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STRATIGRAPHY OF THE TUERTO AND ANCHA FORMATIONS (UPPER SANTA FE GROUP), HAGAN AND SANTA FE EMBAYMENTS, NORTH-CENTRAL NEW MEXICO

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INTRODUCTION

Geologic studies and ^{40}Ar/^{39}Ar dating of subhorizontally bedded strata of the upper Santa Fe Group in the vicinity of the Santa Fe and Hagan embayments (Fig. 1) indicate that revision of the Ancha and Tuerto formations are necessary. The Ancha and Tuerto formations are included in the youngest strata of the Santa Fe Group, as defined by Spiegel and Baldwin (1963), and consist of broad, thin alluvial aprons of Plio-Pleistocene age derived from local uplands along the eastern margins of the Albuquerque and Española basins, Rio Grande rift, north-central New Mexico (Fig. 2). The Ancha Formation is composed mostly of granitic alluvium derived from the southeastern flank of the Sangre de Cristo Mountains and is located in the Santa Fe embayment, a west-sloping piedmont associated with the southwestern flank of the Sangre de Cristo Mountains. The Tuerto formation is composed mostly of porphryitic intrusive, volcanic, and hornfels rocks derived from eroding Oligocene, volcanic edifices of the Ortiz Mountains and Cerrillos Hills and is recognized mainly in the Hagan embayment (Fig. 1 and 2).

ANCHA FORMATION

The Ancha Formation was defined by Spiegel and Baldwin (1963, p. 45-50) for arkosic gravel, sand, and silt, inferred to be late Pliocene to Pleistocene in age, that lie with angular unconformity upon moderately tilted Tesuque Formation near Santa Fe, New Mexico. They established a partial type section for the Ancha Formation in Cañada Ancha, just north of the Santa Fe embayment (section CA, Fig. 3). The lower 3/5 of their type section, however, contains an 8.48±0.14 Ma tephra and is lithologically similar to the Pojoaque Member of the Tesuque Fm, which we correlate to most of their type section. The upper quarter of their type Ancha section contains basalt flows and basaltic tephra of the Cerros del Rio volcanic field, which was emplaced between 2.8 and 1.4 Ma (David Sawyer, personal commun., 2001), with the most voluminous activity occurring between 2.3-2.8 Ma (Woldegabriel et al., 1996; Bachman and Mehnert, 1978; Sawyer et al., 2001). Beneath the upper volcanic flows and volcaniclastics is 12-17(?) m of strata, containing 1-5% quartzite clasts, that is similar to a Pliocene deposit (unit Ta) mapped by Dethier (1997) that interfingers with Pliocene basalt tephra of the Cerros del Rio volcanic field.

The lower Cañada Ancha section contains hard, poorly sorted, grayish to brownish, pumiceous beds (Fig. 3). Although subhorizontal at the type section, these beds belong to a stratigraphic interval that continues 10 km along-strike to the north, where they are overlain by younger strata dipping up to 5° to the west (Fig. 2) (Koning and Maldonado, *in preparation*). Considering that the Ancha Formation is typically subhorizontal, the correlation of these pumiceous beds to strata that locally have been appreciably deformed supports our interpretation that the lower type Ancha section should be assigned to the subjacent Tesuque Formation. We do not assign these granite-bearing deposits (commonly >90% granitic clasts) to the Chamita Formation because paleocurrent data indicates general derivation from the east. In contrast, the more heterolithic, quartzite-bearing deposits of the Chamita Fm were derived from the north and northeast (*cf.* Galusha and Blick, 1971; Tedford and Barghoorn, 1993). Based on these interpretations and the presence of 8.48 Ma tephra, we propose that most of the Ancha Formation partial type section of Spiegel and Baldwin (1963) at Cañada Ancha is correlative to the Pojoaque Member of the Tesuque Formation.

