variegated (green, light to dark brown, reddish brown, black, dark brown, gray, maroon, white) mudstone and silty mudstone interbedded with whitish to grayish, fine- to medium-grained sandstone. Sediments have been slightly metamorphosed adjacent to intrusions in Yates La Mesa Unit #3 well. Approximately 226 m (740 ft) thick in the Yates La Mesa Unit #3 well.

**Jt** **Todilto Formation (Middle Jurassic)** — White, massive gypsum underlain by gypsiferous shale and grayish limestone. 29 m (95 ft) thick in Yates La Mesa Unit #3 well.

**Je** **Entrada Sandstone (Middle Jurassic)** — Light yellowish gray to reddish brown to light gray, medium- to fine-grained sandstone that is cross-laminated. 20 m (68 ft) thick in the Yates La Mesa Unit #3 well.

**Ꞧu** **Triassic Strata, undivided** — Generally reddish brown to orangish brown shale, siltstone, and subordinate sandstone. Assigned to the Chinle Group and Moenkopi Formation (Lisenbee, 1999; Maynard et al., 2002) and deposited in a fluvial environment. Approximately 550 m (1800 ft) thick.

**IPu** **Undivided Paleozoic strata** — Paleozoic strata include the Artesia Group (mostly sandstone and siltstone), San Andres Formation (mostly limestone), Glorietta Sandstone, Yeso, and Sangre de Cristo Formations as well as Pennsylvanian strata (listed youngest to oldest). The Abo and Sangre de Cristo Formations generally consist of reddish sandstone and shale. Pennsylvanian strata (i.e., the Alamitos and La Pasada Formations) are composed of gray to yellowish cherty limestone, yellowish calcareous siltstone, gray shale, and minor very fine- to coarse-grained arkosic sandstone. Minor Mississippian strata may be present at the base of the unit. Interpreted maximum thickness of 1550-1585 m (5100-5200 ft) from interpretation of seismic reflection data of Black (1984, fig. 3).

**Mzu-Pzu** **Undivided Mesozoic and Paleozoic strata** — See above descriptions for Mesozoic and undivided Paleozoic rocks.

**XYu** **Proterozoic Rocks, undivided** — Various basement rocks that likely include gneiss, schist, granite, pegmatite, metaplutonic rocks, and amphibolite.

# STRUCTURE

Recent interpretations of aeromagnetic and gravity data, constrained using borehole and seismic reflection data, indicate two major structural domains in the quadrangle (Grauch et al., 2009). To the south, the base of the Santa Fe Group is not strongly dipping in a particular direction, although it does have relief (up to 100 m) due to pre-Santa Fe Group erosion. This domain is called the Santa Fe platform. North of the New Mexico State Penitentiary, strata dip northwards into the deeper part of the Española Basin. In the northward dipping strata, there is also a broad syncline at the base of the Santa Fe Group whose axis lies in the northeastern part of the quadrangle (labeled on cross-section A-A'). Another broad syncline, older than the aforementioned one, is manifested in pre-Santa Fe Group strata in the Santa Fe platform (west side of cross-section B-B'; Biehler, 1999a; Biehler, 1999b; Black, 1984). The interpretation of these two synclines is compatible with well data, bedding attitudes from the Espinaso Formation northeast of La Cienega, and bedding attitudes in upper Arroyo Hondo adjacent to the Sangre de Cristo Mountains (Read et al., 1999; Spiegel and Baldwin, 1963). There may be minor faults that that cannot be directly observed under the Ancha Formation and Quaternary alluvium. Available data do not confirm the Cienega fault that was previously postulated by Spiegel and Baldwin (1963).

On the west limb of the syncline and near the syncline axis in the south, multiple intrusions (including monzonite, diorite, and trachyte-rhyolite(?)) have locally domed the Espinaso Formation and earlier strata. Based on aeromagnetic data (Grauch et al., 2009), these intrusions commonly appear cylindrical in plan view and probably are stocks or laccoliths. Lithologic and geophysical well logs from the Yates La Mesa Unit #3 and Gianardi #1 CKZ wells indicate multiple sills that probably are branching off from these intrusions (e.g., cross-sections B-B' and C-C').

The Ancha Formation lies as an unconformable, thin veneer (less than 90 m (300 ft) thick) over the tilted strata of the Tesuque, Espinaso, and Galisteo-Diamond Tail formations. The Ancha Formation itself is not notably deformed or faulted. Regionally, the Ancha Formation dips less than 2 degrees to the west.

## HYDROGEOLOGY

The Ancha and Tesuque formations comprise the primary aquifers for the area. Groundwater is unconfined, confined, or locally perched (Lewis and West, 1995). The potentiometric surface, approximating the groundwater table in unconfined groundwater regimes, slopes to the west and indicates that groundwater flow is also to the west.

