STRATIGRAPHY OF THE LOWER SANTA FE GROUP, HAGAN EMBAYMENT, NORTH-CENTRAL NEW MEXICO: PRELIMINARY RESULTS

SEAN D. CONNELL
New Mexico Bureau of Mines and Mineral Resources-Albuquerque Office, New Mexico Institute of Mining and Technology, 2808 Central Ave. SE, Albuquerque, New Mexico 87106

STEVEN M. CATHER
New Mexico Bureau of Mines and Mineral Resources, New Mexico Institute of Mining and Technology, 801 Leroy Place, Socorro, New Mexico 87801

INTRODUCTION

Geologic mapping and stratigraphic studies of upper Oligocene through middle Miocene sedimentary rocks of the Santa Fe Group exposed in the Hagan embayment constrain the initial development of the Albuquerque Basin and Rio Grande rift in north-central New Mexico. These sedimentary rocks are exposed in the Albuquerque Basin along Arroyo de la Vega de los Tanos (herein called Tanos Arroyo) at the northeastern dip-slope of Espinaso Ridge in the Hagan embayment of central New Mexico (Fig. 1). This paper presents preliminary findings of geologic studies on two formations proposed for lower Santa Fe Group strata exposed in the Hagan embayment.

STRATIGRAPHY OF TANOS ARROYO

Stratigraphic sections were measured and described on the northeastern flank of Espinaso Ridge along Tanos Arroyo (Fig. 1). The Tanos Arroyo section comprises two formation-rank units that are informally subdivided into members and lithofacies units. These deposits are composed primarily of recycled volcanic and porphyritic intrusive detritus derived from the adjacent Ortiz Mountains, on the footwall of the La Bajada fault (Fig. 2). The base of this succession is here called the Tanos Formation, which overlies the volcaniclastic Oligocene Espinaso Formation (*ca*. 36-27 Ma, Kautz et al., 1981). The Tanos Formation is a succession of moderately tilted conglomerate, thin- to medium-bedded mudstone and tabular sandstone. The Tanos Formation is 253 m thick at the type section (Figs. 2-3, TA1), where it is subdivided into a basal piedmont conglomerate member, a middle mudstone and sandstone member, and an upper tabular sandstone member. Ripple laminated sandstone beds are common in the lower part of the middle member. These lithofacies occur in a distinct stratigraphic succession at the type section and are assigned to informal member-rank terms. Mudstone beds thin to the southeast, near the mouth of Arroyo del Tuerto (Fig. 3, TA; Arroyo Pinovetito of Stearns, 1953), which is about 4 km south of the type section. The Tanos Formation contains a mudstone and fluviatile sandstone interval, suggesting deposition in a playa-lake and distal, streamflow-dominated piedmont setting. These members are associated with the transition between the piedmont-slope and the basin-floor. An olivine basalt flow, about 9 m above the base at the type section, yielded a whole-rock $^{40}Ar/^{39}Ar$ date of 25.41±0.32 Ma (W.C. McIntosh, 2000, written commun.; Cather et al., 2000), which is consistent with an earlier K/Ar date of about 25.1±0.7 Ma (Kautz et al., 1981) at the northern tip of Espinaso Ridge.

The basal contact of the Tanos Formation is sharp and slightly scoured. No angular unconformity with the underlying Espinaso Formation is apparent in outcrop. A continuous dip-meter log for the Pelto Blackshare Federal #1 well (Sec. 35, T14N, R6W, San Felipe Pueblo NE quadrangle), drilled nearly 5 km south-southeast of the Tanos type section (on file at the New Mexico Bureau of Mines and Mineral Resources in Socorro, New Mexico; Library of Subsurface Data #26,091), indicates an angular unconformity at about 460 m below land surface (bls). Strata encountered in this well are oriented about N25°E, 10-12°NW below 460 m bls, and about N60°W, 8°NE above. Thus we interpret the contact between the Espinaso and Tanos formations to be unconformable. Restoration of Tanos Formation bedding to horizontal attitude indicates that the Espinaso Formation was oriented about N10-12°W, 10-14°NE prior to deposition of the Tanos Formation. The dip-meter log does not show significant steepening in dips that would indicate the presence of a normal fault, which commonly have dips of about 60°. Thus, the dip-meter log indicates that the Espinaso Formation underwent an episode of deformation prior to deposition of the Tanos Formation.