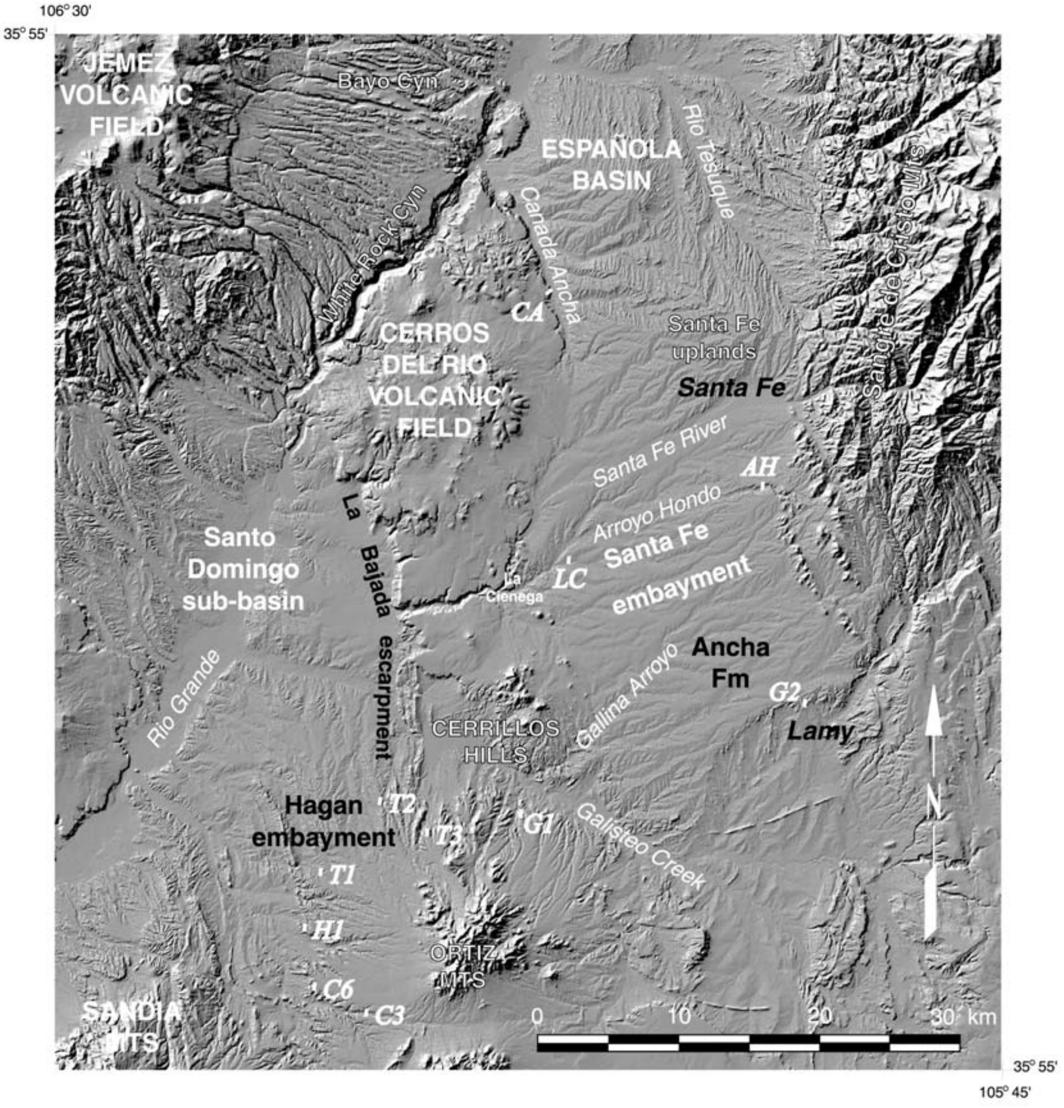

Figure 1. Shaded relief map of the Santa Fe embayment, Hagan embayment, and Santo Domingo sub-basin of the Albuquerque basin. Major geographic and physiographic features include the Cerros del Rio volcanic field, Santa Fe uplands, Sangre de Cristo Mountains, and Cerrillos Hills. Abbreviations of reference stratigraphic sections (shown by short white dash) include: Cañada Ancha (CA), La Cienega (LC), Arroyo Hondo (AH), Galisteo No. 1 and No. 2 (G1 and G2, respectively), Tuerto No. 1 through No. 3 (T1 through T3), Hagen No. 1 (H1), and Cuchillo No. 3 and No. 6 (C3 and C6, respectively). Base created from 30-m DEM data from the U.S. Geological Survey National Elevation Database (NED).