The Ancha Formation on the quadrangle is estimated to be 24-90 m (80-300 ft) thick. Its upper half is unsaturated but its lowermost strata is commonly saturated -- particularly north of Alamo Creek and south-southwest of the Cerrillos-Interstate 25 intersection (Johnson and Koning, 2012). The few wells that probably draw groundwater from only the Ancha Formation and have undergone pump tests indicate hydraulic conductivities of 3-130 ft/day (Table 2). Gravel channel deposits in the saturated zone probably have much higher hydraulic conductivities than 3-130 ft/day and are important conduits for groundwater flow (Jack Frost, pers. comm., 2000). Paleovalleys at the base of the Ancha Formation influence and locally direct ground water flow (Johnson and Koning, 2012). The Ancha Formation is generally ten times more permeable than the underlying Tesuque Formation (Fleming, 1991).

Although it is less permeable than the Ancha Formation, the Tesuque Formation is an important aquifer for this area because its thickness may possibly be as great as 900 m (3000 ft) in the north-central portion of the quadrangle. However, this aquifer is wedge-shaped and pinches out in the south-central portion of the quadrangle. Hydraulic conductivity values from pumping test data within the quadrangle range from 1-20 ft/day (Table 2). The Tesuque Formation is marked by considerable heterogeneity in regards to permeability (Lewis and West, 1995).

The relatively consolidated and cemented Espinaso, Galisteo, and Diamond Tail formations, as well as Tertiary intrusive rocks, are hydraulically connected to groundwater flow in the Santa Fe Group (Lewis and West, 1995). The Espinaso Formation is an important aquifer for homes in the south-central portion of the quadrangle. Hydraulic conductivity values generally are less than 1 ft/day for the Espinaso Formation (Table 2) and wells usually produce less than 5 gallons per minute (Ratcliff, 2000), although some wells encounter fractures that may supply relatively high yields (for example, 10 gallons per minute or greater (Ratcliff, 2000)). Occidental Minerals Corporation reported yields of several hundred gallons per minute from such fractures (Turner, 1984). The Galisteo-Diamond Tail formations generally yield more groundwater than the Espinaso Formation. Typical yield values are thought to lie within

5-10 gallons per minute (Ratcliff, 2000). Analysis of a pumping test determined an average *transmissivity* of 30 $ft^2$/day (220-225 gpd/ft) for the Galisteo-Diamond Tail formations (Turner, 1973 and 1984; Aiken, 1973).

Lower permeability, subsurface, igneous bedrock highs south of Bonanza Hill and northeast of La Cienega probably are responsible for bringing groundwater flow to the surface in Alamo Creek, La Cienega Creek, and Arroyo Hondo. Northeast of the consolidated Espinaso Formation and igneous bedrock exposed in the lower Arroyo Hondo, the Tesuque Formation is exposed or else probably within approximately 15 m (50 ft) of the present-day land surface. Having a lower permeability relative to the Ancha Formation, the shallowness of the Tesuque Formation here is also a factor for bringing groundwater flow in the Ancha Formation to the surface. A similar geologic situation may occur at lower Cienega Creek (in Section 33, T.16N., R.8E.).

