THE ANCHA FORMATION: TEXTURAL SUBDIVISIONS, LOWER CONTACT, AND HYDROGEOLOGIC IMPLICATIONS

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INTRODUCTION AND PURPOSE

The Ancha Formation is the uppermost basin fill unit in the Santa Fe embayment. It consists of gravel, sand, and silt derived from the southwestern flank of the Sangre de Cristo Mountains. Although there are some compositional differences in the Ancha Formation that reflect compositional heterogeneity of the crystalline basement, the gravel is generally dominated by granite or gneissic granite, with minor amounts of amphibolite, quartzite, and schist. This Plio-Pleistocene deposit is mostly non-cemented and weakly consolidated. It unconformably overlies the Tesuque Formation (Miocene) in the Santa Fe embayment, north-central New Mexico (Spiegel and Baldwin, 1963). The Santa Fe embayment is bounded by the Sangre de Cristo Mountains to the east, Galisteo Creek to the south, the Cerrillos Hills to the southwest, basalt-capped mesas of the Cerros del Rio volcanic field to the northwest, and the Santa Fe uplands underlain by the Tesuque Formation north of the Santa Fe River. The Ancha Formation extends under the Cerros del Rio basalts westward towards the Santa Fe River, although here it is not as thick as in the center of the embayment – probably because of footwall uplift associated with the La Bajada fault (Koning et al., 2002b).

The main purpose for studying the geologic characteristics of the Ancha Formation is to gain insight into its hydrogeologic properties. For example, it has been demonstrated that effective grain size and sorting relates to hydraulic conductivity (Hazen, 1911; Shepard, 1989). Non-cemented, relatively coarse-grained channel deposits in the Santa Fe Group have been shown to have higher hydraulic conductivity values than finer deposits (Sigda and Paul, Appendix F, this report). The general sorting of sand or gravel within a bed also influences the hydraulic parameters of an aquifer, with poorly sorted textures tending to have lower hydraulic conductivity and porosity than well sorted textures (Fetter, 1988). It is thus important to estimate the percentage of coarse channel deposits in a clastic hydrogeologic unit, such as the Ancha Formation, in addition to describing the architecture and connectivity of these channels (Fogg, 1986; Tyler and Finely, 1991; Davis et al., 1993; Dreyer et al., 1993; Gaud, 2002). Finer-grained deposits, particularly floodplain clay and mud beds, can create confined or semi-confined conditions in an aquifer. Describing their thickness and lateral extent is also useful in assessing the groundwater conditions in a hydrogeologic unit.

The basal contact of the Ancha Formation corresponds with an angular unconformity in all observed outcrops, and could potentially affect vertical groundwater flow between the Ancha Formation and underlying Tesuque Formation, particularly where there is also a grain size distinction between the two formations. Noting such features as weathering and pedogenic activity along the basal contact of the Ancha Formation, or changes in the dip of the underlying Tesuque Formation, could also have important implications for assessing groundwater flow between this and underlying hydrogeologic units.

The following presents results from a detailed geologic examination of the Ancha Formation. This work builds on previous study of the Ancha Formation summarized in Koning et al. (2002b). In particular, this study differentiates ancestral Santa Fe River deposits from alluvial slope deposits derived from smaller catchments, approximately delineates gradational textural trends (at a scale of 1:50,000), and examines the basal contact.

PREVIOUS WORK

Spiegel and Baldwin (1963) were the first to formally apply the name Ancha Formation to the Pliocene-Pleistocene gravel, sand, and silt that rest with angular unconformity on the Tesuque Formation. They originally defined a partial type section for the Ancha Formation using a 49 m-thick exposed interval of arkosic, weakly consolidated sediment on the southwest slope of Cañada Ancha, 18 km northwest of Santa Fe. Later work restricted the Ancha Formation to the upper 12 m of Spiegel and Baldwin's type section, with the underlying strata assigned to a coarse unit of the Tesuque Formation (Koning et al., 2002b). Koning et al. (2002b) recognized that south of Interstate 25 the Ancha Formation becomes significantly finer to the west. They thus proposed subdividing the Ancha Formation into a fine alluvial member to the west and a coarse alluvial member to the east. Relatively coarse sediment in the general area between the modern Santa Fe River and La Cienega Creek was interpreted to have been deposited by an ancestral Santa Fe River (Koning et al., 2002b).

With three exceptions, geologic mapping over the past three decades (Bachman, 1975; Johnson, 1975; Booth, 1977; Kelley, 1978; Lisenbee, 1999; Read et al., 1999 and 2000; Koning and

Hallet, 2000; Maynard and Lisenbee, 2002) generally agrees with the mapping of Spiegel and Baldwin (1963). One exception is for detritus shed from the Cerrillos Hills. Because this sediment is compositionally and temporally similar to the Tuerto Formation to the south, Koning and Hallet (2000) include it with the Tuerto Formation rather than the Ancha Formation. A second exception is for the area north-northeast of Cañada Ancha. Here, Spiegel and Baldwin (1963) included granite-rich sandy gravel and gravelly sand found in the western Horcado Ranch and northern Agua Fria quadrangles with the Ancha Formation on their map and type section. However, subsequent geologic mapping by Kelley (1978) and Koning and Maldonado (2001), together with dating of tephras, confirm that the Ancha Formation here is restricted to a 10-20 (?) m-thick sand and gravel deposit immediately beneath flows and tephras of the Cerros del Rio volcanic field (Koning et al., 2002b). Lastly, the correlation of the Ancha Formation to high-level gravel deposits in the northeastern Espanola Basin (Miller et al., 1963) was rejected by Manley (1976 and 1979).

Past studies of the Tesuque Formation in the east-central Española Basin may also have relevance to the Ancha Formation, since both were emplaced in the same general depositional environment. Cavazza (1986) subdivided Tesuque Formation strata in this part of the basin into two lithosomes based on composition and paleocurrent data. Sediment associated with lithosome A was derived from the granite-dominated Sangre de Cristo Mountains, and deposited by westward-flowing streams. The Ancha Formation would fall under lithosome A in the nomenclature of Cavazza (1986). Past studies (Smith, 2000, and Smith and Kuhle, 2001, in particular, but also Koning and Maldonado, 2001, Koning, 2002, Koning et al., 2002a, and Koning, 2003) have interpreted an alluvial slope depositional environment for lithosome A of Cavazza (1986). Because of their similarities, information regarding textural and hydrogeologic characteristics of alluvial slopes, such as those derived from study of lithosome A of the Tesuque Formation (Gaud, 2002), would be applicable to much of the Ancha Formation as well. Lithosome B of Cavazza (1986) is not readily applicable to the Ancha Formation because it was deposited by a relatively large, south-southwest flowing river sourced in Paleozoic sedimentary strata and Proterozoic quartzite rocks. It is also worth noting that other lithosomes have been proposed for the Tesuque Formation: lithosome S for ancestral Santa Fe River deposits of

Oligocene-Miocene age (Koning et al., 2004a), in addition to lithosome E for volcanic-bearing sediment derived from erosion of the Espinaso Formation (Daniel Koning, unpublished data).

THICKNESS

The Ancha Formation generally ranges from 10 to 90 m thick in the Santa Fe embayment based on geologic map, drill-hole, and seismic data (Koning et al., 2002b; S. Biehler, personal commun., 1999). Locally it may be slightly thicker than 90 m, such as where it buries paleovalleys developed on the upper Tesuque Formation contact. The Ancha Formation is 19-26 m thick on the western edge of the Caja del Rio Plateau north of the Santa Fe River, where it is appreciably thinner than in the center of the Santa Fe embayment to the east.

AGE

The base of the Ancha Formation is diachronous, and ranges from 2.7-3.5 Ma (?) in the western Santa Fe embayment to ~ 1.6 Ma in the eastern embayment near the Sangre de Cristo Mountains (Koning et al., 2002b). Sedimentation near the Pliocene-Pleistocene boundary appears to have been concentrated in the eastern embayment, and may reflect changes in discharge and sediment supply at that time.

ANCHA FORMATION DEPOSITS AND HYDROGEOLOGIC IMPLICATIONS

The Ancha Formation was deposited on a streamflow-dominated piedmont (i.e., alluvial slope) in the Santa Fe embayment; most of these streams were probably ephemeral. In and southwest of Santa Fe, much of the Ancha Formation corresponds to a fluvial facies of a Plio-Pleistocene Santa Fe River. Although this ancestral Santa Fe River was also deposited on an alluvial slope, it drained an appreciably larger area than streams associated with the alluvial slope to the south or north. Consequently, it was likely perennial and had relatively high flow energy.

South of the ancestral Santa Fe River, the alluvial slope deposits consist of coarse-grained channel facies interbedded with noticeably finer-grained sediment herein called extra-channel sediment, following Koning (2003) and Koning et al. (2004b). The proportion of extra-channel sediment significantly diminishes as one moves towards the mountain front, which probably imparts trending anisotropy to this hydrostratigraphic unit. These particular piedmont deposits are similar to alluvial slope sediment described in the Tesuque Formation by Smith (2000). Alluvial slope deposits generally lack the tabular, planar-bedded couplets of relatively coarse- and fine-grained sediment diagnostic of sheetflood deposits, which are characteristic of alluvial fans (Bull, 1972; Blair, 1987 and 1999; and Blair and McPherson, 1994). The preserved constructional surface of the alluvial slope sediment away from the mountain front is relatively flat, and constitutes the top of the Ancha Formation. This surface has been designated as the Plains surface by Spiegel and Baldwin (1963).

Within about 3 km west of the mountain front south of the ancestral Santa Fe River, gravelly sediment comprises greater than a third of the estimated sediment volume, and lobate, fan-like geomorphic features are recognized on the present land surface. This sediment is dominated by very thin to medium, lenticular beds that probably reflect amalgamated erosionally truncated channels. Locally, about 10-20% of the section consists of poorly sorted deposits interpreted as being laid down as hyperconcentrated flows (including debris flows). Possible sheetflood deposits are very minor (trace to 2%); however, limited outcrop width makes it difficult to verify whether planar, very thin-thin beds of alternating coarse-fine, sand-gravel actually fill broad channels, rather than being unconfined sheetflood deposits. This area adjacent to the mountain front may perhaps be thought of as a gradation between alluvial slope to alluvial fan deposits, but for the purposes of this report we treat them as alluvial slope deposits.

The Ancha Formation north of the ancestral Santa Fe River was deposited on a gently sloping (~1-2 degrees) alluvial slope on the western flank of the Santa Fe uplands. Drainages and their associated channels on this alluvial slope were relatively small, as were their corresponding feeder canyons in the Santa Fe uplands. Eolian sedimentation was significant here.

The interpreted depositional environment has important hydrogeologic implications. Channel avulsion on the alluvial slope south of the Santa Fe River was probably common, and the resulting distribution of channels in an outcrop appears random. The ancestral Santa Fe River probably did not significantly meander, but it may have been more likely to shift back and forth in a continuous fashion because its coarse-grained channels are more laterally continuous and connected than in alluvial slope sediment to the south.

Below, we describe the alluvial slope and ancestral Santa Fe River deposits in detail. Although technically the ancestral Santa Fe River sediments were deposited on an alluvial slope, we will distinguish them separately from alluvial slope deposits north and south of this river. Stratigraphic sections representing these two deposits, and various textural subdivisions within them, are presented in Appendix 1. These stratigraphic sections were measured and described by Daniel Koning except for the Galisteo 2 section, which was described by Sean Connell and Frank Pazzaglia (unpublished data). Section locations are shown on Plate 3 of this report.

Alluvial Slope Deposits (Map Unit QTaas)

General description of alluvial slope deposits south of the ancestral Santa Fe River. The alluvial slope deposits of the Ancha Formation south of the ancestral Santa Fe River can be subdivided into extra-channel and channel facies. The extra-channel facies is characterized by a poorly to moderately sorted, silty or muddy sand (mostly very fine- to medium-grained sand with subordinate coarse- to very coarse-grained sand) that contains minor, scattered pebbles. Some of the poorly sorted beds with scattered pebbles may represent hyperconcentrated flow deposits. The sediment is well-consolidated and commonly weakly cemented by calcium carbonate. The beds in this facies are medium to thick, tabular to broadly lenticular, and internally massive or bioturbated. Scattered very thin to thin lenses of coarse sand and pebbles may be present in sparse quantities. The sediment of this facies is interpreted to have been deposited in very broad channels or swales, or as small depositional lobes on an alluvial slope.

The other sedimentary facies consists of channel deposits of gravelly sand, sandy gravel, and medium- to very coarse-grained sand. These coarse channels are lenticular to broadly lenticular in form and commonly medium to thick. The channels are generally 2-30 m in width. Within a channel, the sand is commonly planar-laminated and the pebbles are in very thin to medium, lenticular beds; local tangential cross-stratification or trough-cross-stratification is present but generally less than 50 cm thick. Gravel is clast-supported, moderately to poorly sorted, and subrounded (more subangular towards the mountain front). Clasts consist of granite, foliated granite, and granitic gneiss with subordinate (3-15%) amphibolite or amphibolite-gneiss; locally, there are trace intermediate-felsic volcanic rocks presumably derived from reworking of the Espinaso Formation or Bishops Lodge Member of the Tesuque Formation. Quartzite clasts comprise less than 2% of the total gravel fraction south of Interstate 25, but become more abundant (1-16%) between the Galisteo River and Gallina Arroyo. Channel sediment is generally loose to weakly consolidated and non-cemented. However, locally there is moderate to strong cementation, especially at the base of the Ancha Formation where it overlies the Galisteo Formation and Mesozoic strata.

The Plains surface contains compound soils that locally exhibit <25 cm-thick, clay-rich Bt orBtk horizons underlain by 50 to >100 cm-thick calcic and siliceous Bk or Bkq horizons with stage II to III+ pedogenic carbonate morphology (Koning et al., 2002b). Below the soils associated with the Plains surface, buried soils are not common. Where exposed, these buried intraformational paleosols are characterized by clay-rich Bt horizon(s) overlying paler-colored calcic horizon(s) with stage II to III pedogenic carbonate morphology (Koning et al., 2002b).

General description of alluvial slope sediment between the ancestral Santa Fe River and upper Cañada Ancha. The Ancha Formation alluvial slope deposits between the ancestral Santa Fe River and upper Cañada Ancha, in particular its tributary of Alamo Creek, are generally very pale brown to light yellowish brown, silty, very fine- to medium-grained sand. They contain 1-20% channel deposits of medium- to very coarse-sand and sandy gravel. The channels are generally in very thin to medium, lenticular beds and only 1-5 m wide, but locally are as much as 2 m thick and 30 m wide. The relative abundance of these coarse channel deposits increases towards the east. The gravel in the channels are pebble- to fine-cobble in size, poorly sorted, subrounded to subangular, and consist of granite with 10-35% quartzite, 0.5-1% chert, 1-15% Paleozoic clasts of limestone and siltstone, 2-5% amphibolite, and 3% micaceous gneiss and schist. The composition of the gravel, combined with the relative small size of the channels, indicates the sediment was locally reworked from the Tesuque Formation in the Santa Fe uplands located north of Santa Fe. Most of the silty very fine- to medium-grained sand is likely eolian in origin but may have been reworked by local slopewash processes. Buried soils are locally present and may be vertically spaced on the scale of 1-5 m.

The fine-grained sediment is interbedded with subordinate, very thin to thick beds of phreatomagmatic deposits; these generally consist of medium- to very coarse-grained sand (basalt with various proportions, but generally <50%, of arkosic sand) and minor very fine to medium basaltic pebbles. Phreatomagmatic deposits are found throughout the Ancha Formation in the northern Santa Fe embayment, but are most abundant northwest of Arroyo Calabasa (Ralph Shroba, 2004, written communication). These are partly indurated (with only minor effervescence in dilute hydrochloric acid) or well consolidated.