Thus, much of the type Ancha section does not correlate to mapped Ancha Fm in the Santa Fe embayment, where it has been generally mapped in a consistent manner. We recommend retaining this term and propose that a new type section be designated near the village of Lamy, New Mexico, approximately 35 km to the southeast of the Cañada Ancha partial type section of Spiegel and Baldwin (1963) (G2, Fig. 2). This revised section is about 11 km S-SE of another drainage named Cañada Ancha on the Seton Village 7.5-minute quadrangle. At the Lamy type section, the subhorizontally bedded Ancha Formation is about 16 m in thickness and overlies the Galisteo Formation with a distinct angular unconformity (Fig. 3). The basal 10 m of section is a well cemented, cliff forming, moderately to well bedded, pebbly sandstone and conglomerate composed primarily of granite with subordinate limestone, metamorphics, sandstone, siltstone, and quartz (Fig. 4). Sparse porphyritic intrusive and volcanic rocks, probably derived from the Cerrillos Hills or related Oligocene igneous centers, are locally recognized. This basal unit is informally called the well cemented member here because it is cemented with sparry calcite and typically forms ledges or cliffs. Conglomeratic beds comprise about 20% of this basal member. The upper 7 m of the Lamy section is informally called the weakly cemented member. The upper member typically forms poorly exposed slopes and is mostly covered. The texture and composition is similar to the underlying member, except that it is weakly cemented with disseminated calcium-carbonate. These informal members are generally not mappable at scale of 1:24,000 but are distinctive in outcrop. The lower member is commonly recognized where the Ancha Formation rests upon Espinaso Formation and older strata, although drill hole data suggest that this relationship is not ubiquitous. The upper member is more laterally extensive than the lower member, which is restricted to the southern portions of the Santa Fe embayment. To the north, the upper member rests upon deposits of the Tesuque Formation. Outcrop and subsurface data suggests that the Ancha Formation is generally 10-90 m-thick. The base is unconformable with moderately tilted Miocene deposits of the Tesuque Formation, as indicated by exposures along the margins of the Santa Fe embayment.

Gravel is generally clast supported, subrounded, and commonly contains 85-97% granite with minor amphibolite, gabbro, diorite, quartzite, and gneiss. Sparse Oligocene intrusive clasts derived from the Cerrillos Hills are scattered in the Ancha Formation near the boundary with the lithologically distinctive Tuerto Formation. Buried soils in the Ancha Formation are generally not common and contain calcic horizon(s) with Stage II to III pedogenic carbonate morphology that are commonly overlain by clayey Bt horizon(s).

West of the Santa Fe uplands, the Ancha Fm is mapped for ~7 km north of the Santa Fe River (Figure 1), although it may continue north as a 5-20(?) m-thick deposit under Cerros del Rio volcanic flows. Pliocene to early Pleistocene deposits on the Santa Fe uplands only consist of locally preserved, thin (typically 1-10 m), stream gravel deposits that descend as a suite of terraces from the Santa Fe River/Rio Tesuque drainage divide down to the Rio Tesuque. In contrast, south of the Santa Fe River, Ancha-related aggradation seems to have been widespread and much thicker. These Pliocene-early Pleistocene deposits reflect markedly different environments, one of general aggradation and one of landscape degradation, indicating a strong base level influence on deposition and significant differences in accommodation space.

We restrict the definition of the Ancha Formation to include Plio-Pleistocene deposits that contain abundant granite derived from the southern Sangre de Cristo Mountains. Deposits of the Tuerto formation are expanded to include deposits containing abundant clasts derived from Oligocene hypabyssal intrusive and volcanic rocks of the Ortiz-Cerrillos Hills. The Ancha Formation, as defined here, contains at least 20% granite clasts. We concur with the recommendation of Manley (1979) to exclude the high-level gravel deposits in the uplands north of the Santa Fe River from the Ancha Formation, principally because of the discontinuous and thin (1-10 m-thick) nature of these deposits and the inherent difficulty in correlating flights of terrace deposits from one drainage to another without adequate age control.

The top is defined by a physiographic surface that is preserved on relatively broad interfluves (Spiegel and Baldwin, 1963; Koning and Hallett, 1963). These broad relict surfaces are part of the Plains surface (Spiegel and Baldwin, 1963), which represents a former piedmont slope that has been subsequently incised by numerous streams draining the Sangre de Cristo Mountains. Soils of the Plains surface are typically modified by erosion and consist of clayey Bt or Btk horizons over calcic and siliceous Bk or Bkq horizons with Stage II to III+ carbonate morphology. We interpret the Plains surface to be a complex and diachronous surface that generally approximates the top of the Ancha Formation, even though it has probably experienced minor erosion. The Plains surface may be correlative, in part, to the upper Ortiz surface, which forms the constructional (upper) piedmont-slope surface of the Tuerto formation along the flanks of the Ortiz Mountains and Cerrillos Hills.

A veneer of sheetwash or colluvium commonly covers the Ancha Formation; exposures tend to be limited to roadcuts and a few arroyo walls. Along major drainages, such as Arroyo Hondo, erosion and subsequent deposition of younger inset stream deposits have modified the Plains surface. For example, exposures in railroad cuts across upper Arroyo Hondo contain interpreted channel fills of loose granitic sand and gravel that disconformably overly the Ancha Formation. Somewhat younger deposits with weakly developed soils are recognized just upstream of the mouths of major mountain front arroyos draining the Sangre de Cristo Mountains. These deposits are nearly indistinguishable from the Ancha Formation and are thus not differentiated.