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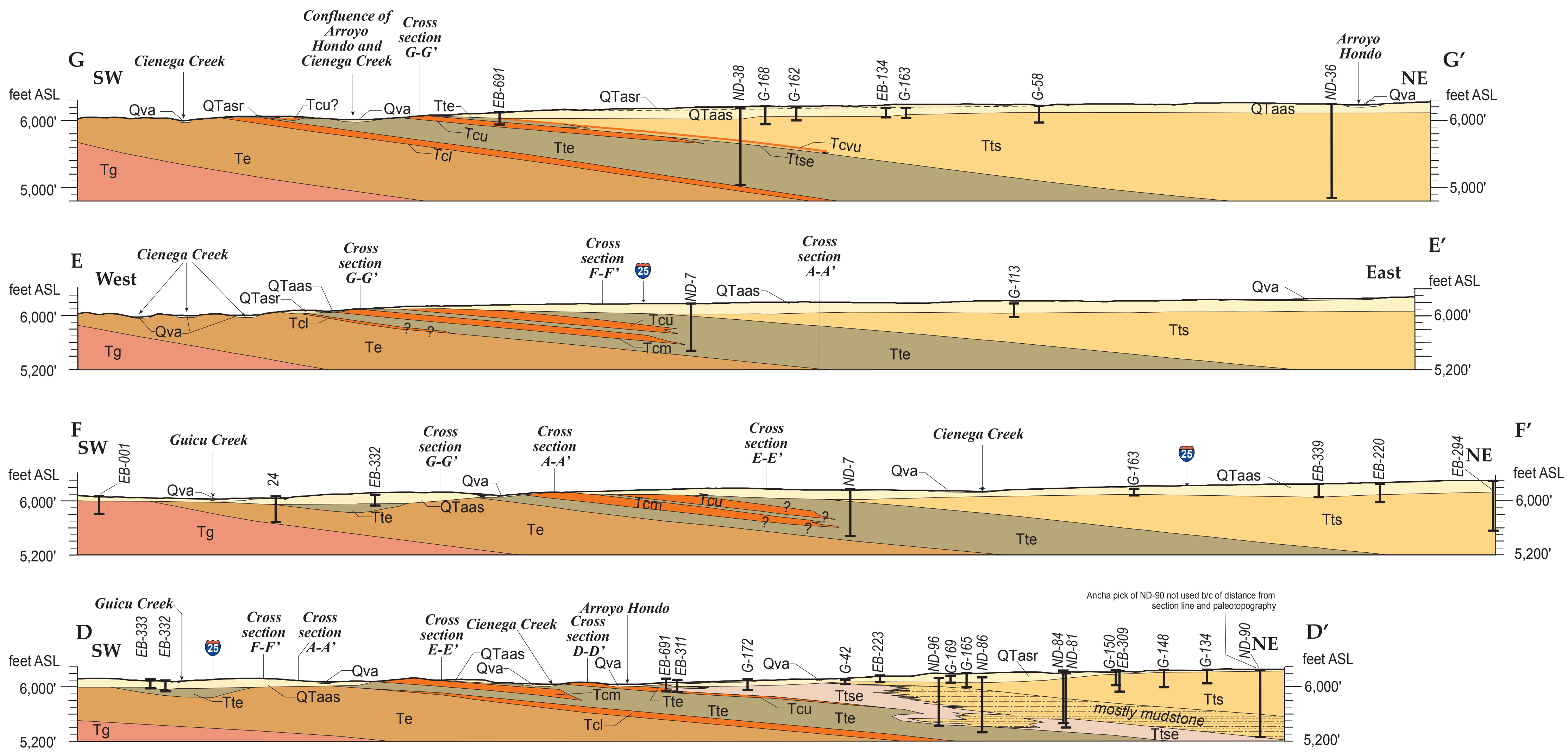
# Appendix.
# Cross sections by La Cienega, northwestern Turqouoise Hill quadrangle

**by**

**Daniel Koning**

**scale 1:24,000, no vertical exaggeration**



## Table 1. Radioisotopic and biostratigraphic age data

| Sample[ξ] | Location in UTM coordinates* ( +/- 15 m error ) | Unit | Material | Lab sample number | Laboratory | Method | Date / Age[ϒ] |
|---|---|---|---|---|---|---|---|
| T-367 | N: 3,940,521 E: 402,116 | Qay | Charcoal | Beta-137382 | Beta Analytic | Standard-AMS | 4160 +/- 40 yr. BP |
| T-318 | N: 3,933,268 E: 400,521 | Qao | Tephra | 51220 | NMGRL** | $^{40}Ar/^{39}Ar$ | 1.25 ± 0.06 Ma |
| T-40 | N: 3,941,939 E: 404,305 | QTa | Ashy Sand | 51221 | NMGRL** | $^{40}Ar/^{39}Ar$ | 1.63 ± 0.02 Ma |
| T-264 | N: 3,940,320 E: 406,299 | QTa | Tephra | 51222 | NMGRL** | $^{40}Ar/^{39}Ar$ | 1.48 ± 0.02 Ma |
| T-231 | N: 3,930,582; E: 398,756 | QTt | Fossil | NMMNH 30493 | NMMNH*** | Biostratigraphic | 2.5 Ma - Holocene |
| 99RBH5 | N: 3,937,491 E: 398,668 | Tc | Basanite | NMGRL-51379-01 | NMGRL** | $^{40}Ar/^{39}Ar$ | 26.08 ± 0.62 Ma |

Notes:

[ξ] Location of sample is plotted on the map; sample 99RBH5 collected by R.B. Hallett, the others were collected by D.J. Koning

* Zone 13

** New Mexico Geochronologic Research Laboratory

*** New Mexico Museum of Natural History (fossil identified as *Cynomys* by Gary Morgan)

[ϒ] $^{40}Ar/^{39}Ar$ data from Peters (2000a and 2000b); standard AMS C-14 data from Beta Analytic Inc. (2000)