The age of this unconformity is bracketed by a K/Ar date of 26.9±0.6 Ma reported for a nepheline latite flow about 130 m below the top of the Espinaso Formation (Kautz et al., 1981) and the basalt dated 25.41±0.32 Ma in the basal Tanos Formation. Thus, the hiatus represented by this unconformity at the type section is thus less than 1.5 m.y. in duration, and likely spans a much shorter interval of time. If there was basal onlap of Tanos Formation to the east, then this unconformity might span an even shorter period of time towards the center of the basin, which was presumably northwest of the type section.

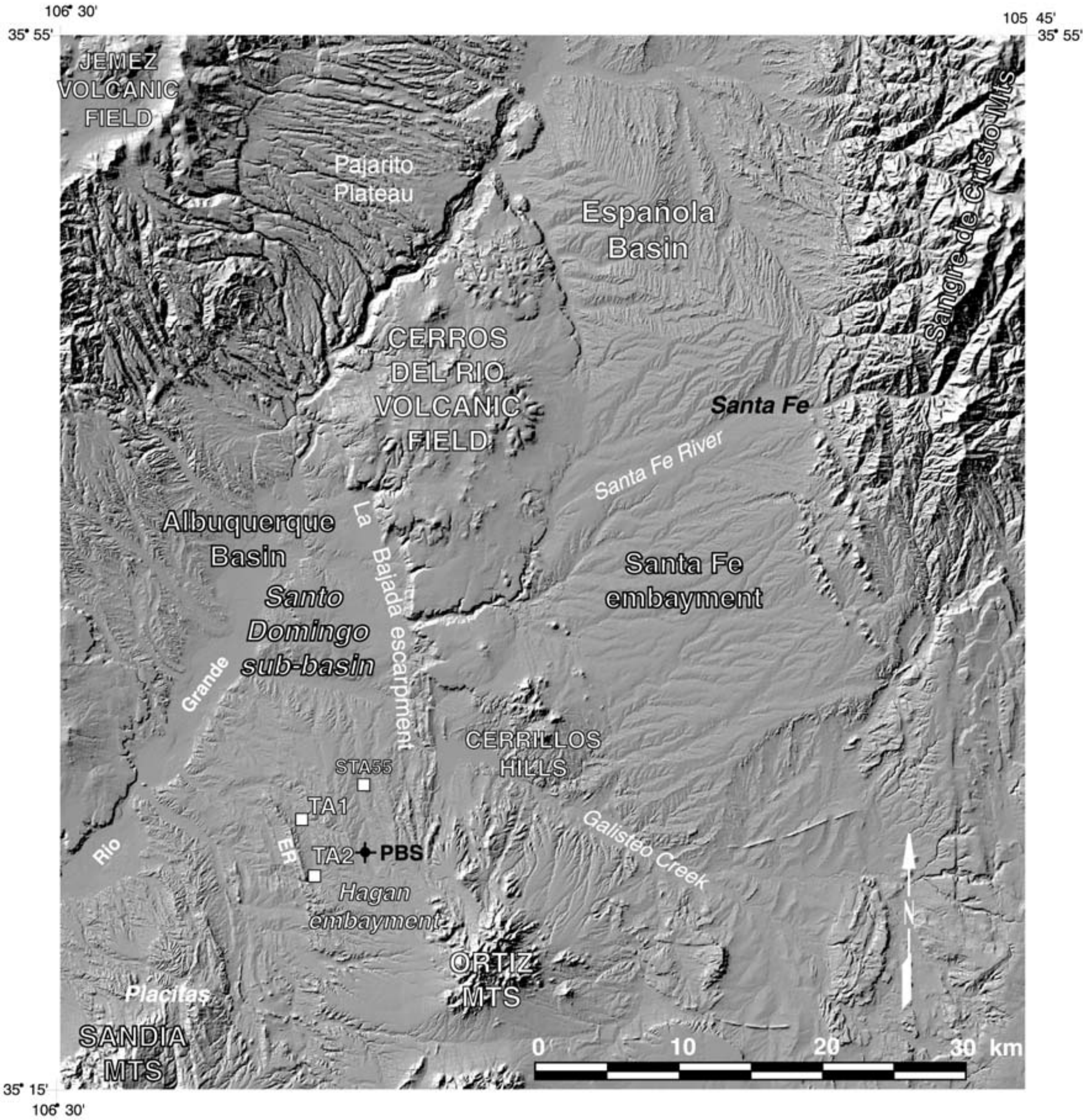

Figure 1. Shaded relief map, illustrating the locations of major geographic features and the study area. Base produced from U.S. Geological Survey 30-m DEM data. Localities include the Pelto Blackshare Federal #1 (PBS), Tanos Arroyo sections (TA1, TA2), and selected localities mentioned in text.