Hydrogeologic implications of features in alluvial slope deposits. The extra-channel facies of the Ancha Formation probably has lower hydraulic conductivity values compared to the coarse channel facies. This inference is based on comparison to air-permeameter measurements on lithosome A extra-channel facies in the Tesuque Formation (John Sigda, 2003, unpublished data). The extra-channel sediment is generally poorly to moderately sorted, with appreciable amounts of silt or mud in the interstices of the sand grains. These fines would be expected to reduce porosity. Strong cementation observed in coarse channels of the Ancha Formation near its base in the southern part of the Santa Fe embayment (see below discussion of the basal contact for this part of the embayment) may dramatically reduce the hydraulic conductivity. Relatively indurated and well consolidated phreatomagmatic deposits, which are particularly common north of the Santa Fe River, may potentially influence unsaturated flow in the Ancha Formation in this area.

Textural-based subdivisions. The Ancha Formation varies considerably in texture, with the general trend of becoming finer to the west (Koning et al., 2002b). We have subdivided the alluvial slope deposits into four units based on the proportions of coarse-grained channels to finer-grained extra-channel sediment. The four textural units corresponding to this subdivision are shown on the compilation map. The boundaries between the units are very gradational in a lateral sense (3 to 4 km in width). We approximated the unit boundaries based on inspection of outcrops and available records of well cuttings. It should be noted that the outcrops south of Interstate 25 are small and of poor quality. Here, most outcrops of the Ancha Formation expose only 1 to 2 m below the ground surface, an interval which has incorporated much eolian silt and fine sand during Pleistocene time. This eolian sediment commonly makes the Ancha Formation appear finer-grained near the surface than it actually is at depth. Consequently, in this textural subdivision we place little weight on small outcrops at the modern surface, especially when they overlie well-developed calcic soils. The four textural subdivisions are described below, in decreasing order of inferred groundwater-resource potential, as well as inferences regarding hydrogeologic characteristics:

>35% coarse channels: More than 35% of this unit contains coarse-grained channel deposits probably associated with ephemeral avulsing streams. Channels are probably interconnected, and there is likely to be greater than 50% coarse channels in most places. The inferred high degree of channel interconnection could make this unit a potentially useful aquifer zone, with relatively high overall hydraulic conductivity. However, most of this textural subdivision is not within the saturated zone.

25-60% coarse channels: This unit is differentiated only in the southernmost Santa Fe embayment, and contains about 25-60% coarse-grained channels. Most channels are probably interconnected, and so the overall hydraulic conductivity of the unit would be inferred to be moderate to high. However, this textural subdivision is generally not located within the saturated portion of the Ancha Formation.

15-60% coarse channels: This unit contains 15-60% coarse-grained channels scattered in finer extra-channel deposits. Some to most coarse channels are interconnected. Overall hydraulic conductivity of the unit is inferred to be moderate to high. Aquifer transmissivity measured in wells completed across this unit and into the underlying Tesuque or Espinaso Formations ranges from 70 to 980 ft^2/day.

1-30% coarse channels: Channels are probably not significantly interconnected. Overall hydraulic conductivity of the unit is generally inferred to be relatively low, but locally may be moderate. Aquifer transmissivity in wells completed across this unit and into the underlying Espinaso Formation ranges from 15 to 280 ft^2/day.

Ancestral Santa Fe River Deposits (Map Unit QTasr)

General description. Sediment deposited by an ancestral Santa Fe River during Pliocene and early Pliostocene times contains sandy gravel in thin to thick, lenticular to broadly lenticular to channel-shaped beds; locally, there is planar- or tangential- cross-stratification up to 90 cm thick. The gravel is generally clast-supported and consists of pebbles with 30 to 50% cobbles; clasts are subrounded, poorly sorted, and composed of granite with 1 to 6% quartzite and 1 to 3% amphibolite. There are minor beds of silty or clayey very fine to fine sand that correspond to floodplain sediment, plus minor beds of extra-channel sediment (muddy very fine to very coarse sand with 1 to15% pebbles) similar to that seen in alluvial slope deposits to the south. Extra-channel sediment become more abundant (30 to 50% of sediment volume) near the southern and northern margins of the ancestral Santa Fe River deposits, likely because of interfingering with alluvial slope deposits. The sediment is weakly to moderately consolidated, and not cemented.

Hydrogeologic implications of features in the ancestral Santa Fe River deposits. The overall coarseness of this deposit, in particular the predominance of sandy gravel channel deposits, is strongly suggestive of relatively high hydraulic conductivity values. In general, the floodplain beds do not appear sufficiently laterally extensive as to form confined conditions within the unit. However, locally there may be laterally extensive floodplain beds which could act as aquitards to groundwater flow. The aquifer transmissivity measured in wells completed in this unit ranges from 470 to 7750 ft^2/day, and reflects the highest transmissivity values measured in the Southern Española Basin.

Rate of Clast Size Diminishment Away From the Mountain Front

Because grain size is known to relate to hydraulic conductivity (Hazen, 1911), a survey of gravel clast size was conducted across the Santa Fe embayment from the mountain-front to the western edge of the Caja del Rio Plateau. Clast diameters in the ancestral Santa Fe River deposits were generally measured from vertical outcrop faces, but many measurements in the alluvial slope deposits to the south were taken from clasts lying on the surface that did not show evidence of recent spallation. At a given locality, the longest and intermediate axes of the 5 to 7 largest clasts were recorded and an arithmetic mean was calculated. The mean intermediate (b) axis of gravel is plotted against distance from the mountain front (Figure 1). On the graph, the data are differentiated into two groups that correspond to the ancestral Santa Fe River and alluvial slope deposits south of the Santa Fe River.

The data plotted in Figure 1 show an appreciable clast size decrease westward away from the mountain front, and there is more variation in the average maximum clast sizes in the alluvial slope deposits compared to the ancestral Santa Fe River deposits of the Ancha Formation. This figure allows some inferences to be made concerning the competency of the drainages that deposited the alluvial slope sediment versus that of the ancestral Santa Fe River. Stream competency is the largest particle that a stream can move under a given set of hydraulic conditions (Ritter, 1986). The data in Figure 1, in particular the difference in slopes of the two data sets, indicates that the Santa Fe River was able to maintain higher competency away from the mountain front than the smaller alluvial slope drainages. Buried clast sizes revealed in good exposures representing both data sets mimic this trend, and so it is difficult to argue that the two slopes in Figure 1 are primarily due to weathering effects such as spallation.

The westward decrease in stream competence indicated in Figure 1 may be due to reduction in original channel depth (lessening the shear stress on a given clast) or reduction in depositional slope in that direction. Loss of discharge due to evaporation or infiltration is also a factor in the westward decrease of the maximum clast sizes. The lesser clast size range and lower regression line slope of the ancestral Santa Fe River data may possibly be related to the more perennial stream discharge in that area. The riparian vegetation associated with perennial streams would likely create more resistance to bank erosion (Smith, 1976), and lead to higher channel depth to width ratios. One would also expect less infiltration under a perennial stream due to relatively constant saturated conditions. Thus, channels associated with the ancestral Santa Fe River may have maintained their depths and a given stream discharge volume transferred farther westward from the mountain front, creating a more constant flow regime and competence. However, possible weathering and spallation effects on surface clasts, in addition to the more numerous measurements, might also contribute to the larger spread of clast size data in alluvial slope deposits south of the ancestral Santa Fe River.

BASAL CONTACT OF THE ANCHA FORMATION

Description

Exposures of the basal contact of the Ancha Formation were described as part of this study. All exposures show an angular unconformity at this contact. Because there are no exposures in the center of the Santa Fe embayment, we cannot be absolutely certain if the basal contact here represents an angular unconformity, disconformity, or conformable transition with the underlying Tesuque Formation. Because of a 5 to 6 Myr age difference between the Tesuque and Ancha Formations along Cañada Ancha (Koning et al., 2002b) it is unlikely that the Ancha-Tesuque Formation is conformable. The Ancha Formation is generally undeformed where exposed, whereas the underlying Tesuque Formation has been mildly to moderately tilted. Thus, it is likely that this unconformity is angular throughout the Santa Fe embayment. In the following, we describe and discuss the basal Ancha Formation contact at various places in the Santa Fe embayment.

Northeastern Santa Fe embayment. The Ancha Formation (both the alluvial slope and ancestral Santa Fe River deposits) overlies the Tesuque Formation with an angular unconformity. The contact is well-exposed in numerous locations in the eastern Santa Fe embayment between the Santa Fe River and Arroyo Hondo. At these localities, there is no cementation or even significant discoloration associated with the Ancha Formation contact. Moreover, the basal contact here corresponds to a scour surface with meter-scale relief, and no noticeable soils were observed in the Tesuque Formation immediately below the contact. Photos and descriptions of the contact and overlying Ancha Fm are shown in Figures 2 and 3.

Northern and northwestern Santa Fe embayment. The base of the Ancha Formation is readily observed on the western edge of the Caja del Rio escarpment, under the basalt flows of the Cerros del Rio volcanic field. Here, the basal contact is an angular unconformity, with the Ancha Formation overlying a distinctive volcaniclastic unit of the Tesuque Formation (lithosome E) whose gravel fraction consists of reworked detritus from the Espinaso Formation. No cemention or discoloration was observed at the contact, nor was there a soil developed in the uppermost Tesuque Formation.

Under the flows of the Cerros del Rio volcanic field near the big bend of Cañada Ancha (near Portales Pond), the Ancha Formation overlies lithosome S and lithosome A of the Tesuque Formation with angular unconformity. Because the Tesuque Formation is only shallowly dipping (less than 6 degrees), this apparent dip discrepancy is generally not obvious in the small exposures of the area. At one locality in the "big bend" (site WA-88;UTM coordinates: 3951930 N, 402025 E, zone 13; NAD 27) the uppermost 60 cm of Tesuque Formation has a calcic soil with a stage III pedogenic carbonate morphology. East of the latter location, the contact is not well-exposed. Here, there may possibly be a soil in the Tesuque Formation immediately below the contact, as seen in WA-88, but there is nothing to suggest development of a petrocalcic horizon with stage IV carbonate morphology.

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North of the prominent eastward bend of Cañada Ancha, the Ancha Formation overlies the coarse upper unit of the Tesuque Formation (lithosome A). Because of the low dips of the Tesuque Fm (1 to 3 degrees), there is no obvious discrepancy in bedding dips between the Ancha and Tesuque Formations on either side of the unconformity.

In the modern Santa Fe River west of Agua Fria, the base of the Ancha Formation is well-exposed. Here, one can observe the basal Ancha contact from northeast to southwest, where a change from locally reworked Tesuque Formation material in the Ancha Formation to ancestral Santa Fe River gravel is well exposed (Figures 4 and 5). In the modern river bed, there is a prominent angular unconformity at the base of the Ancha Formation. However, there is no cementation or discoloration associated with the contact. Furthermore, there is no significant soil development at the top of the underlying Tesuque Formation (lithosome S).

North of the Santa Fe River and south of Cañada Ancha, the relatively fine Ancha Formation overlies lithosome S of the underlying Tesuque Formation in an angular unconformity. No cementation, discoloration, or soils were observed at the contact in this area.

La Cienega area. Although the basal Ancha contact projects to the ground surface at La Cienega, poor exposures precluded an evaluation of this boundary. In the lower part of the

Ancha Formation described in the La Cienega stratigraphic section (Appendix 1), much of the lower units are weakly cemented by $CaCO_3$, and unit 4 has 5% very thin to thin, wavy beds of strongly cemented very fine to fine sand. The lower Ancha Formation may be somewhat more cemented here than to the east, perhaps due to upwelling of groundwater east of the structurally high, and relatively impermeable, Espinaso Formation and Oligocene intrusions at La Cienega.

Bonanza Hill and Turquoise Hill area. In cuttings logs for water wells 1to 4 km east of Bonanza Hill and Turquoise Hill, there is a 3 to 9 m thick interval at the base of the Ancha Formation that is cemented by calcium carbonate (commonly called "caliche" or "hard white shale" in the driller logs). Such beds of dense to powdery calcium carbonate have been noted locally on the surface in the area (e.g., Spiegel and Baldwin, 1963; Koning and Hallet, 2000, for the Plio-Pleistocene sediment re-designated as the Tuerto Formation). It was noted that these exposed "limy" deposits were developed in the Ancha Formation immediately above its contact with underlying, significantly less permeable rocks (Spiegel and Baldwin, 1963). This also appears to be the case for the subsurface basal Ancha Formation 1 to 4 km east of Bonanza Hill and Turquoise Hill, where the Ancha Formation overlies the Galisteo and Espinaso Formations (Koning and Hallett, 2000). This calcium carbonate may have accumulated in the distalmost part of the Ancha Formation early in its deposition, as this sediment on-lapped onto paleo-topographic highs of the La Bajada fault footwall. The actual process of calcium carbonate enrichment may be due to evaporation of shallow groundwater mounding up against these lower-permeability rocks.

Southern Santa Fe embayment. Where the Ancha Formation overlies the Galisteo Formation, there locally is a 1.5 to 2 m-thick zone at the base of the Ancha Formation, with induration of at least some of the beds (Figure 6). This degree of strong cementation was not seen where the Ancha Formation overlies the Espinaso Formation (see section SEO-A87 in Appendix 1), although only a few exposures were accessible for observation. In the latter there were local zones of weak to moderate cementation in the lower units of the Ancha Formation (manifested as white bands); however, the cementation did not result in induration. Eastward towards Lamy, where the Ancha Formation overlies Mesozoic strata, there is significant cementation of the lower 4 to 10 m of the Ancha Formation (see Galisteo 02 section of Appendix 1; Figure 7). Near the syncline axis in the southern part of the Santa Fe embayment, where the Ancha Formation is interpreted to overlie the Tesuque Formation, driller's cuttings logs generally do not mention a cemented zone at the inferred base of the Ancha Formation.

Hydrogeologic Implications

The basal contact of the Ancha Formation corresponds with an angular unconformity in all observed outcrops, and could potentially affect vertical groundwater flow between the Ancha and underlying Tesuque Formation, particularly where there is also a grain size distinction between the two formations. Anisotropy related to sedimentary stratification has been shown to decrease vertical hydraulic conductivity up to an order of magnitude relative to horizontal hydraulic conductivity (Domenico and Schwartz, 1990; Davis, 1969). The effects of an unconformable contact could presumably be even more pronounced as the weathering and pedogenic activity that is likely to occur on an exposed surface over geologic time may lead to an increase in fines or cementation just below the exposed surface (Birkeland, 1999). After burial, any increase in fines and development of cementation associated with the exposed surface would likely reduce vertical hydraulic conductivity across the basal contact. Noting such features as weathering and pedogenic activity, or changes in the dip of underlying formations, along the basal contact of the Ancha Formation could have important implications for assessing groundwater flow between this and underlying hydrogeologic units.

The strong degree of cementation of the basal Ancha Formation in much of the southeast and southwest parts of the Santa Fe embayment appears to coincide with localities where the Ancha Formation overlies Mesozoic strata, the Galisteo Formation, or locally, the Espinaso Formation. Such strong cementation would likely retard vertical water flow through this basal zone. Here one might expect perched aquifers in the Ancha Formation, or local confined conditions in underlying hydrostratigraphic units. This cementation could also impede downward flow into underlying rock units. Immediately east of La Cienega, where the Ancha Formation overlies the Tesuque Formation, the base of the Ancha Formation may possibly be somewhat more cemented than closer to the mountain front.