## Table 2. Whole-rock major element geochemical results

| Sample | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$-T | MnO | MgO | CaO | $Na_2O$ | $K_2O$ | $P_2O_5$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 99RBH5 | 40.19 | 2.53 | 10.88 | 12.90 | 0.20 | 13.96 | 14.32 | 2.76 | 1.16 | 1.11 |
| 99RBH8 | 62.55 | 0.59 | 18.00 | 4.54 | 0.12 | 0.54 | 5.11 | 4.19 | 4.00 | 0.36 |
| 99RBH15 | 40.96 | 2.29 | 11.59 | 11.81 | 0.20 | 14.24 | 13.55 | 3.50 | 0.77 | 1.08 |
| 99RBH16 | 61.86 | 0.73 | 17.21 | 6.75 | 0.10 | 1.27 | 5.11 | 3.39 | 3.27 | 0.31 |
| 99RBH18 | 68.33 | 0.39 | 16.20 | 3.03 | 0.09 | 0.85 | 3.12 | 4.24 | 3.57 | 0.16 |
| 99RBH19 | 50.64 | 1.02 | 19.07 | 8.56 | 0.19 | 2.76 | 9.64 | 3.37 | 4.18 | 0.56 |
| 99RBH20 | 65.39 | 0.43 | 18.51 | 1.70 | 0.03 | 0.21 | 1.16 | 4.77 | 7.70 | 0.10 |
| 99RBH21 | 66.05 | 0.42 | 17.71 | 3.48 | 0.06 | 0.71 | 2.50 | 4.54 | 4.36 | 0.17 |
| 99RBH22 | 54.60 | 0.84 | 18.44 | 8.01 | 0.22 | 2.52 | 6.57 | 4.21 | 4.04 | 0.56 |

# Table 3.  Cross section wells and well pump test data

| Map label* | State Engineer Office Permit Number | Well location number** | Elevation of well head (ft)*** | Total depth of well (ft)*** | Interpreted formation at bottom of well | Primary water-bearing formations | Depth to ground-water (ft)*** | Year ground-water was measured | T**** $ft^2$/day | T**** gpd/ft | Saturated thickness (ft)*** | Length of well screen in saturated zone (ft)*** | K1 (using saturated thickness) (ft/day) | K2 (using saturated screen length) (ft/day) | K1 (m/s) | K2 m/s) | Reference or comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Petroleum exploratory wells** | | | | | | | | | | | | | | | | | |
| Yates La Mesa Unit #3 | | 15.08.13.22241 | 6330 | 4755 | Triassic | | | | | | | | | | | | |
| John Gianardi #1 CZK | | 15.08.22.232111 | 6209 | 7773 | Paleozoic | | | | | | | | | | | | |
| **Monitoring wells** | | | | | | | | | | | | | | | | | |
| Jail Well | Exempt | 15.08.01.1234 | 6341 | 1365 | Te | | | | | | | | | | | | Same as EB-607 of Johnson & Koning, 2012 |
| CDX-OB-A | RG-86221 | 15.08.20.3333 | 6483 | 1802 | Te | | | | | | | | | | | | Same as EB-661 of Johnson & Koning, 2012 |
| **Uranium exploratory wells** | | | | | | | | | | | | | | | | | |
| ND-5 | none | 16.09.32.111 | 6440 | 995 | Tts | | | | | | | | | | | | |
| ND-6 | none | 16.08.36.444 | 6390 | 1699 | Tte | | | | | | | | | | | | |
| ND-7 | none | 16.08.34.311 | 6170 | 680 | Tte | | | | | | | | | | | | |
| ND-8 | none | 16.08.35.432 | 6300 | 1000 | Tte | | | | | | | | | | | | |
| ND-36 | none | 16N.08E.26.122 | 6246 | 1400 | Tts | | | | | | | | | | | | |
| ND-38 | none | 16.08.27.333 | 6176 | 1145 | Tte | | | | | | | | | | | | |
| ND-41 | none | 16.08.15.232 | 6330 | 2000 | Tts | | | | | | | | | | | | |
| ND-55 | none | 16.08.18.213 | 6450 | 1450 | Tts | | | | | | | | | | | | |
| ND-81 | none | 16N.08E.21.344 | 6200 | 800 | Ttse | | | | | | | | | | | | |
| ND-84 | none | 16N.08E.21.343 | 6240 | 775 | Ttse | | | | | | | | | | | | |
| ND-86 | none | 16N.08E.28.213 | 6140 | 810 | Tte | | | | | | | | | | | | |
| ND-90 | none | 16N.08E.21.234 | 6260 | 1000 | Tts | | | | | | | | | | | | |
| ND-96 | none | 16.08.28.231 | 6130 | 705 | Tte | | | | | | | | | | | | |
| **Water Wells** | | | | | | | | | | | | | | | | | |
| 1 | RG-32178 | 16.08.13.3 | 6360 | 595 | Tt | QTa, Tt | 225 | 1980 | 6000 | 45000 | 370 | 345 | 16 | 17 | 5.7E-05 | 6.1E-05 | Jenkins, 1980 |
| 2 | n.a. | 16.08.22.3423 | 6260 | 310 | Tt | QTa, Tt | 310 | 1984 | 470 | 3500 | 182 | n.a. | 2.6 | na | 9.1E-06 | na | Turner, 1984; Fleming, 1991 |
| 3 | n.a. | 16.8.22.3441 | 6240 | 373 | Tt | QTa, Tt | 128.15 | 1984 | 400 | 3000 | 245 | n.a. | 1.6 | na | 5.8E-06 | na | Turner, 1984 |
| 4 | RG-42919 | 16.08.24.411 | 6382 | 400 | Tts | | | | | | | | | | | | |
| 5 | RG-30089 | 16.09.19.3123 | 6405 | 440 | Tts | | | | | | | | | | | | |
| 6 | RG-3824 | 16.08.26.312 | 6250 | 335 | Tts | | | | | | | | | | | | |
| 7 | RG-22251 | 16.08.26.432 | 6260 | 200 | Tt | | | | | | | | | | | | |
| 8 | RG-35280 | 16.08.25.143 | 6320 | 420 | Tt | Tt | 205 | 1985 | 140 | 1000 | 215 | n.a. | 0.65 | n.a. | 2.3E-06 | n.a. | Lazarus, 1985 |
| 9 | RG-59465 | 16.09.30.312 | 6370 | 320 | Tts | | | | | | | | | | | | |
| 10 | RG-30833 | 16.09.30.321 | 6390 | 250 | QTaas | | | | | | | | | | | | |
| 11 | RG-58938 | 16.08.33.332 | 6100 | 104 | QTa | | | | | | | | | | | | |
| 12 | RG-8223 | 16.08.33.34 | 6150 | 103 | QTaas | | | | | | | | | | | | |
| 13 | RG-58260 | 16.08.412 | 6165 | 104 | QTaas | | | | | | | | | | | | |
| 14 | RG-57755 | 16.08.33.421 | 6170 | 80 | Tte | | | | | | | | | | | | |