The mapped extent of the Tanos Formation corresponds approximately with strata tentatively assigned to the Abiquiu Formation by Stearns (1953), and to strata Kelley (1979) correlated to the Zia Formation. The Tanos Formation is in part, temporally equivalent to the Abiquiu Formation (Tedford, 1981; Moore, 2000). The Tanos Formation, however, is lithologically dissimilar to the Abiquiu Formation because it contains abundant locally derived volcanic detritus derived from the adjacent Ortiz Mountains (Large and Ingersoll, 1997). In contrast, the Abiquiu Formation in the Abiquiu embayment, about 70 km northwest of the study area (Smith, 1995; Moore, 2000), consists largely of epiclastic sediments derived from the Latir volcanic field of northern New Mexico. Paleocurrent measurements from the Tanos and Blackshare formations indicate flow to the west-northwest, away from the highlands of the Ortiz Mountains (Fig. 4) and support the petrographic interpretations of Large and Ingersoll (1997) that these deposits were derived from the Ortiz Mountains.

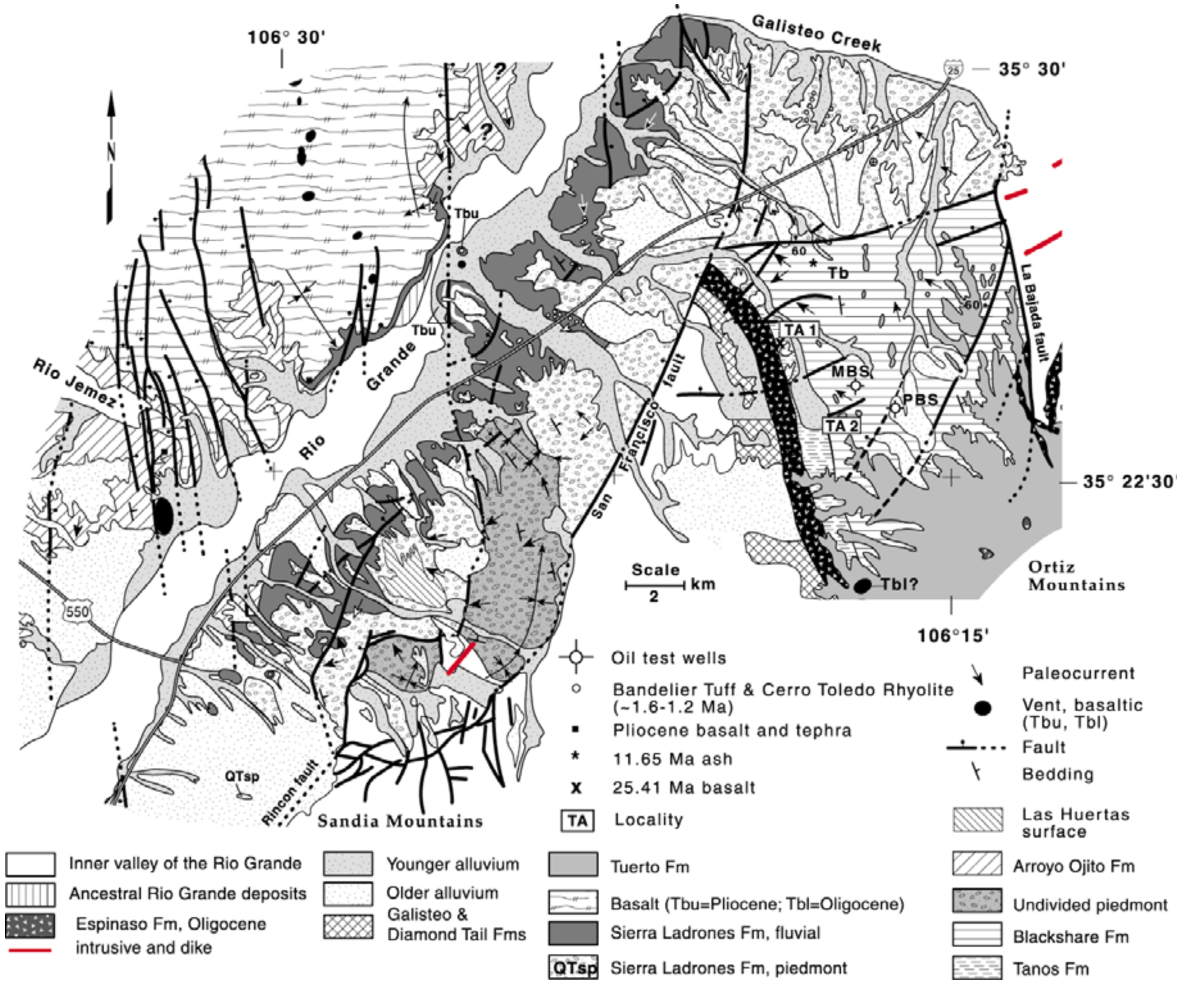

Figure 2. Simplified geologic map of the southeastern Santo Domingo sub-basin, illustrating locations stratigraphic sections along Tanos Arroyo (TA1 and TA2). Compiled from Cather and Connell (1998), Cather et al. (2000), Connell, (1998), Connell et al. (1995), and unpublished mapping.