In the northwest and northeast parts of the Santa Fe embayment, in particular where the Ancha Formation overlies the Tesuque Formation north of La Cienega Creek, there is no evidence of a significant barrier to groundwater flow at the base of the Ancha Formation. Likewise, in the southern embayment near the syncline axis there is no evidence of significant cementation where the Ancha Formation overlies the Tesuque Formation. It is very likely that vertical flow between the Ancha Formation and the underlying hydrogeologic units is significantly greater where Ancha overlies the Tesuque Formation than in the southern part of the embayment where the Ancha Formation overlies pre-Tesuque hydrogeologic units.

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This report was improved greatly by reviews and comments of Sean Connell of the New Mexico Bureau of Geology and Mineral Resources, and of Ralph Shroba of the U.S. Geological Survey.

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FIGURES

Figure 1

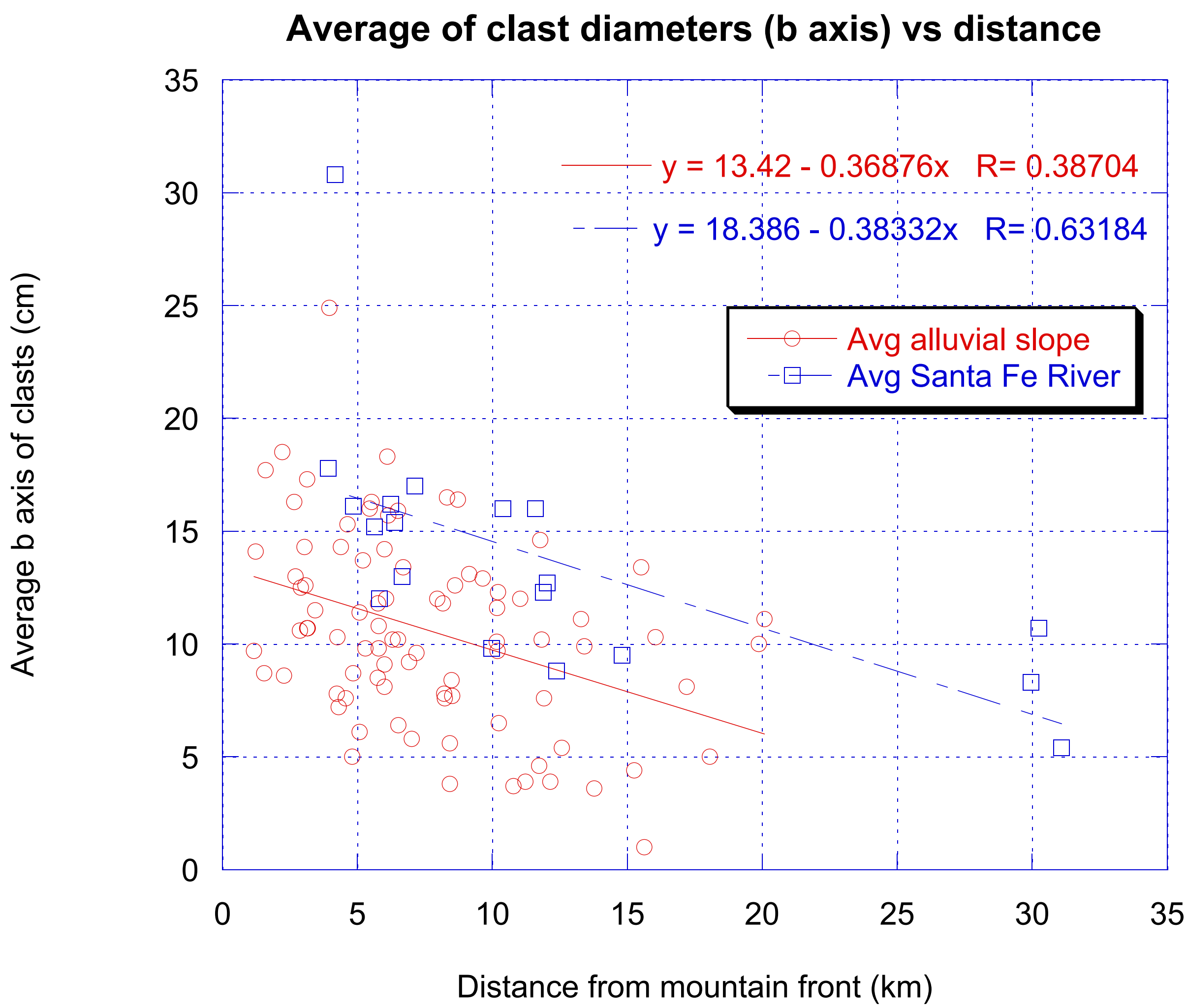

Average of clast diameters (b axis) vs distance
y = 13.42 - 0.36876x R= 0.38704
y = 18.386 - 0.38332x R= 0.63184
Avg alluvial slope
Avg Santa Fe River
Average b axis of clasts (cm)
Distance from mountain front (km)
0
5
10
15
20
25
30
35

Figure 2. Brownish sandy gravel of the Ancha Formation (12 m thick) overlying reddish lithosome S of the Tesuque Formation (4.5 m thick); head of rock hammer is on the contact. Note the lack of discoloration, cementation, or paleosols at the contact. Photo taken at site SEO-A3 in Arroyo de los Chamisos, about 0.4 km east-northeast of Santa Fe High School. UTM coordinates: 3945309N, 412777E (NAD 27, zone 13).

Figure 3. Close-up view of the Ancha Formation in Figure 2. The Ancha Formation here is a sandy gravel interpreted to have been deposited by an ancestral Santa Fe River (unit QTasr). Beds are vague, thin to medium, and broadly lenticular. The sedient is weakly to moderately consolidated and not significantly cemented.

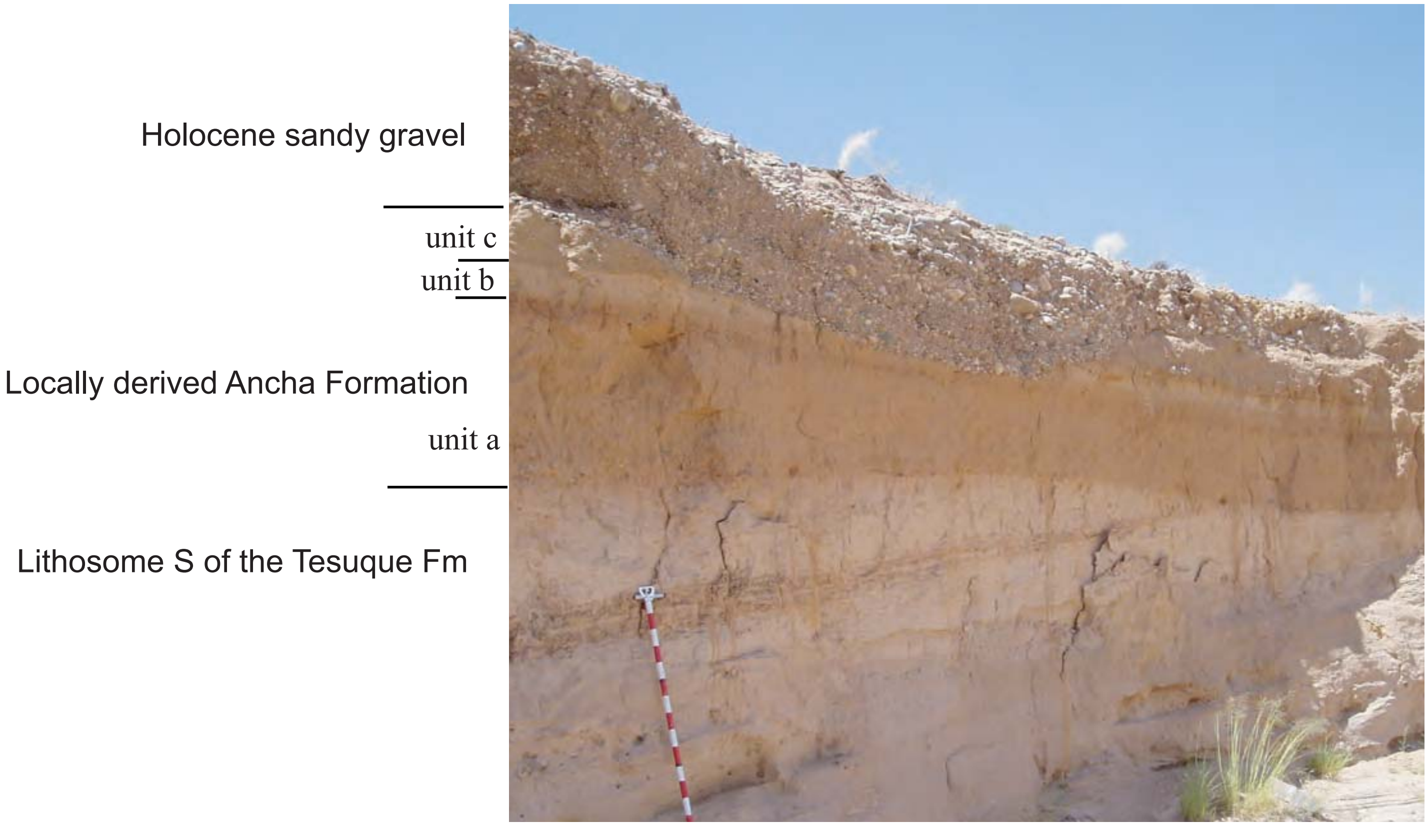


Figure 4. Angular unconformity under the Ancha Formation at site SEO-A76. The Ancha Formation here consists of three units, from base to top: a) 95 cm of a fining-upward, light brown, slighty clayey, very fine to very coarse sand with 3-5% very fine to fine pebbles; lowermost 10 cm of unit a consists of very fine to very coarse pebbles and minor fine cobbles; a reddish Bt soil horizon has formed on upper 11-16 cm of the unit; b) 35 cm of light yellowish brown, very fine to very coarse sand with 7-10% very fine to coarse pebbles; c) 0-95 cm of yellowish brown, clayey-muddy, very fine to very coarse sand (mostly mU-cU) that is in vague, thin to medium, lenticular to broadly lenticular beds. Clast count of basal gravel (unit a, n=106) gives: 39% granite, 34% quartzite, 9% vein quartz, 8% cherty quartzite, 5% altered, epidotized-chloritized granite, and 1% musc-shcist. This clast composition is very similar to the underlying Tesuque Fm and indicates that the Ancha Fm here was locally reworked from the Tesuque Fm. Site is located 260-270 m southeast of the County Road 62 bridge over the modern Santa Fe River (UTM coordinates: 3946077N, 0407098E; NAD 27, zone 13).

Figure 5. Buttress unconformity under the ancestral Santa Fe River facies of the Ancha Formation at site SEO-A78 (also refer to associated stratigraphic section in Appendix 1). UTM coordinates: 3945850N, 0406730E (NAD 27, zone 13).

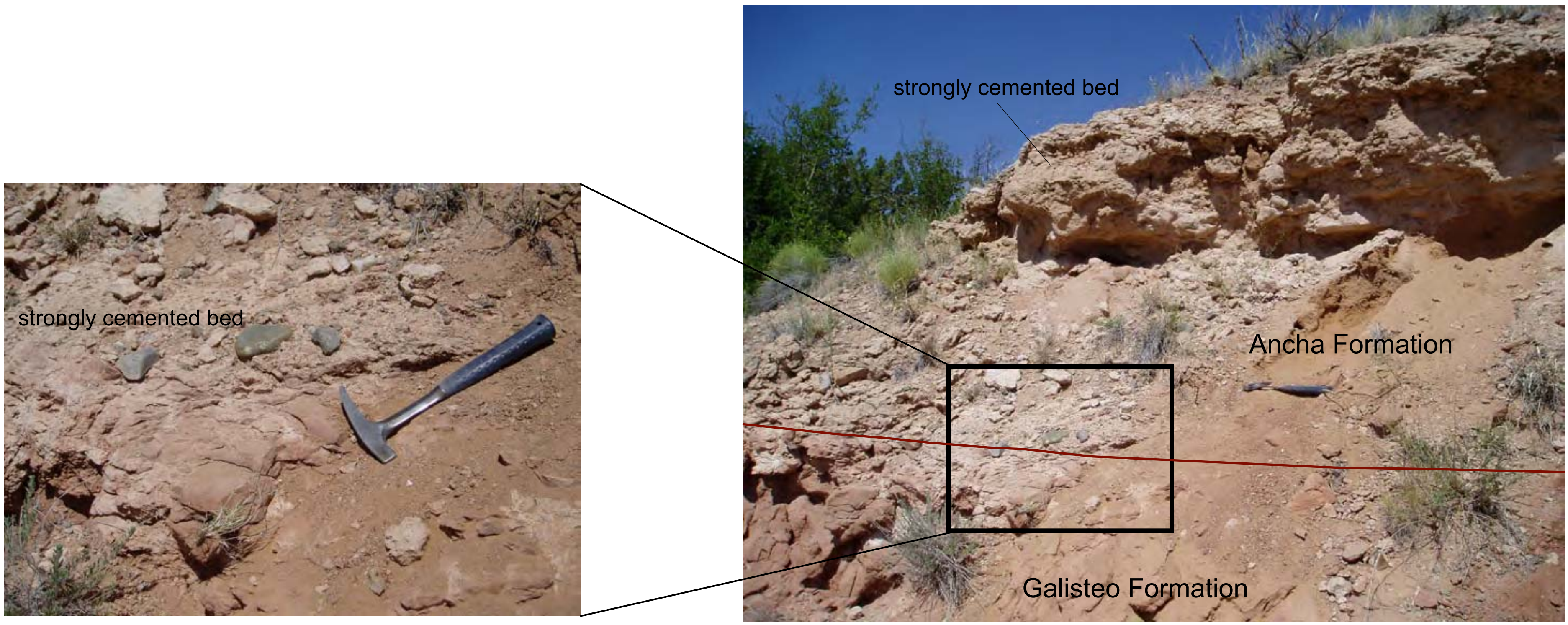


Figure 6. Unconformable contact between the Ancha Fm (top) and sandstone of the Galisteo Fm (base) in the southern Santa Fe embayment. Note the two strongly cemented beds in the basal Ancha Fm, with a non-cemented interval between them. Located at base of stratigraphic section SEO_A80 (west side of Highway 14 about 1.78 km southwest of San Marcos Spring; UTM coordinates: 3923262 N, 402244E, NAD 27, zone 13).

Figure 7. Strongly cemented zone at base of Ancha Formation in the southeastern Santa Fe embayment. Here, it is 7-8 m thick. Location is in lower part of Galisteo 02 stratigraphic section (UTM coordinates of base of section: 3927340 N, 417770 E (NAD 83, zone 13)). This basal cemented zone is also observed in well data at Eldorado 5-6 km to the north.