# Table 3. Cross section wells and well pump test data

| Map label* | State Engineer Office Permit Number | Well location number** | Elevation of well head (ft)*** | Total depth of well (ft)*** | Interpreted formation at bottom of well | Primary water-bearing formations | Depth to groundwater (ft)*** | Year groundwater was measured | T**** $ft^2/day$ | T**** gpd/ft | Saturated thickness (ft)*** | Length of well screen in saturated zone (ft)*** | K1 (using saturated thickness) (ft/day) | K2 (using saturated screen length) (ft/day) | K1 (m/s) | K2 m/s) | Reference or comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | RG-59496 | 16.08.34.331 | 6210 | 200 | QTaas | | | | | | | | | | | | |
| 16 | RG-58825 | 16.08.34.332 | 6210 | 105 | QTaas | | | | | | | | | | | | |
| 17 | RG-58153 | 16.08.34.322 | 6195 | 125 | QTaas | | | | | | | | | | | | |
| 18 | RG-29929 | 16.08.34.241 | 6180 | 143 | Tts | | | | | | | | | | | | Same as G-14 of Johnson & Koning, 2012 |
| 19 | RG-32553 | 16.08.27.314 | 6210 | 137 | QTaas | QTaas | 60 | 1979 | 5200 | 39000 | 77 | 44 | 68.0 | 120 | 2.4E-04 | 4.2E-04 | Geohydrology Assoc., 1979 |
| 20 | RG-32554 | 16.08.27.314 | 6215 | 116 | QTaas | QTaas | 70 | 1979 | 5200 | 39000 | 46 | 39 | 110.0 | 130 | 3.9E-04 | 4.6E-04 | Geohydrology Assoc., 1979 |
| 21 | 67759 | 16.08.36.323 | 6320 | 500 | Tts | | | | | | | | | | | | |
| 22 | 47932 | 16.08.36.344 | 6340 | 400 | Tt | | | | | | | | | | | | |
| 23 | n.a. | 15.08.5.214 | 6100 | 402 | Te | QTa, Te | 50 | 1995 | 100 | 750 | 150 | n.a. | 0.67 | n.a. | 2.4E-06 | n.a. | Cooper, 1995 |
| 24 | RG-61825 | 15.08.4.111 | 6070 | 380 | Te | QTa, Te | 26 | 1995 | 98 | 730 | 354 | n.a. | 0.28 | n.a. | 9.8E-07 | n.a. | Cooper, 1995 |
| 25 | RG-39419 | 15.08.5.323 | 6050 | 225 | Te | QTa, Te | 47 | 1995 | 3200 | 24000 | 174 | n.a. | 180.00 | n.a. | 6.3E-04 | n.a. | Cooper, 1995 |
| 26 | RG-5530 | 15.08.4.113 | 6125 | n.a. | Te | QTa, Te | n.a. | n.a. | 3900 | 29000 | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | Cooper, 1995 |
| 27 | RG-26877 | 15.08.4.113 | 6120 | 116 | Qtaas | | | | | | | | | | | | |
| 28 | RG-61494 | 15.08.4.113 | 6125 | 400 | Te | | | | | | | | | | | | |
| 29 | RG-3824x | 15.08.2.221 | 6300 | 802 | Tte | | | | | | | | | | | | |
| 30 | n.a. | 15.08.02.21132 | 6278 | 715 | Tt | QTa, Tt | 135 | 1953 | 380 | 2800 | 550 | 100 | 0.7 | 3.8 | 2.4E-06 | 1.3E-05 | W.C. Kruger & Assoc., 1953; Fleming, 1991 |
| 31 | n.a. | 15.08.02.22213 | 6315 | 795 | Tt | QTa, Tt | 130 | 1953 | 560 | 4200 | 527 | 100 | 1.1 | 5.6 | 3.7E-06 | 2.0E-05 | W.C. Kruger & Assoc., 1953; Fleming, 1991 |