The basal Santa Fe Group strata in the Hagan embayment are older than the Zia Formation (Fig. 5) and are not directly correlative as originally suggested by Kelley (1977). The Zia Formation is exposed 30-45 km to the west on the northwestern margin of the Albuquerque Basin. The Hagan embayment contains a thick succession of mudstone and fluvial sandstone derived from local sources to the east, whereas the eolian-dominated lower Zia Formation was deposited by westerly winds and sparse, widely spaced southeast-flowing streams (Beckner and Mozley, 1998; Gawne, 1981).

The Tanos Formation is conformably overlain by a >700-m thick succession of sandstone, conglomerate, and minor mudstone herein called the Blackshare Formation, for the nearby Blackshare Ranch, located in a tributary of Tanos Arroyo. The Blackshare Formation is interpreted as stream-flow and hyperconcentrated-flow deposits laid down by streams that originated form the Ortiz Mountains and eastern margin of the Hagan embayment. Conglomerate beds are commonly lenticular and sandstone intervals commonly fine upward into thinly bedded mudstone, which have upper contacts that are commonly scoured by lenticular conglomerate of an overlying fining-upward sequence. The upper boundary of the Tanos Formation is gradational and interfingers with the overlying Blackshare Formation. The contact is placed at the lowest lenticular pebbly to cobbly sandstone in this tabular sandstone/conglomeratic-sandstone transition. This contact was chosen on the basis of measured sections and differs slightly from the mapped contact (Cather et al., 2000), which was placed at the top of the highest, thickly bedded, tabular sandstone.