APPENDIX 1

STRATIGRAPHIC SECTIONS

EXPLANATION FOR STRATIGRAPHIC SECTIONS

Sandy gravel

Gravelly sand

Medium to very coarse sand

Very fine to medium sand

Clay-silt and very fine to fine sand

Clay-silt

No exposure

Silt, mud, or very fine to fine sand with minor pebbles

Pumiceous (lapilli-size) sand

Muddy-sandy phreatomagmatic deposit

Ashy sand

Cross-stratified sand

Strongly cemented

Soil

Miscellaneous abbreviations

ang = angular
subang = subangular
subrnd = subrounded
rnd = rounded
eff = effervescence
lt = light

Sand max grain diameter abbreviations

vfL = very fine-lower; 62-88 μ
vfU = very fine-upper; 88-125 μ
fL = fine-lower; 125-177 μ
fU = fine-upper; 177-250 μ
mL = medium-lower; 250-350 μ
mU = medium-upper; 350-500 μ
cL = coarse-lower; 500-710 μ
cU = coarse-upper; 710-1000 μ
vcL = very coarse-lower; 1000-1410 μ
vcU = very coarse-upper; 1410-2000 μ

Pebble max diameter abbreviations

vf = very fine; 2-4 mm
f = fine; 4-8 mm
m = medium; 8-16 mm
c = coarse; 16-32 mm
vc = very coarse; 32-64 mm

Cobble max diameter abbreviations

f = fine= 64-128 mm
c = coarse; 128-256 mm

Soil development abbreviations (from Birkeland et al., 1991, and Birkeland, 1999)

Soil structure: 1 = weak, 2 = moderate, 3 = strong; f = fine 0.5-1 cm), m= moderate (1-2 cm), c = coarse (2-5), vc = very coarse (>5 cm); sbk = subangular blocky, abk = angular blocky.

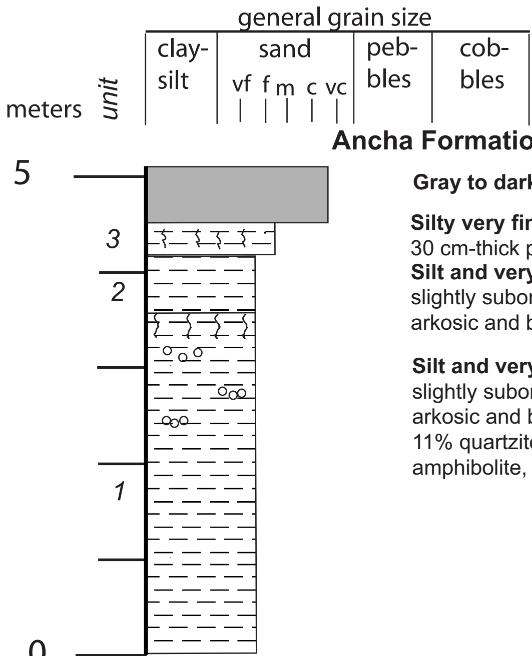
Clay films: v1 = <5% of total surface area, 1 = 5-25% of total surface area, 2 = 25-50% of total surface area, 3 = >50% of total surface area; f = faint, d = distinct, p = prominent; pf = clay films on ped faces, po = clay films line tubular or interstitial pores, br = clay bridges, co = colloid coats mineral grains, cobr = coats and bridges are present.

Soil horizon designations follow those of the Soil Survey Staff (1992) and Birkeland (1999).

Staff in photos is 1.5 m long, with red-white color increments of 10 cm each.

WA-81

alluvial slope, 1-30% coarse channels



Ancha Formation: 4.5 m thick

Gray to dark gray basalt: Thickness not measured.

Silty very fine to coarse sand: Yellowish brown (10YR 5/4); basaltic, minor arkosic sand; loose except for a 30 cm-thick petrocalcic soil horizon.

Silt and very fine sand: Brownish yellow to light yellowish brown (10YR 5-6/4) silt and very fine sand, with slightly subordinate fine to very coarse sand. Sand is subrounded to subangular, poorly sorted, and a mix of arkosic and basaltic sand. Massive and weakly consolidated.

Silt and very fine sand: Yellowish brown to light yellowish brown (10YR 5-6/4) silt and very fine sand, with slightly subordinate fine to very coarse sand. Sand is subrounded to subangular, poorly sorted, and a mix of arkosic and basaltic sand. Some pebbly sand beds near the top; clast count of pebbles (n=114): 71% granite, 11% quartzite, 7% vein quartz, 4% chert, 3% yellowish Paleozoic limestone, 2% micaceous gneiss, 1% amphibolite, 1% basalt. Massive and weakly consolidated.

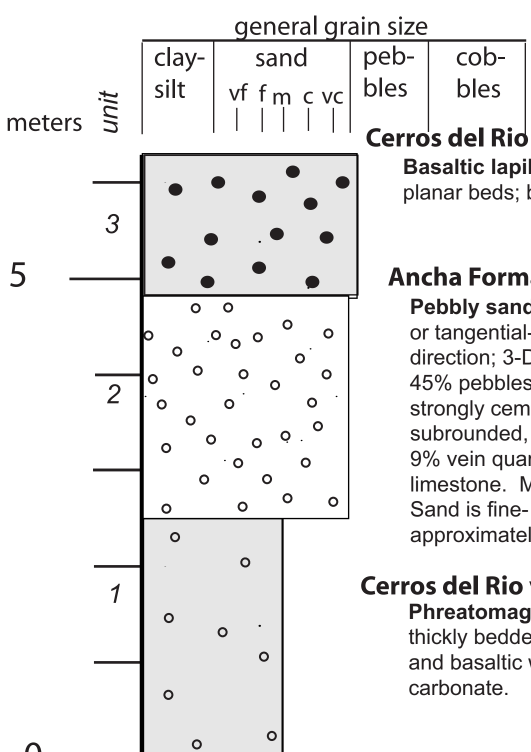
Tesuque Formation: coarse upper unit (lithosome A)

Pebbly sand to sandy pebbles: Reddish yellow(?); not described in detail.

Located on western slope of Canada Ancha, about 580 m north of Portales Pond, in the Agua Fria 7.5-minute quadrangle, New Mexico. Base of section UTM coord: 3952460N, 400760E (NAD 27, zone 13). Measured and described by Daniel Koning, October 9, 2004.

WA-83

alluvial slope, 1-30% coarse channels



Cerros del Rio volcanic field

Basaltic lapilli ejecta: Grayish brown to brown (10YR 5/2-3) and pale brown (10YR 6/3); very thin to thin, planar beds; beds are hard but no HCl effervescence. Some beds have welded cinders.

Ancha Formation

Pebbly sandstone and sandy gravel: Laminated to very thin to thin, trough-cross-stratified (mostly) to planar - or tangential-cross-stratified beds; trough-cross-stratifiction (no 3-D exposure) suggests 290°±20° paleoflow direction; 3-D channel trends give 303-304° and 259° paleoflow directions. Gravel consists of 15% boulders, 45% pebbles, and 40% cobbles. Sandy gravel are generally clast-supported, poorly sorted, and moderately to strongly cemented by calcium carbonate (weak to moderate HCl effervescence). Quartzite are round to subrounded, and granite subangular to subrounded. Clast count (n=113): 66% granite, 15% grayish limestone, 9% vein quartz, 8% quartzite, 2% sheared quartzite, 1% chert, 1% amphibolite, 1% yellowish Paleozoic limestone. Maximum clast sizes: 17x12, 15x14, 16x15, 22x20, 30x19, 23x15, 18x13, 25x20 cm (axb axes). Sand is fine- to very coarse-grained, subrounded to subangular, moderately to poorly sorted, and has approximately subequal pinkish potassium feldspar: basalt grains. Lower part of unit is mostly reworked unit 1.

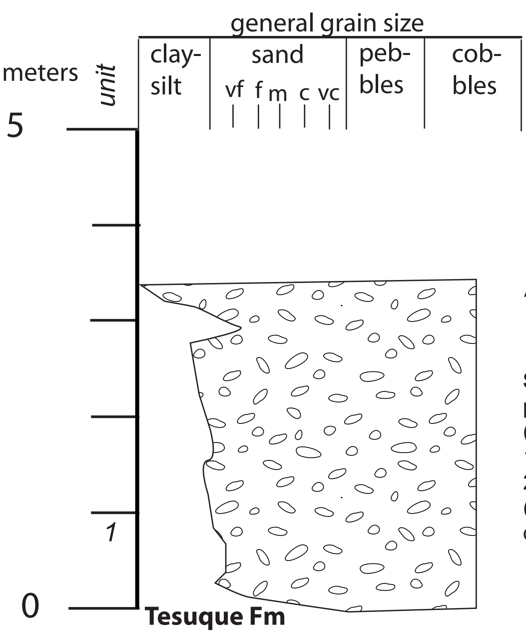
Cerros del Rio volcanic field

Phreatomagmatic deposit: silty sandstone with ~5% very fine to fine pebbles: Yellowish brown (10YR 5/4); thickly bedded and internally massive. Sand is very fine- to very coarse-grained, subrounded, poorly sorted, and basaltic with less than 5% granitic and/or arkosic detritus. Sediment is hard but not cemented by calcium carbonate.

Section located in roadcut on northeast side of Portales Pond, northwestern Agua Fria 7.5-minute quadrangle. Base of section UTM coord: 3951950N,400660E (NAD 27, zone 13). Measured and described by Daniel Koning, Oct. 9, 2004.

SEO-A78
ancestral Santa Fe River

SOUTHWEST NORTHEAST



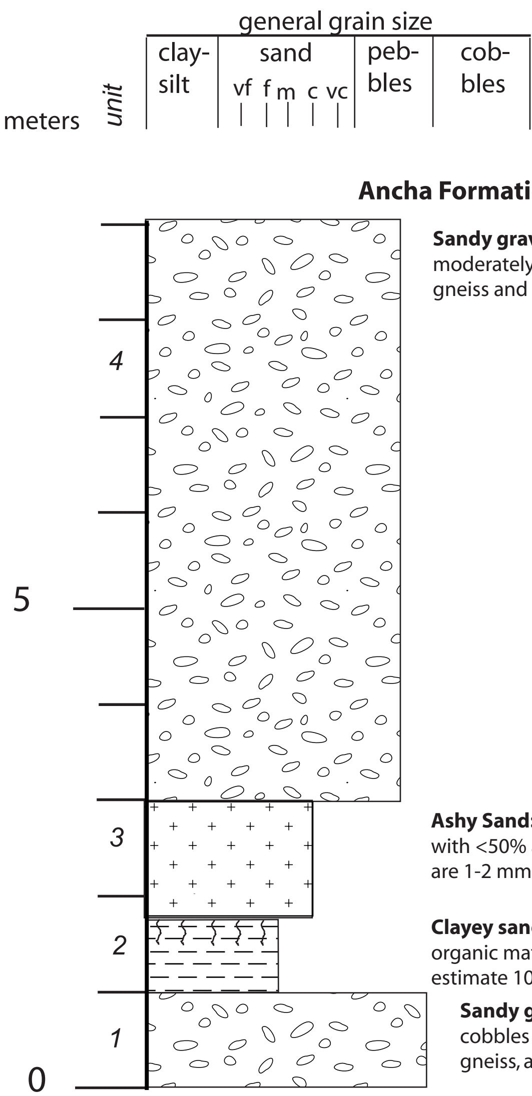
Ancha Formation

Sandy gravel: Clast-supported sandy gravel, with an estimated 50-60% cobbles and 40-50% pebbles. Beds are very thin to 85 cm-thick, and lenticular to broadly lenticular. Clasts are subrounded (some round) and poorly sorted. Clast count (n=158): 95% granite, 3% quartzite, 1% vein quartz, 1% biotite gneiss, 1% amphibolite (deeply weathered). Max clast sizes: 22x17, 21x16, 17x15, 18x12, 27x17, 20x19 cm (axb axes). Sand is light yellowish brown to brownish yellow (10YR 6/5-6), fU-vcU (mostly cL to vcU), subrounded to subangular, poorly sorted, arkosic and rich in coarse granitic detritus. Non-cemented and weakly consolidated.

Located in modern Santa Fe River, 700 m southwest of bridge of County Rd 62, southwestern Agua Fria 7.5-minute quadrangle, New Mexico. Base of section UTM coord: 3945850N, 406730E (NAD 27, zone 13). Measured and described by Daniel Koning, June 16, 2004.

T-36

ancestral Santa Fe River



Ancha Formation

Sandy gravel: Reddish yellow to strong brown (7.5YR 5-6/6); thin, lenticular beds; gravel are subrounded and moderately sorted; about 1:3 ratio of cobbles to pebbles; estimated clast composition: granite with 3% amphib-gneiss and amphibolite, and 2-5% quartzite.

Ashy Sand: Very pale brown (10YR 8/2); beds are 15-30 cm-thick and tabular. Consists of fine to coarse sand with <50% ash shards and pumice fragments. ~10% altered mafic grains (including biotite). These mafic grains are 1-2 mm in diameter.

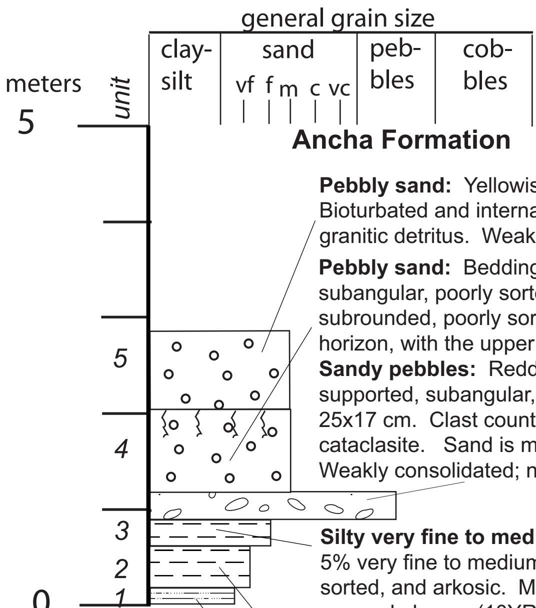
Clayey sand: Reddish yellow to strong brown (7.5YR 5-6/6); massive; sand is very fine to coarse, 0.25-0.5% black organic matter (charcoal?). Estimate of 5% clay. Top 18-34 cm of unit is a Bt soil horizon: yellowish red (5YR 5/6); estimate 10-20% clay; 3,c,abk peds; 3,d,pf clay films; no HCl effervescence.

Sandy gravel: Reddish yellow to strong brown (7.5YR 5-6/6); gravel is mostly coarse to very coarse pebbles and cobbles that are subrounded and moderately sorted. Estimated clast compostion of granite with 2-3% amphib-biotite gneiss, amphib-gneiss, and amphibolite.

Located on north slope of Arroyo de los Chamisos in north-central Turquoise Hill, 7.5-minute quadrangle; outcrop is just above the aquaduct and 1.2 km southwest of Capital High School. Base of section: 3942003N, 404416E (NAD 27, zone 13). Measured and described by Daniel Koning, July 26, 1999.

SEO-A123

alluvial slope, >35% coarse channels



Ancha Formation

Pebbly sand: Yellowish brown (10YR 5/6). Estimate 20-25% very fine to coarse granitic pebbles. Estimate 1-3% silt. Bioturbated and internally massive. Sand is vfL-vcU, subangular-subrounded, poorly sorted, arkosic and rich in coarse granitic detritus. Weakly consolidated; moderate HCl efervescence.

Pebbly sand: Bedding not obvious. ~30% very fine to fine pebbles with some medium to coarse pebbles; pebbles are subangular, poorly sorted, and granitic. Sand is light brown (7.5YR 7/4), fU-vcU (minor vfL-fL and ~1% silt), subangular to subrounded, poorly sorted, and arkosic. Loose but strong HCl effervescence. Unit corresponds with a stage I calcic horizon, with the upper 10-15 cm being a stage II.