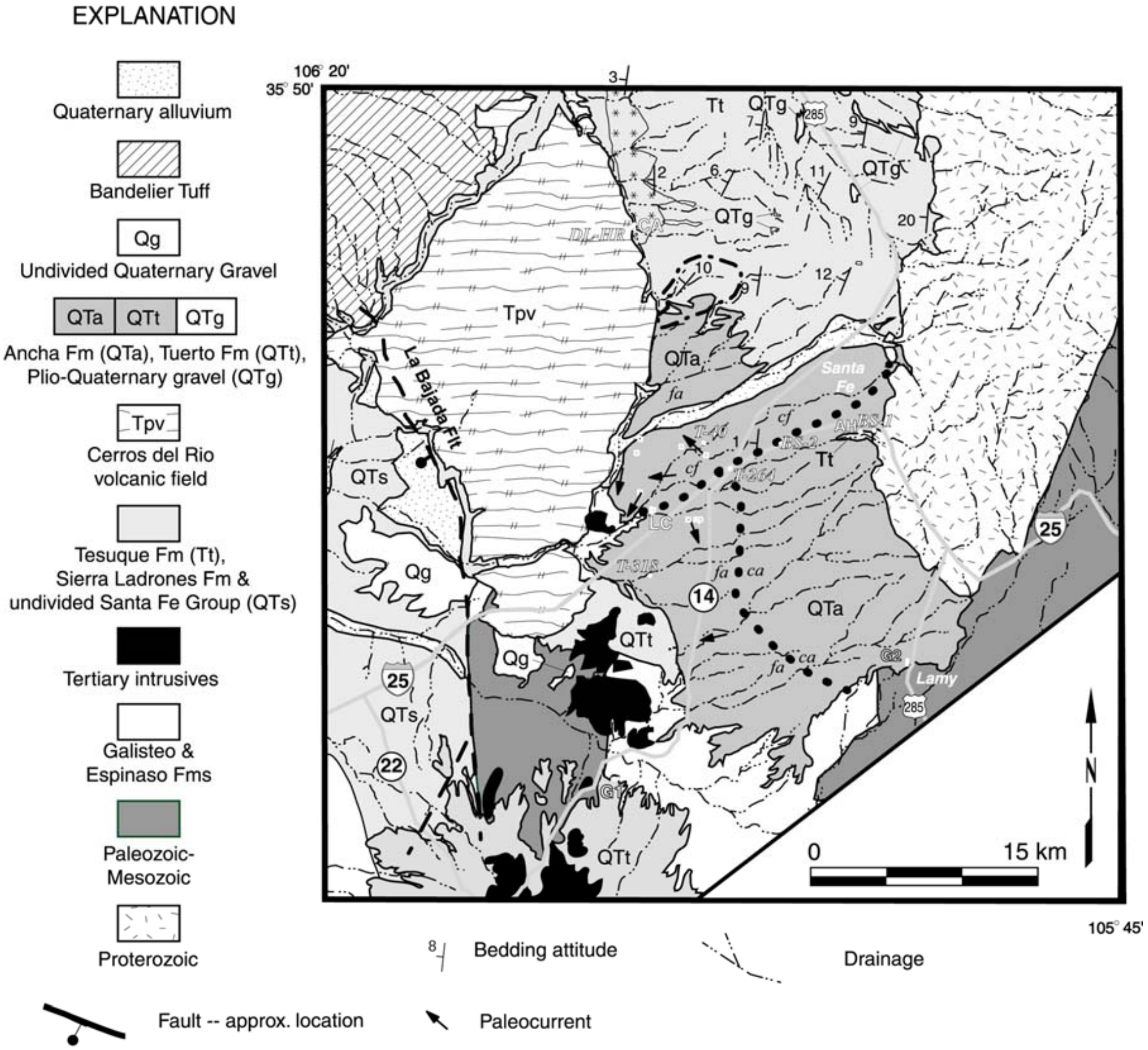

Figure 2. Simplified geologic map of the Santa Fe embayment and vicinity (modified from Koning and Maldonado, 2001; Read et al., 1999 and 2000; Koning and Hallett, 2000; Borchert and Read, 2000; Dethier, 1997; Kelley, 1978; Johnson, 1975; Bachman, 1975; Spiegel and Baldwin, 1963; and Sawyer et al., 2001). Drainages and major highways shown for reference. Abbreviations of reference stratigraphic sections given in Figure 1 caption. Squares mark localities of reworked, basaltic pyroclastic deposits that occupy channels <4 m-thick within the Ancha Formation south of the Santa Fe River; square labeled "sp" is immediately north of the New Mexico State Penitentiary. Circles denote ash sample localities. Asterisks (*) mark pumiceous, brownish to grayish, poorly sorted strata of upper Pojoaque Member of the Tesuque Formation. The bold, black, dotted line separates textural facies of the Ancha Formation (fa=fine alluvial; ca=coarse alluvial, cf=coarse fluvial). The bold, black, alternating dash-dotted line encloses a 6-24 m thick basaltic tephra (Spiegel and Baldwin, 1963). Depicted bedding attitudes are averaged from data within a 1.6 km (1 mi.) radius of the plotted symbol. Paleocurrent observations measured using cross-stratification, imbricated gravel, and channel orientations.