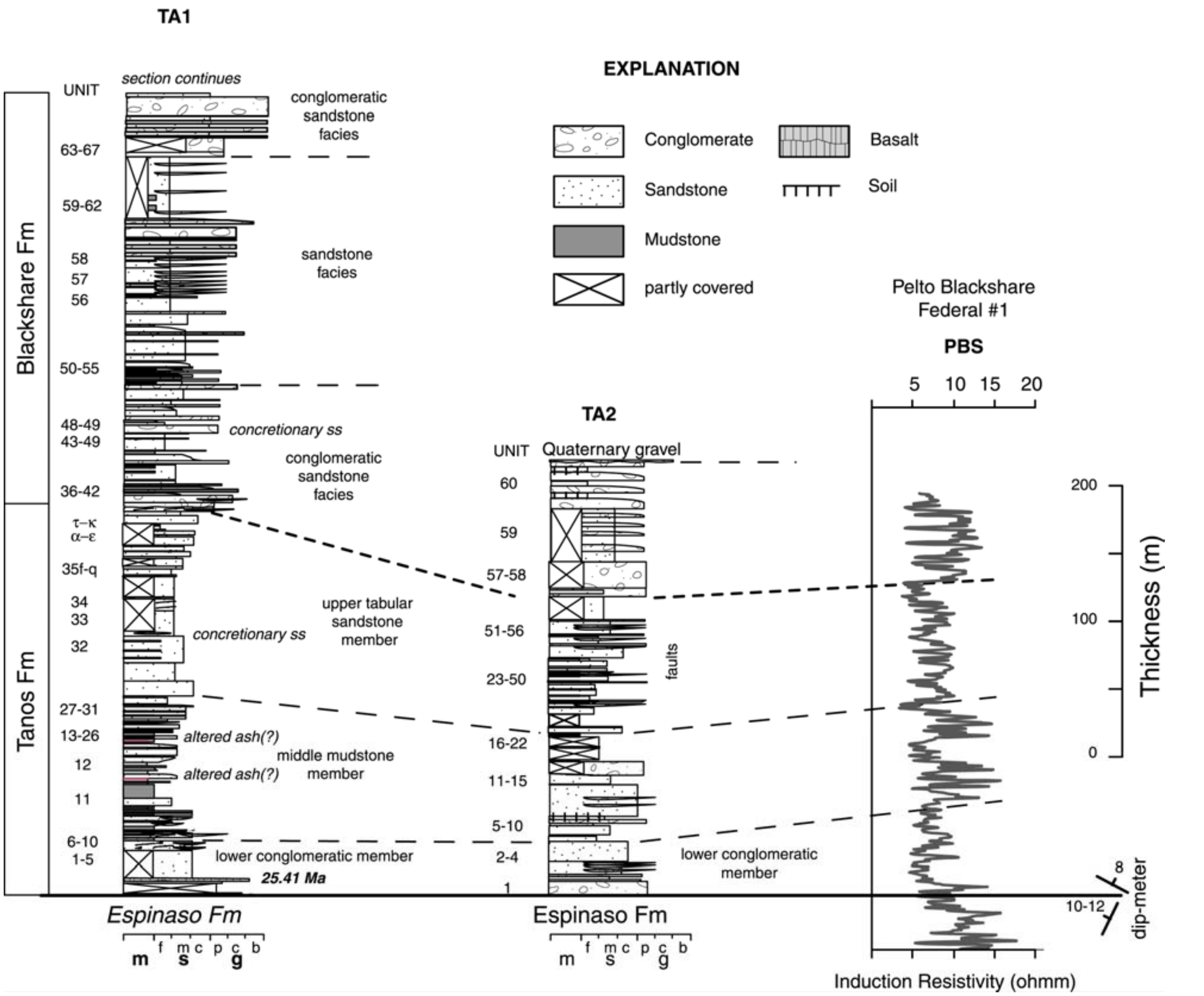

Figure 3. Composite stratigraphic section of the type locality (TA1) and Arroyo del Tuerto reference section (TA2) of the Tanos and Blackshare formations. Horizontal scale indicates approximate maximum grain size. The Pelto Blackshare Federal #1 (PBS), drilled about 6 km to the east, encountered similar deposits as interpreted from borehole geophysics and a continuous dip-meter log.

The type section of the Blackshare Formation is about 312 m above the top of the Tanos Formation type section. A complete section of the Blackshare Formation was not measured because the top is not recognized in the study area and exposures are commonly quite poor northeast of Tanos Arroyo. Discontinuous outcrops of the Blackshare Formation extend 6 km east to the La Bajada fault.

The Blackshare Formation is locally differentiated into three mappable textural lithofacies (Cather et al., 2000), following methods proposed by Cather (1997). These units interfinger, are not superposed, and do not necessarily occur in any particular stratigraphic order. The conglomeratic piedmont lithofacies consists of well cemented conglomerate and subordinate sandstone. The conglomeratic sandstone lithofacies consists of subequal amounts of sandstone and conglomerate. The sandstone member contains sandstone with subordinate conglomerate and mudstone.

An ash within the upper exposures of the Blackshare Formation was projected into the type section, where it is between 670-710 m (estimated from geologic map of Cather et al., 2000) above the base. This ash yielded a single-crystal (on sanidine) $^{40}Ar/^{39}Ar$ date of 11.65±0.38 Ma (W.C. McIntosh, 2000, written commun., Cather et al., 2000). Other fluvially recycled ashes, up to 3 m in thickness, occupy similar stratigraphic positions to the dated ash (Cather et al., 2000; Stearns, 1953); however, they are too fine grained to be dated using the $^{40}Ar/^{39}Ar$ technique.

The Plio-Pleistocene Tuerto Formation overlies the Blackshare and Tanos formations with angular unconformity. The subhorizontally bedded Tuerto Formation overlies beds of the Tanos Formation that tilt 27-36°NE. Dips in the Blackshare Formation progressively decrease upsection, where stratal tilts of 4-16°NE are observed stratigraphically above the 11.65 Ma ash in the Blackshare Formation; higher stratal tilts are commonly near faults. The top of the Blackshare Formation is cut by the La Bajada fault or is unconformably overlain by the subhorizontally bedded Plio-Pleistocene Tuerto Formation.