Sandy pebbles: Reddish yellow (7.5YR 6/6). Vague, thin, lenticular beds. Pebbles are very fine to very coarse, clast-supported, subangular, and poorly sorted; locally cobbles are abundant. Max clast sizes: 23x13, 17.5x17, 23x15, 31x22, 24x14 25x17 cm. Clast count (n=111): 95% granite, 3% amphibolite and amphib-gneiss, 1% biot-geniss, 1% vein quartz, 1% cataclasite. Sand is mL-vcU, subang-subround, low-moderate to poorly sorted, arkosic and rich in coarse granitic detritus. Weakly consolidated; no HCl effervescence. Slightly wavy, sharp and scoured contact.

Silty very fine to medium sand: Reddish yellow (7.5YR 6/6); internally massive; vfL-mU sand with minor cL-vcU sand and 5% very fine to medium, poorly sorted, scattered, subangular granitic pebbles. Sand is subrounded to subangular, poorly sorted, and arkosic. Moderately to well consolidated and moderate HCl effervescence; weakly cemented. Upper 13 cm is very pale brown (10YR 7/3), probably due to increased cementation by CaCO3. Uppermost 5 cm has two slightly wavy laminae of CaCO3.

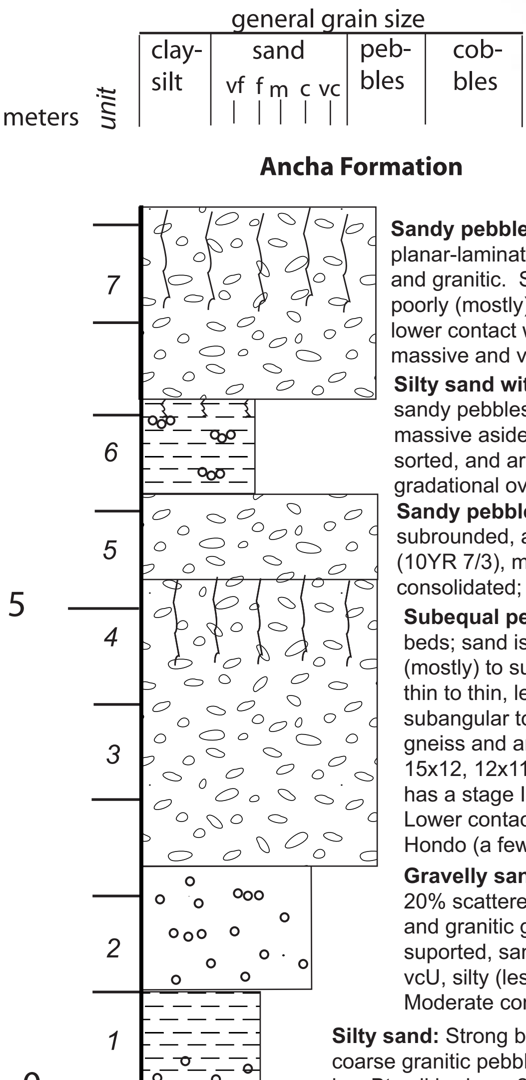
Silty very fine to fine sand: Reddish yellow (7.5YR 6/6); internally massive; sand is vfL-fL, with minor fU-vcU sand and very fine pebbles. Unit has 40-45% white mottles of weak calcium carbonate cementation. Well-consolidated and moderate to strong HCl effervescence. Lower bedding contact is planar.

Silt and very fine sand: Reddish yellow (7.5YR 6/6); internally massive; moderately to well consolidated and moderate HCl effervesence; weakly cemented.

Section located in a cut-bank on northeast side of railroad, 320 m south of Vista Grande Avenida in town of Eldorado, north-central Seton Village 7.5-minute quadrangle. Base of section: UTM coord: 3933253N, 416110 E (NAD 27, zone 13). Measured and described by Daniel Koning, July 1, 2004.

SEO-A122

alluvial slope, >35% cs channels



Ancha Formation

Sandy pebbles with about 40% pebbly sand: Sandy pebbles are in very thin, broadly lenticular beds; pebbly sand is planar-laminated. Pebbles are mostly clast-supported, subangular(mostly) to subrounded, moderately to poorly sorted, and granitic. Sand is light yellowish brown to brownish yellow (10YR 6/4-6), fU-vcU, subangular (mostly) to subrounded, poorly (mostly) to moderately sorted, arkosic and rich in coarse granitic detritus. Loose to weakly consolidated. Scoured lower contact with 10-20 cm of relief. Upper 100 cm is a degraded and bioturbated stage II+ calcic horizon; internally massive and very pale brown (10YR 7/3). Using a dip of 1°, the Guaje pumice projects to upper 2 m of exposure.

Silty sand with minor sandy pebble lenses: Generally a silty vfL-fL sand with 10-15% very thin to thin lenses of sandy pebbles; pebles are very fine to coarse, subangular to subrounded, poorly sorted, and granitic. Internally massive aside from sandy pebble lenses. Sand is has subordinate fU-vcU grains, is subrounded-subangular, poorly sorted, and arkosic. Moderately-well consolidated and moderate HCl effervescence. Lower contact is planar and gradational over 20 cm. Upper 10-15 cm corresponds to a weak stage II calcic horizon.

Sandy pebbles: Very thin to medium, lenticular to broadly lenticular beds. Gravel is clast-supported, subangular to subrounded, and poorly sorted; composition similar to unit 3 but with about 5% amphibolite. Sand is very pale brown (10YR 7/3), mL-vcU, subangular, poorly sorted, arkosic and rich in coarse granitic detritus. Loose to weakly consolidated; no HCl effervescence.

Subequal pebbly sand and sandy pebbles: Pebbly sand has planar-laminated to planar-lenticular, very thin beds; sand is light brown to reddish yellow (7.5YR 4-6/6) and strong brown (7.5YR 5/6); mU-vcU, subangular (mostly) to subrounded, moderately to poorly sorted, and arkosic. Sandy pebbles are clast-suported and in very thin to thin, lenticular beds with minor channel-shaped beds 10-40 cm-thick. Gravel has ~20% cobbles; clasts are subangular to subrounded and poorly sorted; clast count (n=103): 87% granite, 5% biot-gneiss, 4% amphib-biot gneiss and amphib, 2% vein quartz, 1% quartzite, 1% musc-biot gneiss; max clast sizes: 24x17, 12x10, 16x9.5, 15x12, 12x11, 12x7, 12x8 cm (axb axes). Loose to weakly consolidated and no HCl effervescence. Upper 90 cm has a stage III carbonate horizon: white (2.5Y 8/1), more cemented and hard near top, strong HCl effervescence. Lower contact not well-exposed. Unit is approx the same elevation as the Guaje pumice on north wall of Arroyo Hondo (a few 100 m to west).

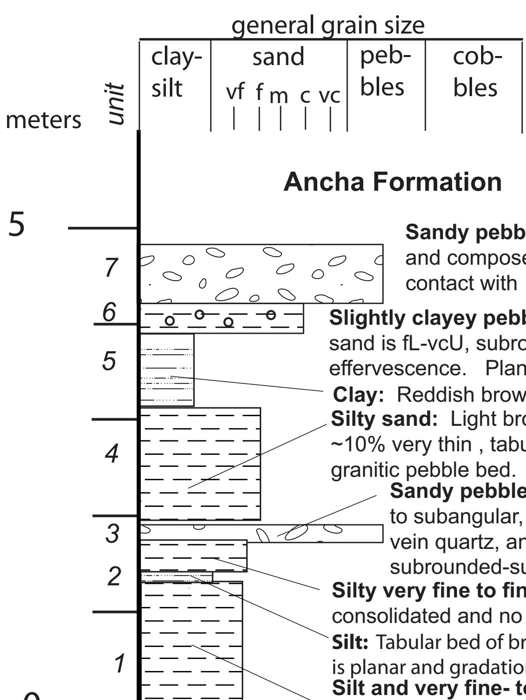
Gravelly sand: Reddish yellow (7.5YR 6-7/6); massive except for the pebbly lenses described below. 15-20% scattered, very fine to very coarse pebbles that are subangular, poorly sorted, and dominated by granite and granitic gneiss; 10% of gravel are cobbles. 10-20% of unit are very thin to medium lenses of clast-suported, sandy pebbles: very fine to very coarse, subangular to subrounded, and poorly sorted. Sand is vfL-vcU, silty (less silt than underlying unit), and subangular (mostly) to subrounded, poorly sorted, and arkosic. Moderate consolidated with no HCl efferevescence. Lower contact is sharp and scoured (4 cm of relief).

Silty sand: Strong brown to reddish yellow (7.5YR 5-6/6). Unit represents one fining-upward bed. 7-10% very fine to coarse granitic pebbles near base. Sand is vfL-mU, subrounded to subangular, poorly sorted, and arkosic. Upper 11 cm is a Bt soil horizon: 2dpf clay films and 3vf-m, ,subang blocky, hard peds; reddish yellow (5YR 6/6); lower contact is planar and gradational over 2 cm. Well consolidated, no to weak HCl effervesncence. Base of exposure is 1.5 m below that of the QTa/Tt contact on north side of Arroyo Hondo (bearing of N2°W).

Located in first cut-bank along railroad south of Arroyo Hondo, northwest Seton Village 7.5-minute quadrangle. Base of section UTM coord: 3942106N, 409461E (NAD 27, zone 13). Measured and described by Daniel Koning, July 1, 2004.

SEO-A83

alluvial slope, 15-60% cs channels



Ancha Formation

Sandy pebbles: Gravel is clast-supported and includes 3-5% fine cobbles. Pebbles are subrounded, poorly sorted, and composed of granite and granitic gneiss, 10% amphibolite, 5% quartzite, and 2% vein quartz. Sharp lower contact with 12 cm of scour relief.

Slightly clayey pebbly sand: Strong brown (7.5YR 5/6), estimate ~3% clay; pebbles are very fine to medium and granitic; sand is fL-vcU, subrounded (mostly) to subangular, poorly sorted, and arkosic. Moderatelyto well consolidated and no HCl effervescence. Planar and sharp lower contact.

Clay: Reddish brown (5YR 5/4), well consolidated.

Silty sand: Light brown to light yellowish brown (7.5-10YR 6/4), silty vfL-mL sand. Medium, tabular beds with ~10% very thin , tabular silt beds. Sand is subrounded to subangular, well-sorted, and arkosic. One 5 cm-thick granitic pebble bed. Well to moderately consolidated and no cementation.

Sandy pebbles: A 20cm-thick, lenticular bed of very fine to medium pebbles. Pebles are clast-supported, subrounded to subangular, poorly to moderately sorted, and dominated by granite, with 2-3% quartzite,1-5% granitic gneiss, 1-3% vein quartz, and trace volcanic rocks. Sand is light brown to light yellowish brown 7.5-10YR 6/4, fU-vcU (minor vfL-fL), subrounded-subangular, high-poorly sorted, and arkosic. Sharp lower contact.

Silty very fine to fine sand: Internally massive; sand is vfL-fU, well sorted and arkosic. Moderately to well consolidated and no HCl effervescence. 32 cm thick.

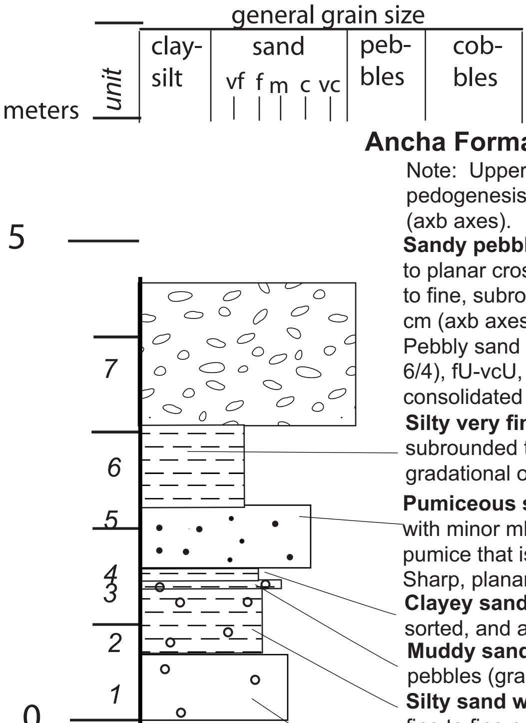
Silt: Tabular bed of brownish yellow to reddish yellow (10-7.5YR 6/6) silt; internally massive; 20-40% root pores. Lower contact is planar and gradational over 1 cm. 12 cm thick.

Silt and very fine- to fine-grained sand: Internally massive with minor medium to very coarse sand and ~5% scattered, very fine to fine, granitic pebbles. Sand is light yellowish brown to light brown (10-7.5YR 6/4), subrounded (mostly) to subangular, moderately sorted, and arkosic. 42 cm from top is a 10 cm-thick lens of pebbly fU-vcU sand; pebbles are granitic and sand is subrounded to subangular, poorly sorted, and arkosic. Moderately consolidated and no to moderate HCl effervescence.

Section measured along west side of Highway 14 about 1.58 km north of San Marcos Spring; northwest Picture Rock quadrangle. Base of section UTM coord: 3925915N, 403036E (NAD 27, zone 13). Measured and described by Daniel Koning, June 17, 2004.

SEO-A125

alluvial slope, 15-40% coarse channels



Ancha Formation

Note: Upper 30 cm on top of unit 5 is a silty vfL-fU sand with minor mL-vcU sand and pebles. Disturbed because of pedogenesis and surface activity. Max clast sizes of surface graveL 16x10, 12x9, 13x9.5, 16x6, 20x15, 21x14 cm (axb axes).

Sandy pebbles with about 1/3 pebbly sand: Sandy pebbles are in very thin to thin, lenticular beds; also tangential to planar cross-stratification (laminations and very thin beds) up to 12 cm tall. Pebbles are clast-supported, very fine to fine, subrounded to subangular, and moderately to poorly sorted; max clast size: 5x3.5, 4.5x3, 4.5x4, 6x4.5, 5x4.5 cm (axb axes); clast count (n=104): 88% granite, 5% amphib-gneiss, 2% amphibolite, 2% biot-gneiss, 3% vein quartz. Pebbly sand is planar-laminated or low-angle-cross-stratified (up to 6 cm-thick). Sand is light yellowish brown (10YR 6/4), fU-vcU, moderately sorted within a bed, subangular (minor subrounded), and arkosic. Moderately to weakly consolidated with weak HCl effervescence.

Silty very fine-grained sand: Pink (7.5YR 7/4) with subordinate fL-cL sand. Internally massive. Sand is subrounded to subangular, moderately sorted, and arkosic. Contact not readily visible but probably planar and gradational over 10-20 cm. Well consolidated with moderate-strong HCl effervescence.

Pumiceous sand: Light yellowish brown to very pale brown (10YR 6-7/4) and internally massive. Sand is vfL-fU with minor mL-vcU; subrounded to subanular, moderately sorted, and arkosic. Sand is mixed with subordinate pumice that is sand-size to very fine to medium pebble-size. Moderately consolidated with weak HCl effervescence. Sharp, planar lower contact.

Clayey sand: Strong brown (7.5YR 5/6) clayey (est 3-5% clay) vfL-mU sand; sand is subround to subang, moderately sorted, and arkosic. Moderately consolid. with weak HCl effervescence. Lower contact is planar(?) and gradational.

Muddy sand: Est 3-5% mud. Sand is vfL-vcU, subang-subrnd, poorly sorted, and arkosic. 2-3% very fine to medium pebbles (granitic, subang-subrnd, poorly sorted). Lower contact is slightly wavy and gradational over 2 cm. 5 cm thick.