| 32 | RG-25573 | 15.08.1.44 | 6338 | 228 | QTaas? | | | | | | | | | | | | |
| 33 | RG-27728 | 15.08.14.423 | 6268 | 105 | Te | | | | | | | | | | | | |
| 34 | RG-27729 | 15.08.14.424 | 6275 | 150 | Te | | | | | | | | | | | | |
| 35 | RG-50386x | 15.08.13.111 | 6285 | 203 | Te | | | | | | | | | | | | |
| 36 | RG-50386 | 15.08.13.112 | 6300 | 500 | Tte | | | | | | | | | | | | |
| 37 | RG-72842 | 15.08.13.211 | 6315 | 250 | Te | | | | | | | | | | | | |
| 38 | RG-58052 | 15.08.13.14 | 6300 | 480 | Te | | | | | | | | | | | | |
| 39 | RG-44553 | 15.08.13.41 | 6295 | 510 | Te | Te | 114 | 1985 | 15 | 110 | 310 | 60 | 0.05 | 0.25 | 1.7E-07 | 8.8E-07 | American Groundwater Consultants, 1985 |
| 40 | RG-56326 | 15.08.13.411 | 6275 | 400 | Te | | | | | | | | | | | | Same as G-83 of Johnson & Koning, 2012 |
| 41 | RG-70259 | 15.08.13.224 | 6315 | 480 | Te | | | | | | | | | | | | |
| 42 | RG-59640 | 15.08.13.234 | 6315 | 295 | Te | | | | | | | | | | | | Same as G-17 of Johnson & Koning, 2012 |
| 44 | RG-44554 | 15.09.18.23 | 6360 | 430 | Te | Te | 170 | 1985 | 23 | 170 | 230 | 60 | 0.1 | 0.38 | 3.5E-07 | 1.4E-06 | American Groundwater Consultants, 1985 |
| 45 | RG-44753 | 15.09.18.444 | 6315 | 430 | Te | Te | 122.4 | 1985 | 13 | 100 | 238 | 238 | 0.1 | 0.055 | 1.9E-07 | 1.9E-07 | American Groundwater Consultants, 1985 |
| 46 | RG-72836 | 15.08.18.324 | 6325 | 380 | Te | | | | | | | | | | | | |
| 47 | RG-72408 | 15.08.18.321 | 6343 | 620 | Te | | | | | | | | | | | | |
| 48 | RG-71772 | 15.08.18.241 | 6375 | 600 | Te | | | | | | | | | | | | |
| 49 | RG-6212 | 15.08.21.313 | 6185 | 400 | Ti | | | | | | | | | | | | |
| 50 | RG-27014 | 15.08.22.311 | 6210 | 90 | Ti | | | | | | | | | | | | |
| 51 | RG-47738 | 15.08.22.212 | 6187 | 200 | Tgd | | | | | | | | | | | | |
| 52 | RG-63131 | 15.08.24.221 | 6295 | 280 | Tte | | | | | | | | | | | | |
| 53 | RG-28030 | 15.08.24.214 | 6285 | 130 | Qtaas | | | | | | | | | | | | |
| 54 | RG-28149 | 15.08.24.131 | 6276 | 190 | Tte? | | | | | | | | | | | | |
| 55 | RG-32704 | 15.08.24.144 | 6262 | 140 | Te | | | | | | | | | | | | Same as G-14 of Johnson & Koning, 2012 |
| 56 | RG-71895 | 15.08.24.322 | 6258 | 163 | Tte? | | | | | | | | | | | | |
| 57 | RG-65815 | 15.08.24.414 | 6245 | 200 | Te | | | | | | | | | | | | |
| 58 | RG-65318 | 15.08.24.433 | 6225 | 220 | Tte | | | | | | | | | | | | Same as G-219 of Johnson & Koning, 2012 |
| 59 | RG-42091 | 15.08.24.111 | 6263 | 165 | Te | | | | | | | | | | | | |
| 60 | RG-58749 | 15.08.25.221 | 6230 | 940 | Tgd | | | | | | | | | | | | |