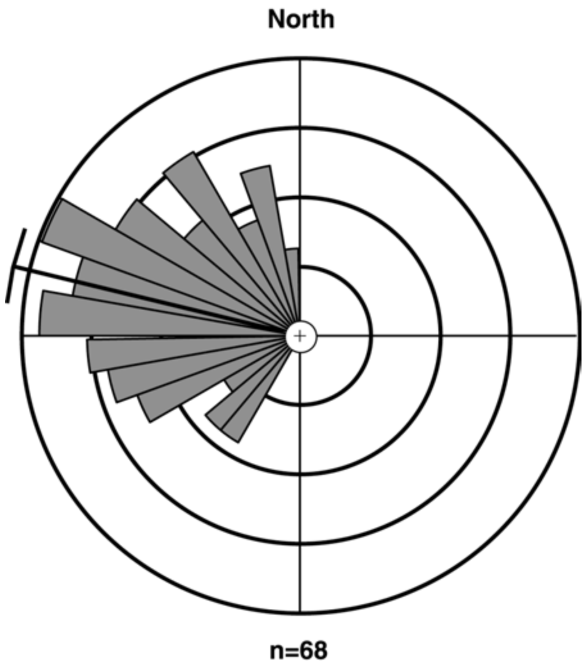

Figure 4. Rose diagram of paleocurrent data determined from gravel imbrication, channel orientation and cross stratification, indicating westward paleoflow from the Ortiz Mountains. Eight measurements were made in the basal Tanos Formation, which are not significantly different from paleocurrent directions measured in the overlying Blackshare Formation. Data compiled from geologic map of the San Felipe Pueblo NE quadrangle and measured sections (Cather et al., 2000). Data is combined into 10° intervals and the correlation coefficient (r) is 0.85.

Gravel in the Tanos and Blackshare formations are predominantly composed of monzanite and andesite porphyry with sparse (<2%) rounded quartzite, petrified wood, iron-stained sandstone, and hornfels (Fig. 6). The hornfels clasts are interpreted to be thermally metamorphosed sandstone and shale from the Cretaceous Mesaverde Group or Mancos Shale, which was intruded by the Oligocene Ortiz porphyry in the footwall of the La Bajada fault (S. Maynard, oral commun., 2000). Hornfels pebbles increase in abundance upsection in the interval above the measured section (Fig. 6). Sand in the Tanos and Blackshare formations is mostly lithic arkose and feldspathic litharenite, and differs from the nonquartzose lithic arkose of the subjacent Espinaso Formation (Large and Ingersoll, 1997; Kautz et al., 1981).

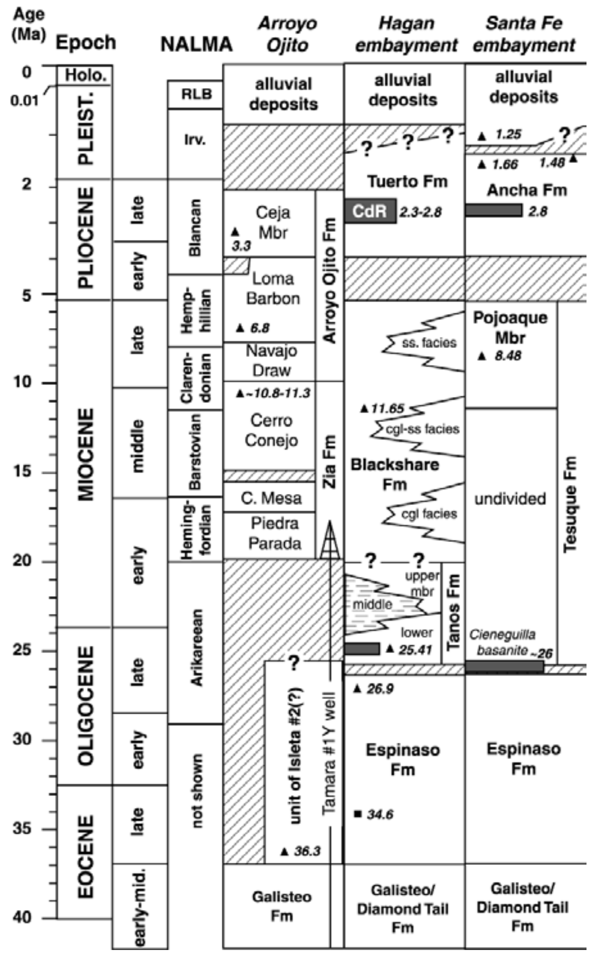

Figure 5. Correlation chart, illustrating correlations of selected Santa Fe Group units at Arroyo Ojito in the northwestern Calabacillas sub-basin (Connell et al., 1999), Hagan embayment (this study), and Santa Fe embayment (Koning et al., *this volume*). The Cerros del Rio volcanic field is denoted by CdR. Triangles are dates (in Ma) from primary volcanic units; boxes are recycled volcanic deposits; and shaded boxes are basaltic flows.