Figure 3

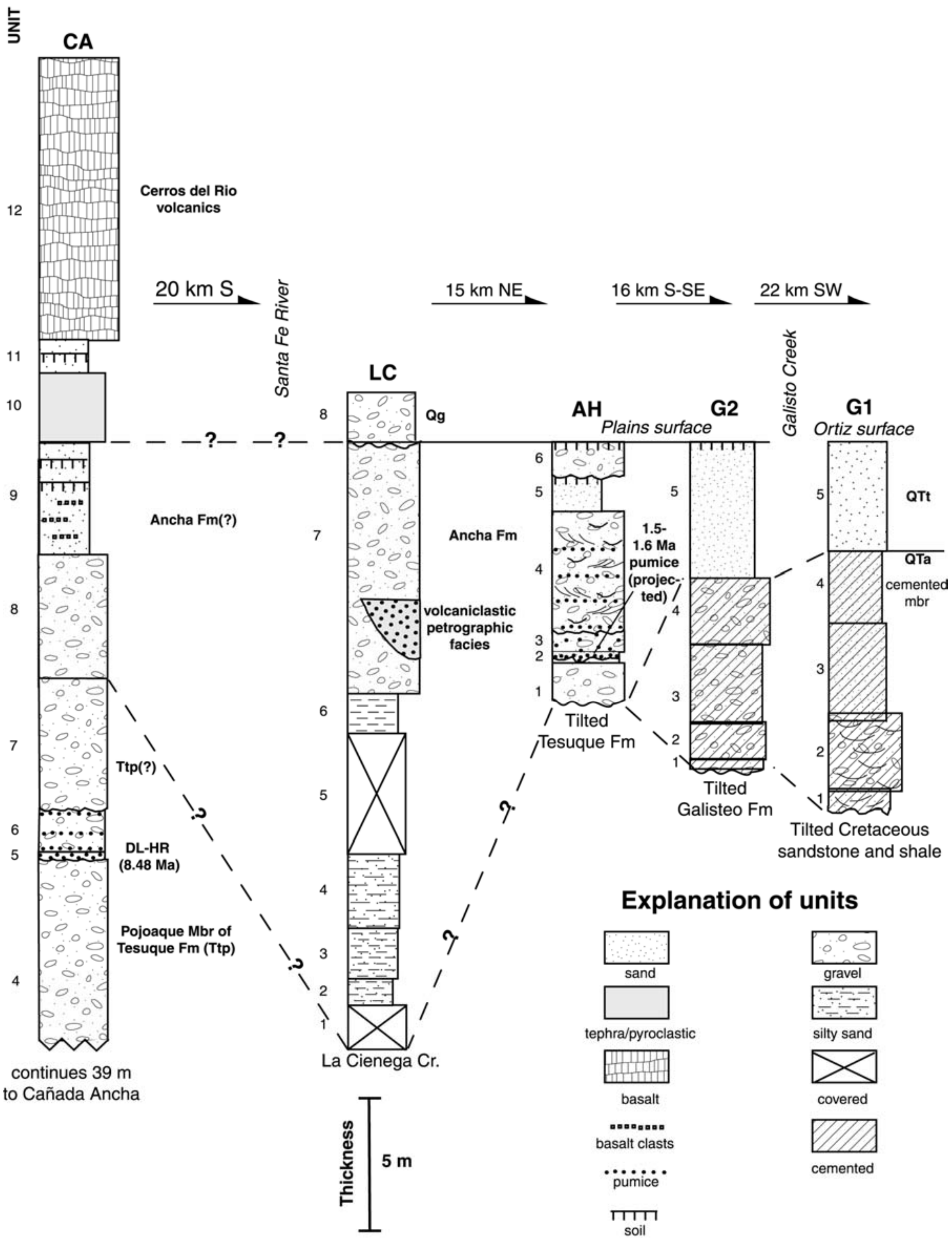

Figure 3. Type and reference stratigraphic sections of the Ancha Formation in the Santa Fe embayment. The initial partial type section of Spiegel and Baldwin (1963) was measured in Cañada Ancha and their stratigraphic column is also shown for reference. Descriptions of these sections are given in Connell et al. (*in preparation*).