## Table 3. Cross section wells and well pump test data

| Map label* | State Engineer Office Permit Number | Well location number** | Elevation of well head (ft)*** | Total depth of well (ft)*** | Interpreted formation at bottom of well | Primary water-bearing formations | Depth to ground-water (ft)*** | Year ground-water was measured | T**** $ft^2$/day | T**** gpd/ft | Saturated thickness (ft)*** | Length of well screen in saturated zone (ft)*** | K1 (using saturated thickness) (ft/day) | K2 (using saturated screen length) (ft/day) | K1 (m/s) | K2 m/s) | Reference or comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 61 | RG-67769 | 15.08.25.213 | 6240 | 340 | Tc? | | | | | | | | | | | | |
| 62 | RG-55611 | 15.08.25.241 | 6660 | 927 | Tgd | | | | | | | | | | | | |
| 63 | n.a. | 15.8.26.234 | 6190 | 146 | Te | QTa | 80 | 1977 | 300 | 2200 | 80 | | 3.75 | | | | Jenkins, 1977a |
| 64 | RG-48358 | 16.08.26.311 | 6300 | 740 | Tt | Tt, QTa | 168.5 | 1987 | 250 | 1900 | 576 | 200 | 0.4 | | | | Lazurus, 1987 |
| 65 | RG-50256 | 15.08.21.424 | 6238 | 320 | Km? | | | | | | | | | | | | |
| 66 | n.a. | 16.08.26.132 | 6265 | 220 | Tt? | QTa | 136 | 1977 | 8000 | 60,000 | | | | | | | Jenkins, 1977b |
| 67 | RG-57209 | 15.08.13.342 | 6280 | 400 | Te | | | | | | | | | | | | |
| 68 | RG-56326 | 15.08.13.342 | 6280 | 500 | Te | | | | | | | | | | | | |
| 69 | RG-57752 | 15.08.13.412 | 6295 | 595 | Te | | | | | | | | | | | | |
| 70 | RG-65293 | 15.09.18.321 | 6340 | 260 | Te | | | | | | | | | | | | |
| 71 | RG-62646 | 15.09.18.243 | 6370 | 420 | Te | | | | | | | | | | | | |
| EB-001 | RG-39419 | 15.08.5.323 | 6063 | 221 | Tgd | | | | | | | | | | | | |
| EB-113 | RG-13786 | 16.08.25.3212 | 6333 | 210 | Tts | | | | | | | | | | | | |
| EB-127 | RG-19274 | 16.08.24.124 | 6361 | 300.00 | Tts | | | | | | | | | | | | |
| EB-134 | RG-32553 | 16.08.27.342 | 6187 | 137 | Tts | | | | | | | | | | | | |
| EB-214 | RG-44712 | 15.08.15.3111 | 6191 | 210 | Tgd | | | | | | | | | | | | |
| EB-220 | RG-03824T | 16.08.26.32112 | 6256 | 161 | Tts | | | | | | | | | | | | |
| EB-221 | RG-22251x7 | 16.08.26.44334 | 6243 | 220 | Tts | | | | | | | | | | | | |
| EB-222 | RG-22251x8 | 16.08.26.4443 | 6269 | 220 | Tts | | | | | | | | | | | | |
| EB-223 | RG-25952 | 16.08.28.134 | 6168 | 100 | Tts | | | | | | | | | | | | |
| EB-294 | RG-48358 | 16.08.26.1444 | 6300 | 740 | Tts | | | | | | | | | | | | |
| EB-309 | RG-23683x2 | 16.08.21.3321 | 6226 | 300 | Tts | | | | | | | | | | | | |
| EB-311 | RG-71045 | 16.08.28.3343 | 6107 | 180 | Tc | | | | | | | | | | | | |
| EB-331 | RG-61494 | 15.08.5.2132 | 6101 | 400 | Tc | | | | | | | | | | | | |
| EB-332 | RG-74595 | 15.08.4.13324 | 6094 | 160 | Tte | | | | | | | | | | | | |
| EB-333 | RG-55622 | 15.08.4.13344 | 6119 | 140 | Tte | | | | | | | | | | | | |
| EB-339 | RG-44219 | 16.8.26.313 | 6257 | 200 | QTaas or Tts | | | | | | | | | | | | |
| EB-346 | RG-44753 | 15.09.18.4222 | 6332 | 366 | Te | | | | | | | | | | | | |
| EB-369 | RG-53523 | 16.08.24.2343 | 6388.00 | 425.00 | Tts | | | | | | | | | | | | |
| EB-380 | RG-51711 | 15.08.14.1443 | 6253 | | Te | | | | | | | | | | | | |
| EB-411 | RG-44554 | 15.09.18.34132 | 6336 | 430 | Te | | | | | | | | | | | | |
| EB-412 | RG-44553 | 15.08.13.34132 | 6274 | 510 | Te | | | | | | | | | | | | |
| EB-658 | RG-86222 | 16.09.20.3333 | 6480 | 1320 | Tts | | | | | | | | | | | | |
| EB-664 | RG-86218 | 16.09.30.2222 | 6473 | 1400 | Tts | | | | | | | | | | | | |
| EB-666 | RG-86219 | 16.09.30.2121 | 6418 | 450 | Tte | | | | | | | | | | | | |
| EB-691 | RG-92758 | 16.08.28.344 | 6119 | 180 | Tc | | | | | | | | | | | | |
| G-18 | n.a. | 15.08.13.412 | 6310 | 480 | Te | | | | | | | | | | | | |
| G-19 | RG-57545 | 15N.08E.13.4113 | 6298 | 455 | Te | | | | | | | | | | | | |
| G-23 | RG-77679 | 15N.08E.13.222 | 6327 | 460 | Te | | | | | | | | | | | | |
| G-24 | RG-72833 | 15N.08E.13.132 | 6286 | 600 | Te | | | | | | | | | | | | |
| G-27 | RG-73794 | 15N.08E.18.144 | 6305 | 340 | Tc? | | | | | | | | | | | | |
| G-29 | RG-37223 | 15N.08E.23.112 | 6217 | 298 | Tgd | | | | | | | | | | | | |
| G-39 | RG-4697 | 16N.08E.13.421 | 6380 | 368 | Tts | | | | | | | | | | | | |
| G-40 | RG-4697 | 16N.08E.13.230 | 6423 | 410 | Tts | | | | | | | | | | | | |
| G-42 | RG-31960 | 16N.08E.28.233 | 6115 | 65 | Tts | | | | | | | | | | | | |