The stratigraphically lower Galisteo and Diamond Tail formations are arkosic to subarkosic and contain abundant quartz (Fig. 7). The abrupt increase in quartz content of the Tanos Formation, relative to the subjacent Espinaso Formation, suggest that older quartzose rocks were rapidly exposed on the footwall of an emerging La Bajada fault. The composition of the Tanos-Blackshare deposits relative to the Espinaso and Galisteo formations do not suggest a simple mixing of the Espinaso and Galisteo and Diamond Tail formations, principally because of the greater abundance of lithic fragments in Tanos-Blackshare succession. These data suggest contributions from other lithic sources, or possibly differences in grain size of the components analyzed among the various studies compiled for Figure 7 (Ingersoll et al., 1984); however, compositional differences are probably too great to be accounted for by grain size alone. The rather sharp increase in quartz content across the Espinaso-Tanos contact indicate a rather abrupt change in the composition of upland drainages, rather than progressive unroofing of the formerly extensive volcanic cover of the Espinaso Formation. Fairly rapid exhumation of the basin border along major faults, such as the nearby La Bajada fault, could account for this abrupt change in source lithology. Oligo-Miocene movement along this fault might have also resulted in the development of the angular unconformity recognized on dip-meter log of the Pelto Blackshare Federal #1.

IMPLICATIONS

The base of the Tanos Formation is younger than the >30.48 Ma onset of deposition of the Nambé Member of the Tesuque Formation reported by Smith (2000) in the Española basin. The Nambé Member is one of the oldest basin-fill units of the Santa Fe Group in the Española basin. The Tanos Formation, however, is older than the eolianites of the Piedra Parada Member of the Zia Formation, which overlie Eocene and Upper Cretaceous strata along the western margin of the Albuquerque Basin. The basal contact of the Piedra Parada Member contains scattered Oligocene volcanic clasts, indicating the presence of formerly extensive, but probably thin, Oligocene deposits prior to deposition of the Zia Formation. Many of these volcanic cobbles and pebbles have been sculpted into ventifacts (Tedford and Barghoorn, 1999), suggesting that this boundary was subjected to prolonged exposure and erosion on the hangingwall dip slope of the Calabacillas sub-basin. The presence of playa-lake mudstone and distal-piedmont sandstone on the hanging wall of the La Bajada fault in the Hagan embayment suggests that basin subsidence started with extensional block faulting, probably along the La Bajada fault. Definitive constraints on the onset of movement of the La Bajada fault are not available at this time, however the abrupt change in sand composition across the Espinaso-Tanos boundary and the lack of playa-lake deposits in the lower part of the Tesuque Formation in the Santa Fe embayment and southeastern Española basin suggests that the La Bajada fault was probably active since late Oligocene time.

Oligo-Miocene activity on the La Bajada fault does not support the two-stage model of development of the Albuquerque Basin (Large and Ingersoll, 1997; Ingersoll and Yin, 1993), which proposes that the northern portion of the Albuquerque Basin was a part of the Española basin (their Tesuque basin) during early Miocene time. In their model, the western margin of the basin was the depocenter until middle or late Miocene time, when they propose that a younger La Bajada fault and the range-bounding faults of the Sandia Mountains (Sandia-Rincon faults) began to move and establish the generally east-tilted character of the northern Albuquerque Basin.

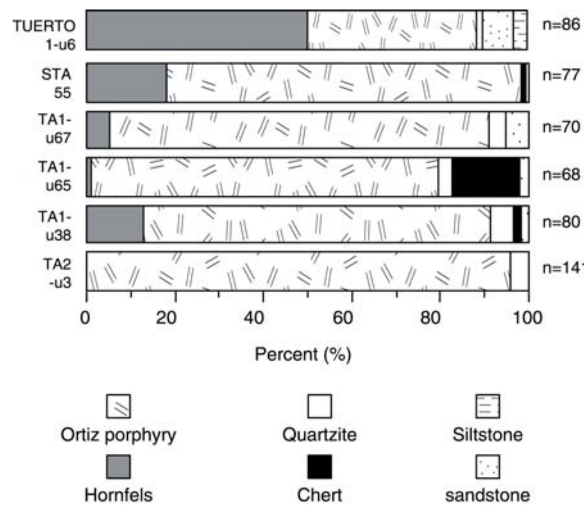

Figure 6. Stacked bar graph illustrating upsection variations (from bottom to top) in gravel composition in the Tanos, Blackshare, and Tuerto formations. Porphyritic hypabyssal intrusive and volcanic rocks derived from the Ortiz Mountains (Ortiz porphyry) dominate the basal Tanos Formation (TA2-u3). Gravel within the Blackshare Formation (TA1-u38, u65, u67, and STA 55) tends to become more diverse upsection. The Tuerto Formation (Tuerto 1-u6) is typically more heterolithic and contains a greater abundance of hornfels gravel than the underlying Blackshare Formation.