The results of $^{40}Ar/^{39}Ar$ analyses on five tephras collected in the upper Ancha Formation and younger deposits indicate that the samples are age equivalent to tephras derived from the neighboring Jemez volcanic field. These tephras include the lower Bandelier tuff (1.61 Ma, Izett and Obradovich, 1994), Cerro Toledo Tephra (1.62-1.22 Ma, Spell et al., 1996), and upper Bandelier tuff (1.22 Ma, Izett and Obradovich, 1994). Rhyolite lapilli (1.48±0.02 Ma), temporally correlative to one of the Cerro Toledo events, is recognized near the top of the section. Deposits containing lapilli (1.25±0.06 Ma) that are temporally correlative to the upper Bandelier Tuff are recognized within deposits that are interpreted to be inset against the Ancha Formation along Bonanza Creek. These tephra, found northwest of the Cerrillos Hills, constrain the end of Ancha Formation deposition in this area to early Pleistocene time.

Weakly developed soils in deposits that are not differentiable from the Ancha Formation are recognized just within mountain-front drainages of the Sangre de Cristo Mountains. These might be younger deposits that overlie, or are part of, the Ancha Formation, which suggests that sedimentation may have occurred within these mountain front drainages during middle or perhaps late Pleistocene time.

The lower age limit of the Ancha Formation is poorly constrained; however, regional stratigraphic relationships and radioisotopic dates restrict this lower limit. Deposition began prior to emplacement of the basalt flows of the Cerros del Rio volcanic field (~2.3-2.8 Ma) (Stearns, 1979; Bachman and Mehnert, 1978; Koning and Hallett, 2000; WoldeGabriel et al., 1996; Manley, 1976a, Sawyer et al., 2001) and after deposition of the 8.48 Ma ash in the Cañada Ancha section. In the western Santa Fe embayment, basaltic tephra that may be derived from the Cerros del Rio field is found in the lower to middle Ancha Formation (Koning and Hallett, 2000). The Ancha Fm also interfingers with 2.3-2.8 Ma Cerros del Rio basalts (Spiegel and Baldwin, 1963; Bachman and Mehnert, 1978; Koning and Hallett, 2000; WoldeGabriel et al., 1996; Sawyer et al., 2001). The Cañada Ancha section is similar to an exposure in Bayo Canyon on the west side of the Rio Grande (Fig. 1), where a *ca* 5.3 Ma vitric ash near the base of the Plio-Pleistocene Puye Formation disconformably overlies Tesuque Formation strata that contains an ash dated at about 8.4 Ma (G. Woldegabriel, personal commun., 2001). The base of the Ancha Formation is probably diachronous. For example, in upper Arroyo Hondo about 2.3 km west of the mountain front, 2 m of gravelly Ancha Fm overlies tilted Tesuque Fm strata (AH, Fig. 3). Above this 2 m interval is about 11 m of gravelly sediment with reworked pumice that is interpreted to stratigraphically correlate to nearby beds of lower Bandelier tuff or Cerro Toledo tephra (Read et al., 2000). Using this limited data, we interpret the base of the Ancha formation to generally be 3-3.5(?) Ma in the western Santa Fe embayment, but acknowledge that it may be as young as 1.7-2.0 Ma near the mountain front in the eastern embayment.

TUERTO FORMATION

Stearns (1953) defined the Tuerto formation for a thin, alluvial apron associated with drainages in the Ortiz Mountains. The Tuerto formation contains hypabyssal intrusive and volcanic rocks derived from Oligocene igneous rocks of the Ortiz Mountains and Cerrillos Hills. The Tuerto formation is exposed in the Hagan embayment and eastern flank of the Albuquerque and Española basins. The Tuerto Formation is commonly thinner than the Ancha and contains clasts of augite monzanite and andesite porphyry, hornfels, and sparse granite. Deposits derived from the Cerrillos Hills contain Oligocene intrusive and volcanic rocks associated with magmatic events that created the Ortiz Mountains, however, these deposits do not contain andesite porphyry or hornfels.

Stratigraphic relationships along Galisteo Creek indicate that the Ancha and Tuerto formations are generally correlative and likely coeval. Here, the Ancha Formation is interpreted to interfinger with the Tuerto formation. The Tuerto formation is commonly 7-21 m in thickness and consists of light-brown to pink pebble to cobble conglomerate and sandstone. The base is commonly well cemented with sparry calcite where it overlies pre-Santa Fe Group strata. This well cemented lower unit locally forms cliffs. The upper part of the Tuerto formation is generally loose and poorly exposed. The Tuerto formation is also locally divided into two informal members: a cliff-forming, lower well cemented member containing abundant sparry calcite cement; and a slope-forming, upper weakly cemented member. Surface soils are partially stripped and exhibit Stage II to III+ carbonate morphology.