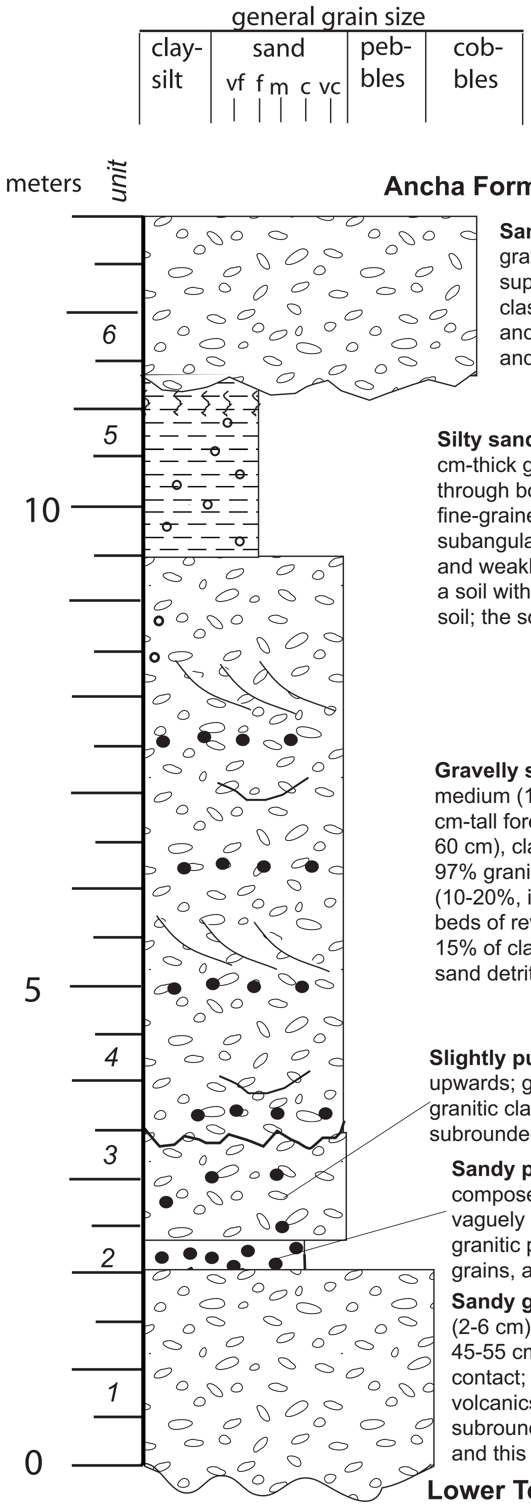
Silty sand with minor pebbles: Light yellowish brown (10YR 6/4) vfL-mU sand with minor cL-vcU sand and 1% very fine to fine pebbles. Internally massive. Estimate 3-5% silt. Sand is subrounded to subangular, moderately to poorly sorted, and arkosic. Moderately consolidated with moderate HCl effervesence. Sharp, planar(?) lower contact.

Sand with minor pebbles: Light yellowish brown (10YR 6/4), very slightly silty (est 1%) silt) vfL-vcU sand. Internally massive. Sand is subangular with some subrounded, moderately to poorly sorted, and arkosic; 1-5% very fine to fine, subangular granitic pebbles. Moderately consolidated with weak HCl effervescence. Locally, upper 3-5 cm is strongly cemented by $CaCO_3$ -- often in wavy laminations.

Located in road-cut on east side of Richards Avenue, a short distance (approximately 30 m) north of the southern Interstate 25 overpass, northwest Seton Village 7.5-minute quadrangle. Base of section UTM coord: 3942108N, 409461E (NAD 27, zone 13). Measured and described by Daniel Koning, July 3, 2004.

Arroyo Hondo

alluvial slope, >35% coarse channels



Ancha Formation: 13 m thick

Sandy gravel: Light yellowish brown (10YR 6/4); vague, thin to medium (3-35 cm), lenticular beds; gravel is generally cobbles with 15-20% boulders (25-35 cm long) and 25% pebbles; gravel is clast-supported, subrounded to subangular, poorly sorted, and composed of 3% amphibolite and 97% granitic clasts; sand is fU to vcU but mostly mU to vcU, subangular to subrounded, moderately to poorly sorted, and arkosic with no pumice; lower contact is scoured with 50-70 cm of relief; weak HCl effervescence and loose.

Silty sand with 10-20% gravel: Very pale brown (10YR 7/3); generally massive except for minor, vague, 20-50 cm-thick gravel beds; gravel is clast- and matrix-supported, subrounded to subangular, poorly sorted pebbles through boulders (30-35 cm long) which consist of 1% amphibolite and 99% granitic clasts; sand is very fine- to fine-grained with 15-25% medium- to very coarse-grained sand, well to poorly sorted, subrounded to subangular, and arkosic; lower contact is poorly exposed but probably gradational; moderate HCl effervescence and weakly consolidated. This unit was very close to a former land surface that was stable long enough to form a soil with a stage III calcic horizon; the surface received a lot of eolian influx which was incorporated into the soil; the soil was later buried by Unit 6 and the $CaCO_3$ later redistributed by vadose water.

Gravelly sand with pumiceous beds: Brownish yellow to very pale brown (10YR 6-7/4-6); very thin to medium (1-50 cm), lenticular beds; channels are about 45 cm deep; some sand beds are cross-stratified (5-20 cm-tall foresets); gravel is clast-supported, poorly sorted pebbles to boulders (generally 30-40 cm long, max of 60 cm), clasts are generally subrounded but pebbles are subrounded to subangular, 3-5% amphibolite and 95-97% granitic clasts; sand is fU to vcU, subangular to subrounded, moderately to poorly sorted, and a lithic-rich (10-20%, including pumice) arkose. 5-10% of unit is composed of scattered, lenticular, medium (10-50 cm) beds of reworked pumice; beds are commonly internally massive; pumice is <5 cm in diameter, occupies 5-15% of clasts or grains, and is poorly sorted; color is very pale brown; the amount of pumice versus gravel and sand detritus varies. Lower contact is scoured with <10 cm of relief; no HCl effervescence and loose.

Slightly pumiceous, gravelly sand: Very pale brown (10YR 7/4); thin to medium, lenticular beds; sediment fines-upwards; gravel is clast-supported, mostly cobbles with subordinate pebbles, and contains 2% amphibolite and 98% granitic clasts; sand has ~1% pumice and is fine- to very coarse-grained, poorly to moderately sorted, subangular to subrounded, and a lithic-rich feldspathic arkose; lower contact is a planar scour; no HCl effervescence and loose.

Sandy pumice: Very pale brown (10YR 8/2); occupies a channel up to 50 cm-deep in sandy gravel composed of subequal pebbles and cobbles but otherwise similar to Unit 1; the sandy pumice may be vaguely cross-laminated (8 cm-tall foresets) and contains ~70% pumice (vfL sand to vf pebble in size), 3% granitic pebbles, and 30% sand; sand is mostly mL to cU, contains 25-30% lithic grains and 70-75% granitic grains, and is subangular to subrounded; lower contact is a planar scour; no HCl effervescence and loose.

Sandy gravel: Light yellowish brown to strong brown (10YR 6/4 and 7.5YR 5/6); very thin to medium (2-6 cm), lenticular beds; gravel is a poorly sorted mix of clast-supported pebbles to boulders (generally 45-55 cm long, max of 70 cm), cobbles and boulders are slightly more common within 1-1.5 m of lower contact; gravel are subrounded to subangular and consist of 3% amphibolite, trace intermediate volcanics, and 97% granitic clasts; sand is fL to vcU but mostly mL to vcU, subangular with minor subrounded, poorly sorted, and arkosic; sand may locally be slightly clayey (up to 2% of total volume) and this clayey sand is strong brown (non-clayey sand is light yellowish brown); no HCl effervescence.

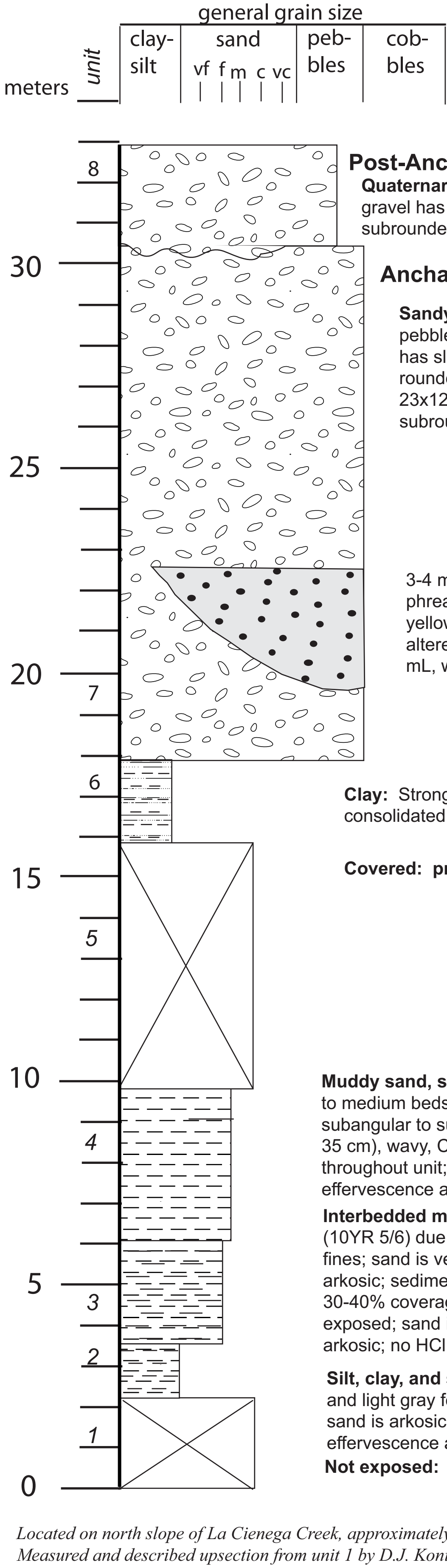
Lower Tesuque Formation of Santa Fe Group

Sand and clayey sand: Light reddish brown (5YR 6/4); sand is in medium to thick, tabular beds with internal planar laminations and cross-laminations; sandstone is fine- to medium-grained, well sorted, and subangular to subrounded; clayey sand is planar laminated or thinly bedded whose sand is very fine- to coarse-grained, poorly sorted, subangular to subrounded, and arkosic; no HCl effervescence and weakly consolidated.

Located on upper north slope of Arroyo Hondo near south terminus of Old Pecos Trail, Santa Fe 7.5-minute quadrangle, Santa Fe County, New Mexico. Measured and described upsection from unit 1, along N71E trend, by D.J. Koning October 16, 2000. Base of measured section at N: 3,942,778 m; E: 414,823 m (UTM zone 13, NAD 27). Section is on private property of Gaylon Duke (46 Old Agua Fria Road W., Santa Fe, N.M., 87505).

Cienega Creek

ancestral Santa Fe River (18-30.5 m) and alluvial slope, 1-30% coarse channels (0-18m)



Post-Ancha Formation terrace deposit

Quaternary(?) terrace deposit: Poorly exposed gravel and sand: slightly more pebbles than cobbles; surface gravel has 1% amphibolite, trace chert, 1% quartzite, and 98% granitic clasts; cobbles and very coarse pebbles are subrounded, very fine to coarse pebbles are subangular to subrounded; largest cobbles are 13-21 cm long.

Ancha Formation

Sandy gravel: Light yellowish brown (10YR 6/40; thin to very thin, lenticular beds; cobbles and very coarse pebbles are subrounded, very fine to coarse pebbles are subrounded to subangular; gravel has no boulders, has slightly more cobbles than pebbles, and consists of 1-2% amphibolite, 92-93% granitic clasts, and 5-7% rounded quartzite (including Ortega quartzite); maximum clast sizes: 19x11, 22x8, 29x20, 16x15, 30x18, 26x10, 23x12 cm (axb axes). Sand is very fine- to very coarse-grained, poorly to moderately sorted, subangular to subrounded, and arkosic; loose.

3-4 m-thick, non-laterally extensive, channel(?) deposits of reworked pyroclastic (probably phreatomagmatic) sediment: muddy sand with 10-50% altered tephra and volcanic pebbles; brownish yellow to yellowish brown (10YR 5-6/6); matrix-supported and not stratified; pebbles are very fine to fine and altered to yellow (10YR 7/6) to strong brown (7.5YR 5/8) to various shades of gray; sand is generally vF to mL, well sorted, subangular to subrounded, and a lithic to arkosic wacke; weakly consolidated.

Clay: Strong brown (10YR 4/6); bedding not exposed; 10% arkosic sand; lower contact not seen; weakly consolidated. Slope increases above this unit.

Covered: probably underlain by sediment similar to unit 4.

Muddy sand, sand, and mud: Brownish yellow to light yellowish brown (10YR 6/4-6); massive to vague, very thin to medium beds; 3% granitic pebbles, 0.5-1% of sediment is composed of distinct sandy pebble beds, pebbles are subangular to subrounded; sand is very fine to very coarse; sediment is alkaline with 5% distinct, thin to medium (2-35 cm), wavy, $CaCO_3$-indurated beds in very fine to fine sand; trace rhizoconcretions (0.5 - 2 cm in diam) are found throughout unit; lower contact is sharp and planar to wavy (up to 20 cm of relief); moderate to strong HCl effervescence and weakly consolidated (except for indurated beds).

Interbedded muddy to clayey sand and sandy mud (4:1 ratio): Muddy to clayey sand: mostly yellowish brown (10YR 5/6) due to oxidation; no fabric or bedding, sediment has probably been bioturbated; estimated 15-30% fines; sand is very fine- to very coarse-grained, poorly sorted, matrix-supported, subrounded to subangular, and arkosic; sediment grades into a silty sand towards top of the unit (sand is very fine- to fine-grained); locally up to 30-40% coverage by 1 mm-diameter, soft, $CaCO_3$ nodules. Sandy mud: strong brown (7.5YR 5/6); bedding not exposed; sand is very fine- to very coarse-grained, poorly sorted, matrix-supported, subrounded to subangular, and arkosic; no HCl effervescence and loose. Lower contact not exposed.

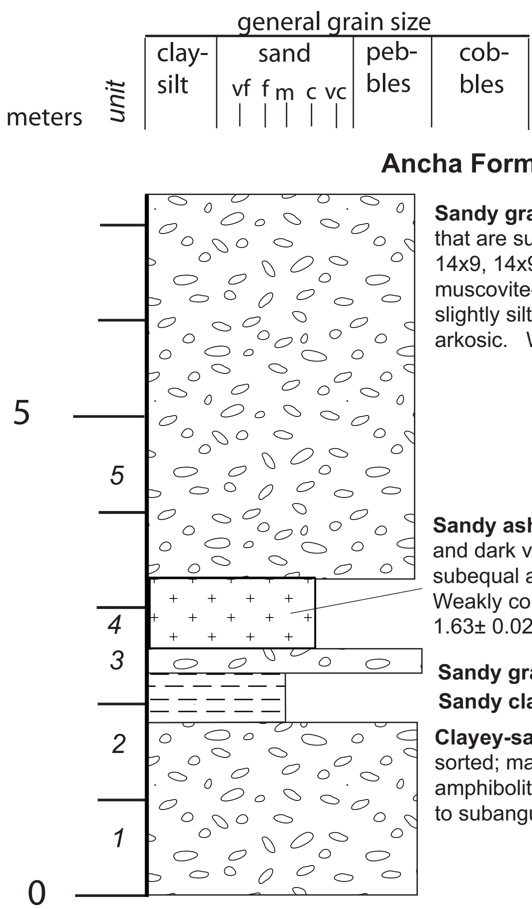
Silt, clay, and sandy mud: Light yellowish brown for silt (2.5Y 6/3 and 10YR 6/4); yellowish brown for clay (10YR 5/4); and light gray for clay and mud (2.5Y 7/2); insufficient exposure to describe bedding; trace very fine to medium pebbles; sand is arkosic, very fine- to coarse-grained, and comprises about 10-40% of sediment; none to strong HCl effervescence and loose.