The eastward thickening of the Miocene Zia Formation (Connell et al., 1999) and preservation of probable Oligocene sedimentary rocks in the Tamara #1-Y well (Connell, Koning and Derrick, *this volume*), indicates that local stripping of Oligocene volcanic rocks occurred during late Oligocene or early Miocene time along the western margin of the basin. During this time, the Hagan embayment was receiving sediment. The unconformity between Tanos and Espinaso formations in the Pelto Blackshare Federal #1 indicates late Oligocene deformation in the Hagan embayment. The progressive decrease in stratal tilts upsection in the Tanos-Blackshare section indicates that deformation and concomitant sedimentation occurred after 25.4 Ma. Deformation of the Tanos-Blackshare succession is partially constrained by a 2.8 Ma (K/Ar date) on a basalt flow of the Cerros del Rio volcanic field (Bachman and Mehnert, 1978) that interfingers with hypabssyal-intrusive- and volcanic-bearing conglomerate correlated to the sub-horizontally bedded Tuerto Formation. The presence of late Pliocene basalt flows interbedded with the Tuerto Formation indicates that much of the stratal tilting in the Hagan embayment occurred prior to about 2.8 Ma. A paleomagnetic study of a 30.9 Ma mafic dike near the northern flank of the Sandia Mountains also indicates that much of the deformation and stratal tilt at the southern end of the Santo Domingo sub-basin occurred after 30.9 Ma (Lundahl and Geissman, 1999; see also Salyards et al., 1994; Brown and Golombek, 1985, 1986).

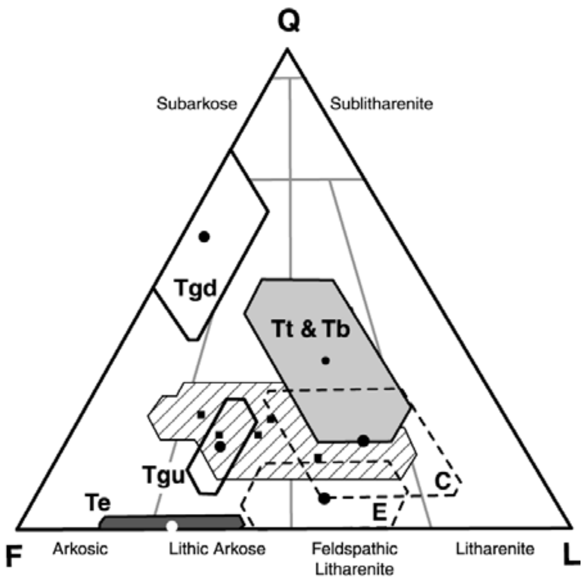

Figure 7. Sandstone petrographic data (means and fields of variations based on one standard deviation) for undivided Galisteo-Diamond Tail Formations (Tgd), upper Galisteo Formation (Tgu), Espinaso Formation (Te), Cordito (C) and Esquibel (E) petrofacies (Abiquiu Formation correlatives, see Large and Ingersoll, 1997), and undivided Tanos and Blackshare formations (Tt, Tb, shaded). The hachured area denotes the Abiquiu Formation and sub-unit lithofacies in the Abiquiu embayment (Moore, 2000). The Tanos and Blackshare formations contain more quartz than the underlying Espinaso Formation, but contain more lithic fragments than would be expected from mixing of Te and Tgd only. Data are summarized from Gorham (1979), Kautz et al. (1981), Large and Ingersoll (1997), and Moore (2000).

Estimates of stratal accumulation rates (not corrected for compaction) suggest that the basal Santa Fe Group accumulated between 69-83 m/m.y. along the western margin (Tedford and Barghoorn, 1999) during early through middle Miocene time, and about 72 m/m.y. along the eastern margin in the Hagan embayment during late Oligocene through Miocene time. These estimates are significantly lower than estimates of 600 m/m.y. for stratigraphically higher, late Miocene, playa-lake deposits of the Popotosa Formation in the southern part of the Albuquerque Basin (Lozinsky, 1988).

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