The Tuerto formation overlies a broad surface of erosion (the lower Ortiz surface of Stearns, 1979) developed on the subjacent Blackshare and Tanos formations. Near the front of the Ortiz Mountains, most notably along Arroyo Tuerto and Arroyo Cuchillo, the Tuerto formation fills in paleovalleys cut into Cretaceous-Triassic strata. Former channels of the Tuerto formation commonly armor the margins of the modern drainages. This geomorphic association suggests that the Tuerto formation had entrenched and partially backfilled its own channels, which could be the result of incision due to uplift along the southern end of the La Bajada fault; however, preliminary measurement and estimates from geologic maps of the Madrid quadrangle (S. Maynard, in preparation; Bachman, 1975) indicate only slight thinning of the Tuerto across the mapped trace of the La Bajada fault, between NM-22 and Galisteo Creek (Fig. 5).

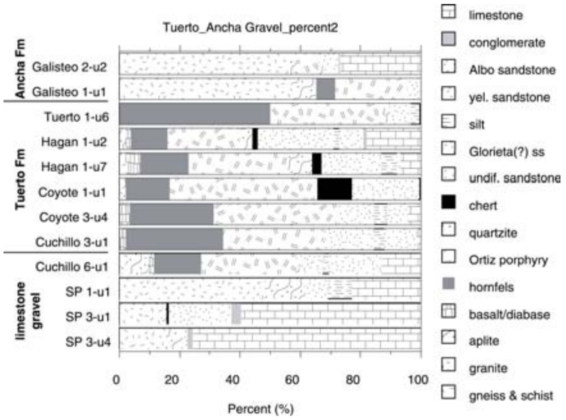

Figure 4 Percentages of clasts found in selected reference stratigraphic sections(see Figure 1 caption for stratigraphic section name abbreviations).

The base is unconformable with moderately titled Miocene deposits of the Tanos and Blackshare formations (Connell and Cather, this volume) in the Hagan embayment. Along the southern margin of Galisteo Creek, porphyritic andesite- and monzonite-bearing gravel of the Tuerto Formation overlies about 13 m of well-cemented, trough-cross stratified, granite-bearing conglomerate and sandstone (Fig. 3). Based on granitic lithology and the presence of a basal angular unconformity, we interpret the lower granite-bearing conglomerate and sandstone to approximate the southern limit of the Ancha Formation.

Limestone-bearing gravel is present in the same stratigraphic position as the Tuerto and Ancha Formation. This unit is interpreted to interfinger with the Tuerto formation near San Pedro Creek. This unit will be defined in later studies.

DISCUSSION

The Ancha, Puye, and Tuerto formations are gravelly deposits of Pliocene and early Pleistocene age that unconformably overlie older, generally tilted strata of the Santa Fe Group and older rocks. The Puye Formation is a coarse-grained, volcaniclastic, alluvial sequence that is generally located north of the Cerros del Rio volcanic field and west of the Rio Grande. Pliocene sand and gravel successions in the Arroyo Ojito and Sierra Ladrones formations in the Albuquerque basin conformably overlie older, finer deposits (Connell et al., 1999; Smith and Kuhle, 1998). The coarse-grained character of these upper Santa Fe Group units, exposed over a wide area and in different structural basins, suggests a climatic influence on deposition.

However, we interpret that tectonic factors were responsible for the significant differences of accommodation space, as reflected by the relative thickness of the Ancha and Tuerto formations, between the Santa Fe and Hagan embayments during the Pliocene to early Pleistocene. Between 2.7 and 0.5 Ma, up to 500 m of offset along the La Bajada fault (Sawyer et al., 1999) uplifted the Cerrillos Hills footwall block relative to the Santo Domingo sub-basin of the Albuquerque Basin. The relative uplift of the footwall of the La Bajada fault would have likely resulted in the development of a canyon along the ancestral Rio Santa Fe; such a canyon has been inferred from coarse gravel deposits under andesitic volcanic cones about 6 km north of the present Santa Fe River Canyon (David Sawyer, personal commun., 2001). Except for near this paleocanyon, geologic map relationships suggest that the Ancha Formation thins along the present-day Santa Fe River west of La Cienega and probably pinches out beneath the Cerros del Rio volcanic field (Sawyer et al., 2001). Aggradation of the Tuerto and Ancha formations and emplacement of the Cerros del Rio volcanic field began at similar times. Geologic map relations and ^{40}Ar/^{39}Ar dates in the Tetilla Peak quadrangle (Sawyer et al., 2001) suggest that particular Cerros del Rio basalt flows, dated at~2.6-2.7 Ma, may have raised local base level by 20-50 m and the resulting topographic sill would have been an impediment to westward-flowing drainages. This may have contributed to aggradation in the western Santa Fe embayment during the emplacement of the basalt flows. Concurrent tectonic subsidence may have also occurred near the center of the Santa Fe embayment. Either would likely serve to increase Ancha Formation thickness and may explain why the Ancha Formation is generally thicker than the Tuerto formation.