Not exposed: covered by vegetation and Holocene alluvium

Located on north slope of La Cienega Creek, approximately 550 m west of Arroyo de los Tanques, Turquoise Hill 7.5-minute quadrangle, Santa Fe County, New Mexico. Measured and described upsection from unit 1 by D.J. Koning on October 17, 2000. Section trends N15E for 290 m, then N-S for 335 m. Base of measured section located at bottom of La Cienega Creek at N: 3,937,427 m; E: 400,840 m (UTM zone 13, NAD 27).

T-27

ancestral Santa Fe River



Ancha Formation

Sandy gravel: Bedding not well-exposed. Gravel consists of pebbles and slightly subordinate cobbles that are subrounded and moderately sorted; maximum clast size: 20x11, 16x9, 17x10.5, 10x9, 11x9, 14x9, 14x9 cm (axb axes); clast count (n=137): 95% granite, 1.5% vein quartz, 2.5% biotite- and muscovite-gneiss, 2% amphib-biot gneiss and amphibolite. Sand is light yellowish brown (10YR6/4), slightly silty (est 1% silt), vfL-vcU but mostly mL-vcU), subangular to subrounded, poorly sorted, and arkosic. Weakly consolidated and no HCl effervescence.

Sandy ash to ashy sand: Very pale brown (10YR 8/2). Ash includes glass, pumice shards, quartz crystals, and dark volcanic lithic grains and is fL-cU (lithic grains are mL-vcU and vf pebble-size). Unit includes subequal arkosic, detrital sand that is generally mU-vcL, subrounded to subangular, and moderately sorted. Weakly consolidated and no to little HCl effervescence. Ash seems to project and correlate to the ash dated at 1.63± 0.02 Ma in Koning et al. (2002).

Sandy gravel: As in unit 5.

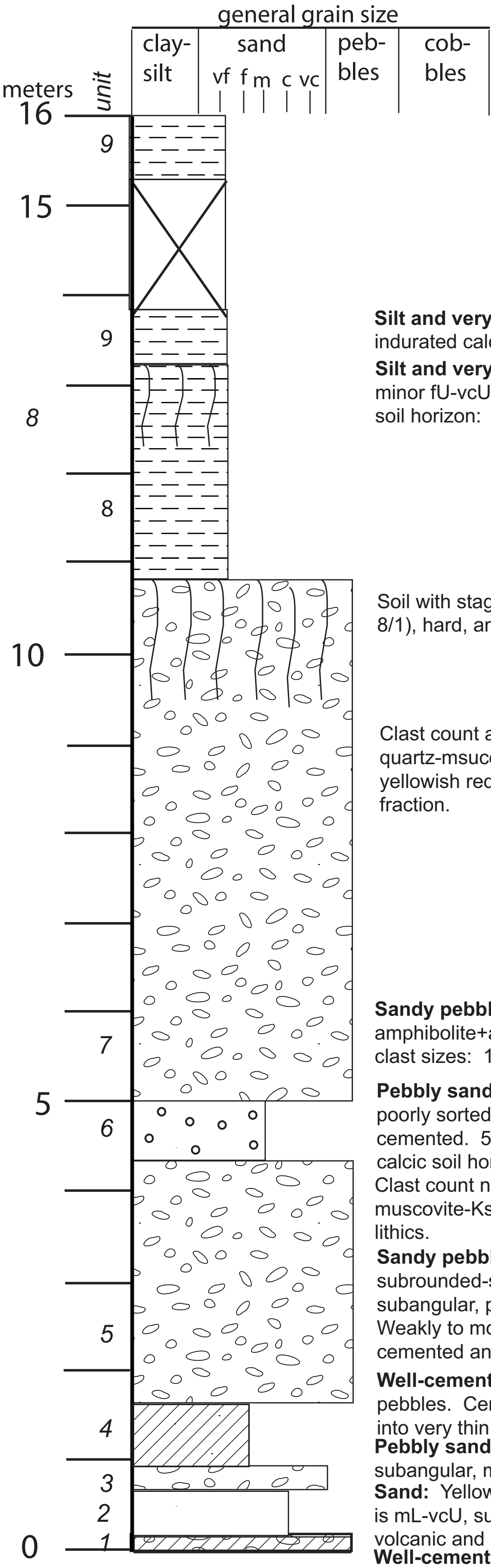
Sandy clay: Strong brown (7.5YR 5/6); sand is generally vfL-vfU. Moderately consolidated; no HCl

Clayey-sandy gravel: Clay and sand color: strong brown (7.5YR 5/6). Gravel is subrounded and moderately sorted; max clast sizes: 16x9, 18x9, 21x11, 15x9, 14x9, 12x8 cm (axb axes); clast count (92% granite, 3% amphibolite, 3% amphib-gneiss, 1% un-identified, 1% quartzite. Sand is mL-vcU (mostly cL-vcU), subrounded to subangular, poorly sorted, and arkosic. Weakly consolidated; no HCl effervescence.

Section measured in cut-bank on east side of HIghway 599, where the highway cuts through the south wall of Arroyo de los Chamisos, SW of center of the Turquoise Hill 7.5-minute quadrangle. Base of section UTM coord: 3940902N, 403012E (NAD 27, zone 13). Measured and described by Daniel Koning, July 26, 1999.

SEO-A80

alluvial slope, 25-60% coarse channels



Silt and very fine to fine sand: Sediment similar to unit 8; basal 6 cm has abundant white, cm-size rip-ups of indurated calcium carbonate (probably from erosion of underlying soil).

Silt and very fine to fine sand: Light brown to light yellowish brown (7.5-10YR 6/4); sand is vfL-fL and mixed with minor fU-vcU sand. Massive. Well-consolidated and has strong HCl effervescence. Top 90 cm is a stage III+ calcic soil horizon: very pale brown (10YR 8/2), strong HCl effervescence.

Soil with stage III calcic horizon developed on parent material of pebbly sand; internally massive, white color (7.5YR 8/1), hard, and strong HCl effervescence. Lower horizon conatct gradational over 10 cm.

Clast count a few m below top of unit: 52% granite, 43% latite and other felsic-intermediate volcanic clasts, 4% quartz-msucovite gneiss, 1% quartz-biotite gneiss, 1% muscovite-Kspar gneiss. Gravel are poorly sorted. Sand is yellowish red (5YR 4-5/6, mL-vcU, has 30%-35% sand-size clay bits; more latite-rich lithics than Kspar in the sand fraction.

Sandy pebbles: Similar to sediment in unit 5. Clast count (n=123): 69% granite, 13% latite, 5% amphibolite+amphibolite gneiss, 5% quartzite, 4% granitic gness, 3% vein quartz. 1% muscovite schist. Maximum clast sizes: 13x8, 15x8.5, 19x18, 16x10, 16x9, 14x13, cm (axb axes).

Pebbly sand: Light brown (7.5YR 6/4) pebbly very fine to very coarse sand. Sand is subrounded to subangular, poorly sorted, and has an approximate ratio of 50-60%:50-50% Kspar:volcanic and mafic lithic grains. Loose and not cemented. 5 m to the north, the unit becomes silty and has strong effervescence in HCl; here, it looks like a stage II+ calcic soil horizon.

Clast count near top of unit (n=100): 50% intermediate to felsic volcanic clasts, 45% granite, 2% vein quartz, 2% muscovite-Kspar gneiss, and 1% quartzite. Sand has a ratio of about 50-60% : 40-50% kspar: volcanic and mafic lithics.

Sandy pebbles: Very thin to medium, lenticular to broadly lenticular beds. Pebbles are mostly clast-supported; subrounded-subangular and poorly to moderately sorted. Sand is light brown (7.5YR 6/4), fL-vcU, subrounded to subangular, poorly to moderately sorted, and arkosic; 3-5% clay present as films coating 10-20% of grain surface. Weakly to moderately consolidated and no HCl effervescence -- except for lower 22 cm of unit, which is well-cemented and weathers into very thin to thin plates. Sharp and planar lower contact.

Well-cemented sandstone: Pinkish white to pink (7.5YR 8/2-3); sand is vfL-vcU (mostly vfL-fU), 2-3% scattered pebbles. Cement is hard but not as indurated as unit 1; in lower 30 cm the cement is massive, but above it weathers into very thin to thin plates. Lower conatct is gradational over 4 cm.

Pebbly sand to sandy pebbles; Sand and bedding style similar to underlying unit; pebbles are subrounded to subangular, moderately sorted, and granitic with subordinate volcanic and gneiss clasts. Loose and non-cemented.

Sand: Yellowish red to reddish yellow (5YR 5-6/6); very thin to medium(?), lenticular to broadly lenticular beds; sand is mL-vcU, subrounded to subangular, moderately sorted, and has an estimated 50-60%:40-50% ratio of Kspar : volcanic and mafic lithics. Loose and non-cemented. Sharp lower contact.

Well-cemented pebble conglomerate: Pink (7.5YR 8/3), pebble conglomerate; pebbles are very fine to very coarse, with very sparse fine cobbles, subrounded-subangular, and poorly sorted; clasts are granitic with an estimated 5% quartztie and 25-35% intermediate-felsic volcanic rocks. Very hard due to strong calcium carbonate cementation. Basal contact is an unconformity and relatively planar.

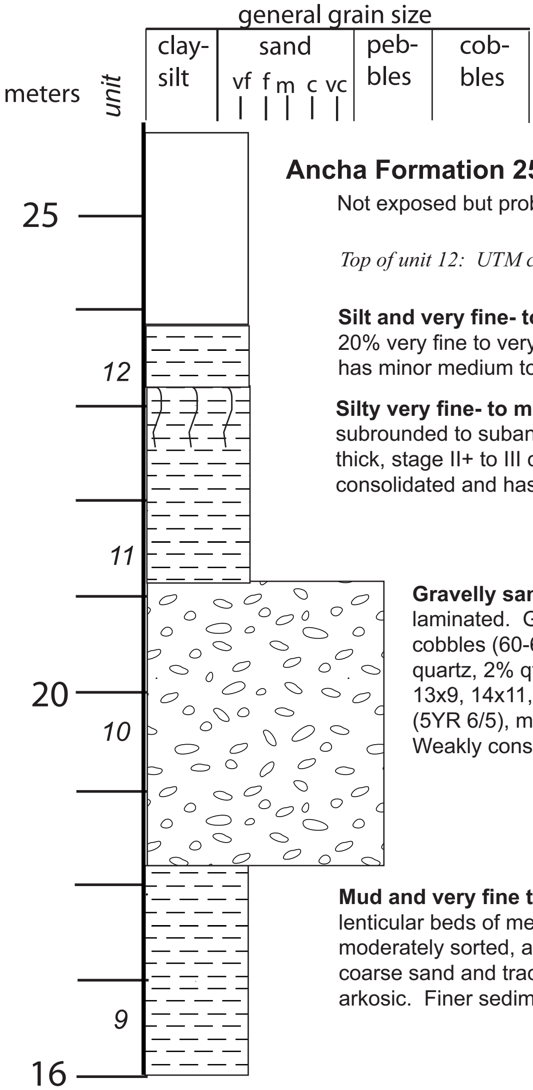
Galisteo Formation

Sandstone: Steeply tilted fL-fU sand; well-sorted, arkosic, and cemented (hard; strong HCl effervescence).

Section measured along west side of Highway 14 about 1.78 km southwest of San Marcos Spring; northwest Picture Rock quadrangle, New Mexico. Base of section UTM coord: 3922778N, 402219 E. Top of section UTM coord: 3923262, 402244E (NAD 27, zone 13). Measured and described by Daniel Koning, June 17, 2004.

SEO-A80 (continued)

alluvial slope, 25-60% coarse channels



Ancha Formation 25.8 m

Not exposed but probably like unit 12 with suboridnate gravel interbeds; also not accessed because it is on private property.

Top of unit 12: UTM coord: 3923264N, 402237 E (NAD 27, zone 13).

Silt and very fine- to fine-grained sand: Light yellowish brown to light brown (10-7.5YR 6/4); massive and hard. 15-20% very fine to very coarse pebbles and fine cobbles. Sand is subrounded to subangular, poorly sorted, arkosic, and has minor medium to very coarse sand. Biotubated; strong HCl effervescence and weak consoldiation.

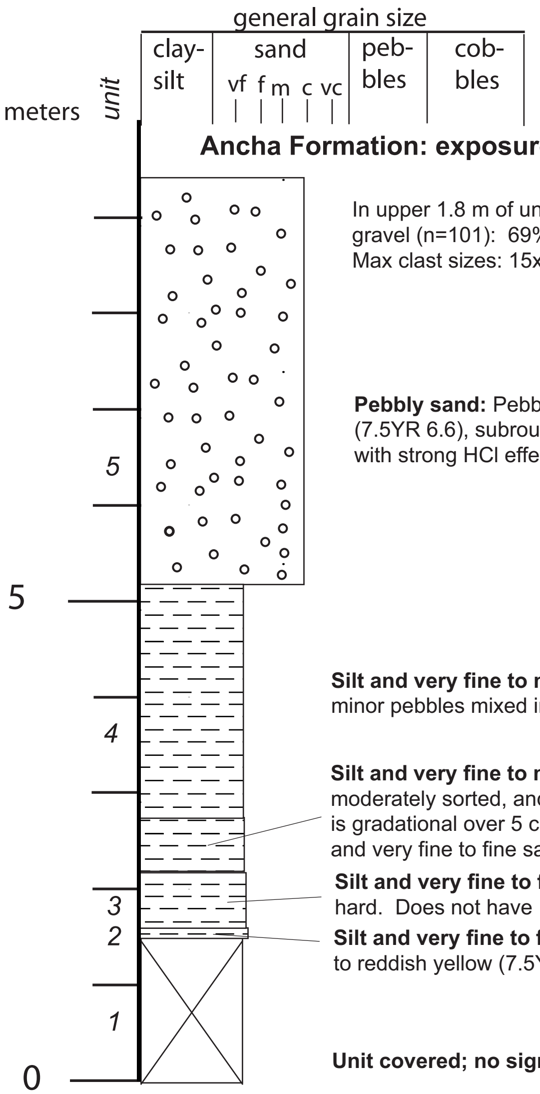
Silty very fine- to medium-grained sand: Light yellowish brown to light brown (10-7.5YR 6/4); massive. Sand is subrounded to subangular, moderately sorted, and arkosic; minor coarse to very coarse sand. Top of unit has a 60 cm-thick, stage II+ to III calcic soil horizon (slightly hard peds and strong HCl effervescence). Below soil, unit is weakly consolidated and has strong HCl efervescence.

Gravelly sand and sandy gravel: Very thin to medium, lenticular or channel-shaped beds; sand may be planar-laminated. Gravel is clast-supported, subrounded, moderately to poorly sorted, and has slightly more pebbles than cobbles (60-65% : 35-40%); clast count (n=102) gives: 80% granite, 11% quartzite, 2% granitic gneiss, 2% vein quartz, 2% qtz-musc schist, 2% biot-Kspar gn, 1% felsic-intermediate volcanic rocks; max clast sizes: 10x10, 13x8, 13x9, 14x11, 12x7, 15x13, 15x10, 15x9 cm (axb axes); avg clast imbrication (n=11): 262°. Sand is yellowish red (5YR 6/5), medium to very coarse, subrounded (mostly) to subangular, moderately to poorly sorted, and arkosic. Weakly consolidated; no to weak HCl effervescence.