## Table 3.  Cross section wells and well pump test data

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| G-58 | RG-11826 | 16N.08E.27.2321 | 6218 | 248 | Tts | | | | | | | | | | | | |
| G-90 | RG-71772 | 15N.09E.18.2434 | 6381 | 600 | Te | | | | | | | | | | | | |
| G-97 | RG-79539 | 15N.09E.18.3221 | 6345 | 500 | Te | | | | | | | | | | | | |
| G-113 | RG-81008 | 16N.08E.34.242 | 6181 | 200 | Tts | | | | | | | | | | | | |
| G-134 | RG-76803 | 16N.08E.21.3221 | 6256 | 200 | Tts | | | | | | | | | | | | |
| G-148 | RG-73997 | 16N.08E.21.3232 | 6251 | 253 | Tts | | | | | | | | | | | | |
| G-150 | RG-72234 | 16N.08E.21.423 | 6244 | 220 | Tts | | | | | | | | | | | | |
| G-159 | RG-72558 | 16N.08E.25.3414 | 6282 | 300 | Tts | | | | | | | | | | | | |
| G-162 | RG-71405 | 16N.08E.27.3131 | 6203 | 200 | Tts | | | | | | | | | | | | |
| G-163 | RG-71047 | 16N.08E.27.4313 | 6182 | 140 | Tts | | | | | | | | | | | | |
| G-165 | RG-77392 | 16N.08E.28.1234 | 6197 | 200 | Tts | | | | | | | | | | | | |
| G-168 | RG-73550 | 16N.08E.28.42424 | 6208 | 270 | Tts | | | | | | | | | | | | |
| G-169 | RG-72197 | 16N.08E.28.1422 | 6161 | 100 | Tts | | | | | | | | | | | | |
| G-172 | n.a. | 16.08.28.332 | 6111 | 160 | Ttse | | | | | | | | | | | | |
| G-220a | n.a. | 15.08.25.222 | 6245 | 1000 | Tgd | | | | | | | | | | | | |

Notes:

* Wells beginning with "EB-" or "G-" are from Johnson and Koning (2012), see the map report for complete citation.

**  Numbering system used by the New Mexico State Engineer's Office to locate wells.  The first digit (before the first period) is the township, the second digit the range, and the third digit the section.  After the last period, numbers 1 through 4 stand for NW, NE, SW, SE (respectively) and successively divide up a section as in the township and range location system.  The precision of the well number reflects the precision of the well's location on the map (see Figure 5).

***  To obtain meters from feet, divide by 3.281

****  Average calculated if a range of values were given in the referenced report; values rounded off to two significant figures

n.a. = not available

T is transmissivity; K is hydraulic conductivity; T = K multiplied by the thickness of saturated strata affected by pumping.

Because well construction data in referenced consultant reports are commonly inadequate, K was calculated using both the saturated thickness (depth to groundwater subtracted from total depth of the well) and length of the screen interval (if known) in saturated strata.