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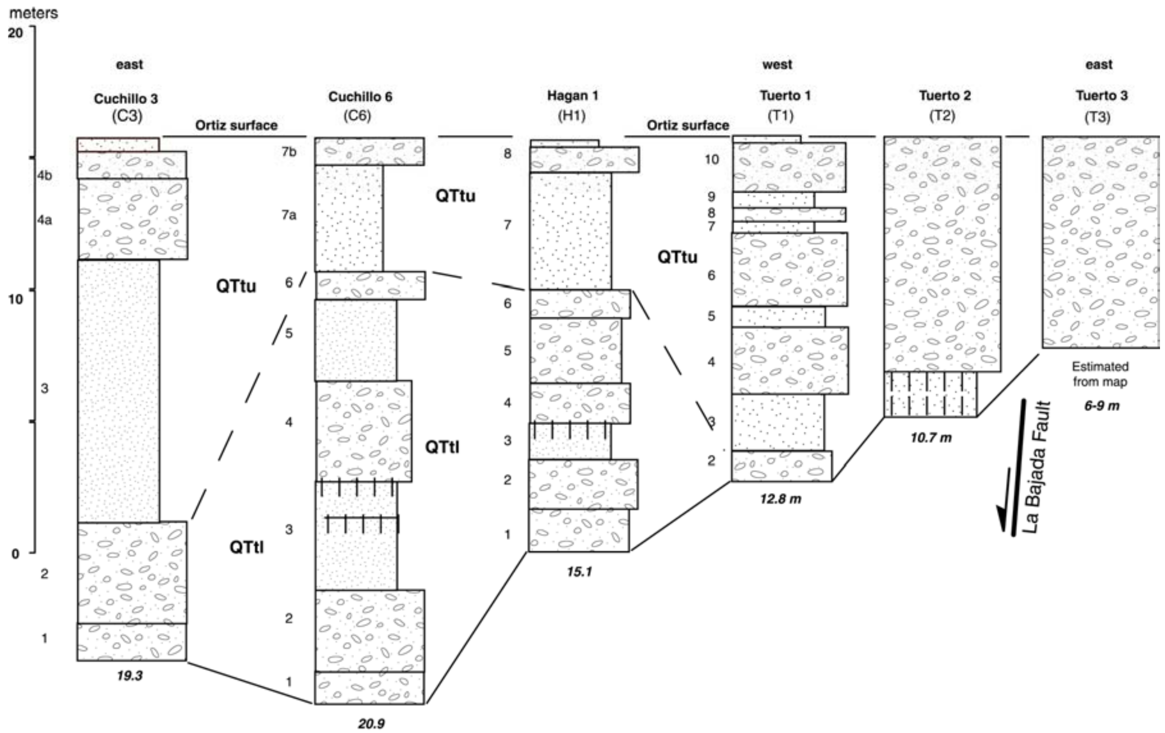

Figure 5. Reference stratigraphic sections of the Tuerto Formation in the Hagen embayment.

Table 1. Geochronologic data for late Tertiary and early Pleistocene tephras in the Santa Fe embayment. Tephras were analyzed by the New Mexico Geochronological Research Laboratory (NMGRL) by Peters (2000a and Winick (1999). Locations of tephra sample localities given in Figure 2.

Sample No.	Map Unit	Location, UTM, NAD83, Zone 13S (m)	Description	NMGRL No.	Weighted mean±2σ age (Ma)
T-318	Qa	N: 3,933,270 E: 400,520	<10 cm lapilli bed interbedded with pebbly sand along south margin of Bonanza Creek.	51220	1.25±0.06
T-264	QTa	N: 3,940,320 E: 406,300	White, 80 cm thick, pebbly pumice bed overlain by 50 cm of pumiceous sand in west roadcut just south of Interstate 25.	51222	1.48±0.02
BS-2	QTa	N: 3,953,470 E: 404,420	Intersection of I-25 and Richards Avenue. About 1 m below eroded Ancha Fm surface.	9778, 9779, 9780	1.61±0.02
BS-1	QTa	N: 3,942,350 E: 415,900	About 1 m below eroded Ancha Fm surface north of Arroyo Hondo.	9777	1.67±0.03
T-40	QTa	N: 3,941,940 E: 404,305	120 cm thick, white ash and pumice mixed with sand and sandy gravel in roadcut by aqueduct. Overlies soil with Bt horizon.	51221	1.63±0.02
DL-HR*	Tt	N: 3,956,680 E: 399,870	White lapilli bed ~20 m below basalt flow and ~9 m below QTa(?) at Cañada Ancha section	6049	8.48±0.14

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