Mud and very fine to fine sand: Thick, tabular beds. Unit includes minor 10-50 cm-thick, lenticular to broadly lenticular beds of medium to very coarse sand and very fine to coarse pebbles. Pebbles are subrounded, poorly to moderately sorted, and granitic. Finer sediment is reddish yellow (7.5YR 6/6) and includes 10% medium to very coarse sand and trace gypsum crystals (up to 5 mm long); sand is subrounded to subangular, moderately sorted, and arkosic. Finer sediment is bioturbated, has no internal stratification, and has 0.5-1% root pores (0.5 mm diam).

SEO-A87

alluvial slope sediment, 25-60% coarse channels



Ancha Formation: exposure too poor to see bedding

In upper 1.8 m of unit: gravel on surface (which may be lag) is composed of pebbles with 1/3 cobbles. Clast count of gravel (n=101): 69% granite, 16% quartzite, 6% qtz-musc gneiss, 6% vein quartz, 2% biot-hbl(?) gneiss, 1% latite. Max clast sizes: 15x8, 12x10, 14x10, 16x10.5, 14x12.5, 15x11, 16x10 cm (axb axes).

Pebbly sand: Pebbles are very fine to very coarse, granitic, and comprise 30-40% of unit. Sand is reddish yellow (7.5YR 6.6), subrounded to subangular, poorly sorted, and arkosic. Minor thin, white CaCO3-enriched zones (loose, but with strong HCl effervescence). Weakly consolidated. Sharp lower contact.

Silt and very fine to medium sand: Light yellowish brown (10YR 6/4); sand is vfL-mL and has subordinate mU-vcU sand; minor pebbles mixed in. Otherwise sediment is like underlying unit. CaCO3-enriched and white for 10 cm below upper

Silt and very fine to medium sand: Reddish yellow (7.5-5YR 6/6); sand is vfL-mL, subrounded (mostly) to subangular, moderately sorted, and arkosic. Moderately to well consolidated, with moderate to strong HCl effervescence. Lower contact is gradational over 5 cm. @55-60 cm from base is a 20-30 cm-thick, pinkish white (7.5YR 6/6), weakly CaCO3-cemented silt and very fine to fine sand with minor medium-very coarse arkosic sand; strong HCl effervescence.

Silt and very fine to fine sand, but with powder, bright white CaCO3: Strong HCl effervescence but weak to slightly hard. Does not have expected structure or hardness of a calcic horizon.

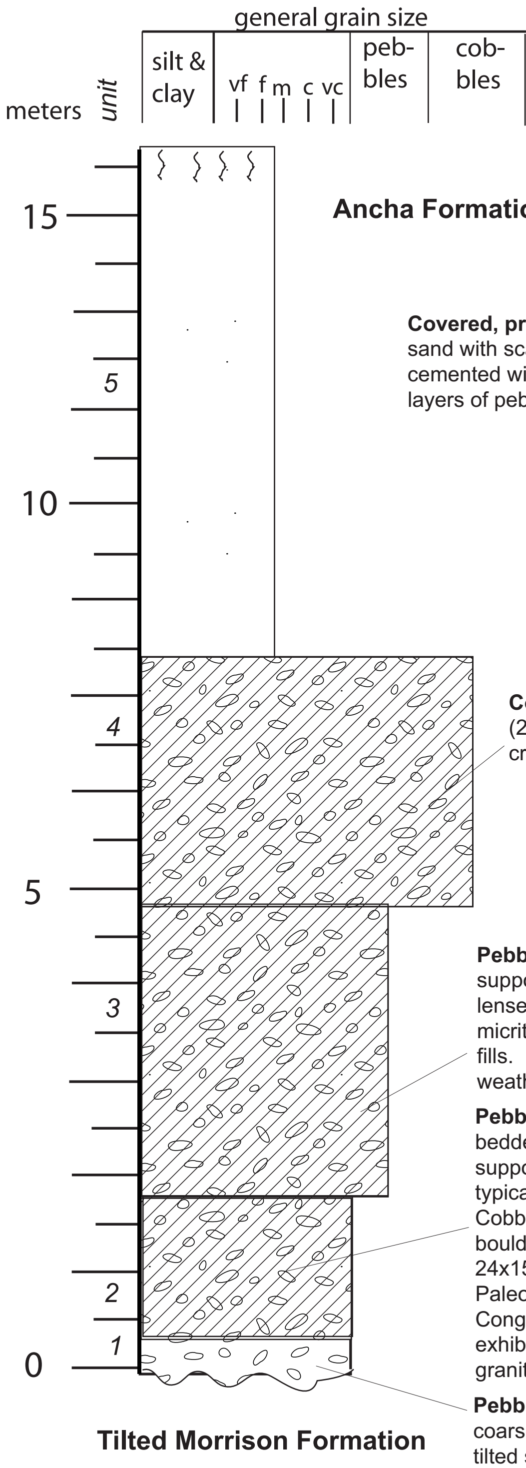
Silt and very fine to fine sand: Minor medium to very coarse sand of granite and latite mixed with finer sand. Brown to reddish yellow (7.5YR 5/4-6/6). Hard, with moderate HCl effervesce near the top.

Unit covered; no sign of strong cementation here or in vicnity.

Section located in a small road-cut along the south side of a dirt road about 5.76 km southeast of San Marcos Spring. Base of section UTM coord: 3921555N, 408540E (NAD 27, zone 13). Top of section UTM coord: 3921527N, 408615E (NAD 27, zone 13). Measured and described by Daniel Koning, June 17, 2004.

Galisteo 02

alluvial slope, >35% coarse channels



Ancha Formation : 16.4 m thick

Covered, probably sand and scattered pebble to small boulder gravel: Fine- to medium-grained silty sand with scattered pebbles to small boulders. Forms slope. Lower part of unit appears to be moderately cemented with disseminated calcium carbonate; upper 3-4 m is noncemented. Upper 1 m of unit contains layers of pebbles to small boulders that mantle rounded, partly degraded summit constructional surface.

Cobble conglomerate: Pink (7.5YR 8/3), moderately exposed and moderately cemented, medium- (20-40 cm thick) bedded, massive, matrix- and clast-supported. Grades upsection into finer grained cross bedded pebbly sandstone.

Pebble conglomerate: Pink (7.5YR 8/3), well cemented, medium- (10-30 cm thick) bedded, mostly matrix-supported pebble conglomerate with scattered medium- bedded, clast-supported cobble conglomerate lenses and fine- to very coarse-grained (fL-vcU) slightly pebbly sandstone. Discontinuously cemented with micritic carbonate that forms bedding parallel pebbly sandstone beds and 1-10 cm wide subvertical fracture fills. Numerous granite and schist clasts are partly to entirely grussified and split, suggesting extensive weathering zones or buried soils.

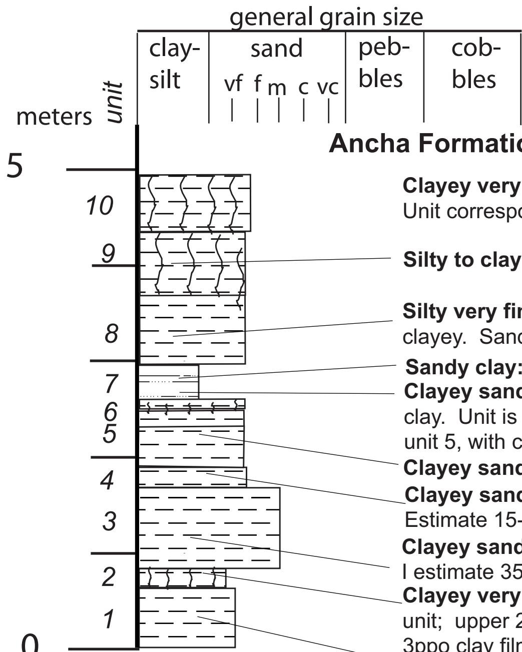
Pebbly sandstone and cobble conglomerate: Pink (7.5YR 7/3), well cemented, medium- (20-60 cm thick) bedded, moderately to well bedded, poorly sorted, fine- to very coarse-grained (fL-vcU), mostly clast-supported pebbly sandstone and cobble conglomerate. Pebbly sandstone beds contain clasts that are typically less than 5 cm diameter. Cemented with fine-grained sparry calcite that entirely plugs pores. Cobble conglomerate beds are mostly 3-12 cm in diameter with scattered sparse (<5%) small to medium boulders up to 50 cm. Max clast sizes and clast count (by Dan Koning; 08): 16x10, 14x11, 20x13, 22x22, 24x15, 24x16, 27x20, 18x13 cm; clast count (n=166) gives 90% granite, 3% amphibolite, 2% yellowish Paleozoic limestone, 2% quartzite, 2% qtz-biot gneiss, 1% chert, 1% intermediate volcanic rock. Conglomeratic beds comprise about 20% of unit. Pebbly sandstone beds are cross-bedded and generally exhibit weak normal grading. Unit generally fines upward into fine pebbly sandstone and sandstone. A few granite and schist clasts are slightly grussified and split.

Pebbly sand and gravel: Yellowish-red (5YR 5/6), very weakly cemented, poorly sorted, fine- to very coarse-grained (fL-vcU) pebbly sandstone and pebbly conglomerate. Base unconformably rests on tilted sandstone and shale of the Galisteo Formation. Basal contact has at least 2 m of relief in outcrop.

Reference section of the Ancha Formation described on exposures of private dirt road, northwest of intersection of AT&SF shortline to Lamy, NM, and US 285. Described by S.D. Connell and F.J. Pazzaglia on June 9, 2000. Base at N: 3,927,340 m, E: 417,770 m (Zone 13, NAD 83), Galisteo 7.5-minute quadrangle, Santa Fe County, New Mexico.

T-158

alluvial slope, 1-30% coarse channels



Ancha Formation

Clayey very fine- to fine-grained sand: Yellowish brown (10YR 5/6); 10-20% medium- to coarse-grained sand. Unit corresponds to a Bt soil horizon(s).

Silty to clayey very fine- to fine-grained sand: Pink (7.5YR 7/4). Stage II to II+ Bk horizon(s).

Silty very fine- to medium-grained sand: Strong brown to reddish yellow (7.5YR 5-6/6), Top 20 cm is slightly clayey. Sand is vfL to mL, with 5-10% mU-vcU sand and very fine to fine pebbles.

Sandy clay: Brown (7.5YR 5/4).

Clayey sand: Light brown (7.5YR 6/4). Sand is mostly very fine- to fine-grained; ~5% mL to cL sand. Estimate 30-35% clay. Unit is semi-indurated because of calcium carbonate cementation. This may be a Btk soil horizon developed in unit 5, with clay films masked by $CaCO_3$. Alternatively, the cementation may be due to vadose zone phenomena.

Clayey sand: Strong brown (7.5YR 6/5); sand is generally very fine- to fine-grained.

Clayey sand: Light brown (7.5YR 6/4), very fine- to very coarse-grained sand, but mostly very fine- to fine-grained. Estimate 15-35% clay.

Clayey sand: Strong brown (7.5YR 5/6); sand is very fine- to very coarse-grained; sand is subrounded and arkosic. I estimate 35-50% clay.

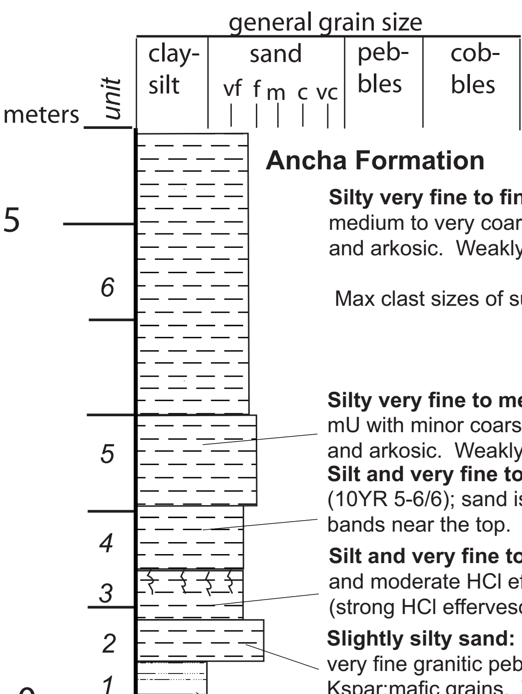
Clayey very fine- to fine-grained sand: Reddish yellow to strong brown (7.5YR 5-6/6). A soil has developed in this unit; upper 20 cm is a Btk: 40-50% white mottles of $CaCO_3$ which effervesce strongly with HCl; 2m-csbk structure, 3ppo clay films.

Silty very fine- to fine-grained sand: Brownish yellow (10YR 6/6). Moderate HCl effervescence; weakly cemented.

Located in roadcut on east side of Highway 599, about 1 km south of the New Mexico State Penitentiary. Base of section UTM coord: 3934555 N, 404555 E (NAD 27, zone 13). Measured and described by Daniel Koning, August 10, 1999.

SEO-A124

alluvial slope, 1-30% coarse channels



Ancha Formation

Silty very fine to fine sand: Light yellowish brown (10YR 6/4); estimate ~5% silt; sand is vfL-fU with subordinate medium to very coarse sand; trace very fine to fine pebbles. Sand is subagular to subrounded, low-moderately sorted, and arkosic. Weakly consolidated with no HCl effervescence.

Max clast sizes of surface lag gravel: 10x4.5, 2.5x5.5, 7x6, 7x5.5, 7x5.5, 6x6 cm (axb axes).

Silty very fine to medium sand: Light yellowish brown (10YR 6/4); no obvious bedding; estimate ~5% silt; sand is vfL-mU with minor coarse to very coarse sand and 0.5% very fine pebbles; subangular to subrounded, moderately sorted, and and arkosic. Weakly consolidated and no HCl effervescence.

Silt and very fine to fine sand: Strong brown to reddish yellow (7.5YR 5-6/6) or yellowish brown to brownish yellow (10YR 5-6/6); sand is vfL-fL, with minor scattered fU-cU arkosic sand. Two thin pinkish white (7.5YR 8/2) weakly cemented bands near the top. Weakly cemented and no HCl efferevescence. Lower contact is gradational over 10-20 cm.

Silt and very fine to fine sand: Lt yellowish brown (10YR 6/4); internally massive; sand is vfL-fL; moderately consolidated and moderate HCl effervescence. Upper 15 cm is very pale brown (10YR 8/2) and may be a stage II carbonate soil horizon (strong HCl effervescence).

Slightly silty sand: Light yellowish brown (10YR 6/4); estimate 3% silt; sand is vfL-cU with ~10% very coarse sand and very fine granitic pebbles; sand is subrounded to subangular, moderately sorted, and arkosic with an approx. ratio of 2/3:1/3 Kspar:mafic grains. Very minor, scattered lenses of 1-3 cm-thick mU-vcU sand and very sparse granitic very fine pebbles. Weakly consolidated and weak HCl effervescence. Unit fines upward to a silty very fine to fine sand. Planar, sharp lower contact.

Silt: Light yellowish brown (10YR 6/4); moderately consolidated; weak to moderate HCl effervescence.

Section located in cut-bank on west side of Interstate 25, immediately southwest of the south-bound on-ramp from Highway 587; southwest Turquoise Hill 7.5-minute quadrangle. Base of section UTM coord: 3934548 N, 398323 E (NAD 27, zone 13). Measured and described by Daniel Koning, July 1, 2004.