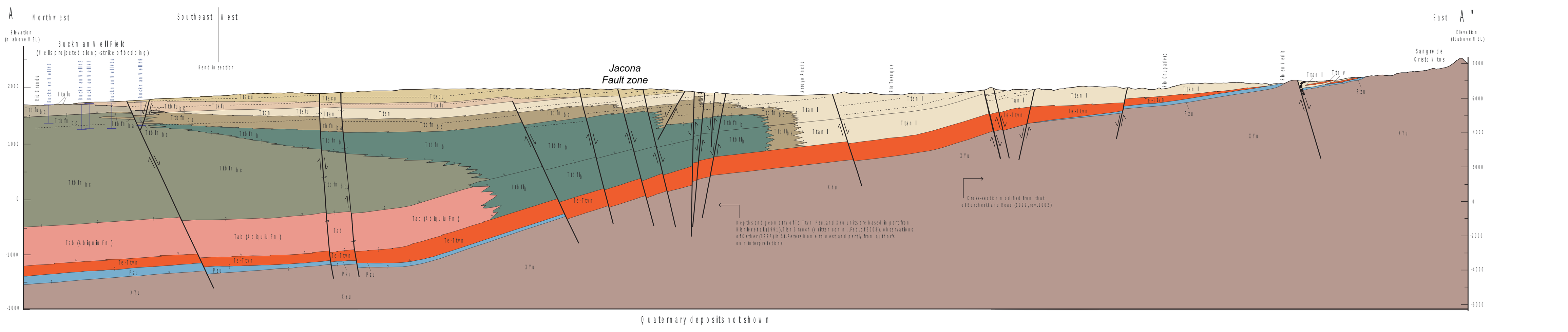
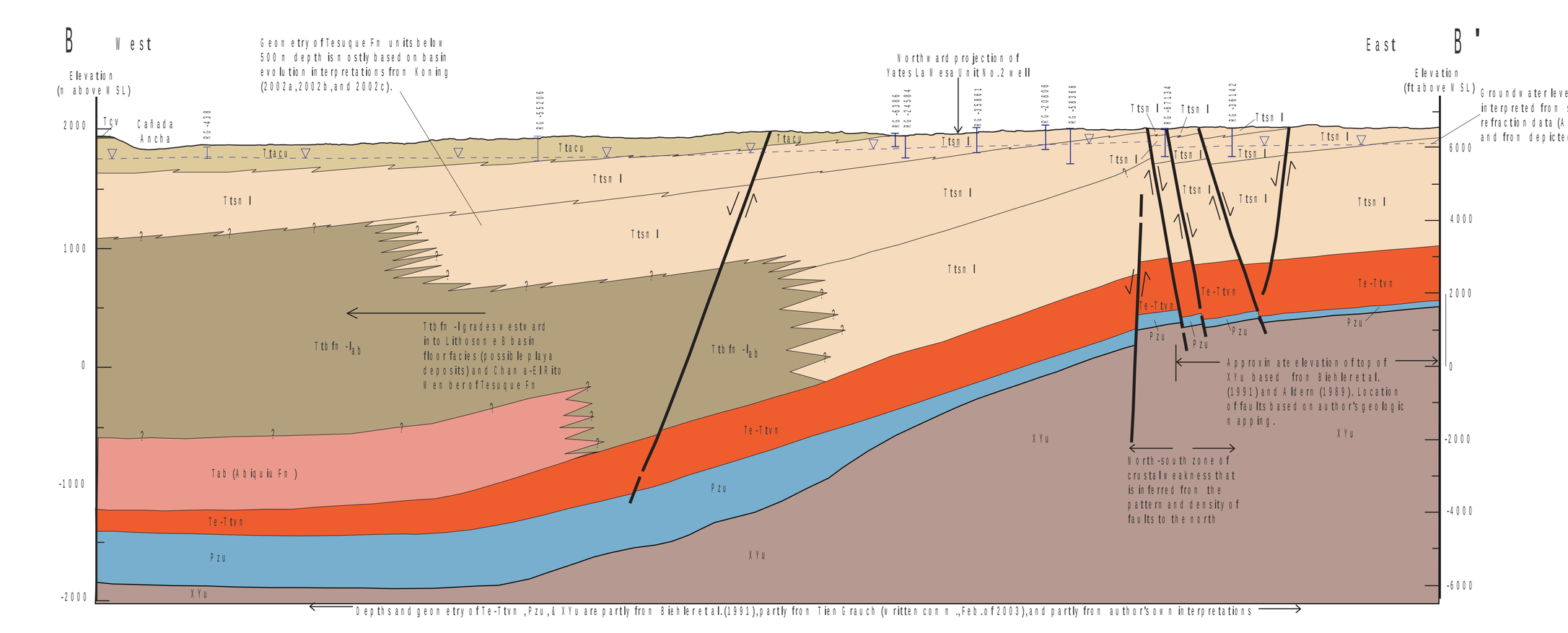
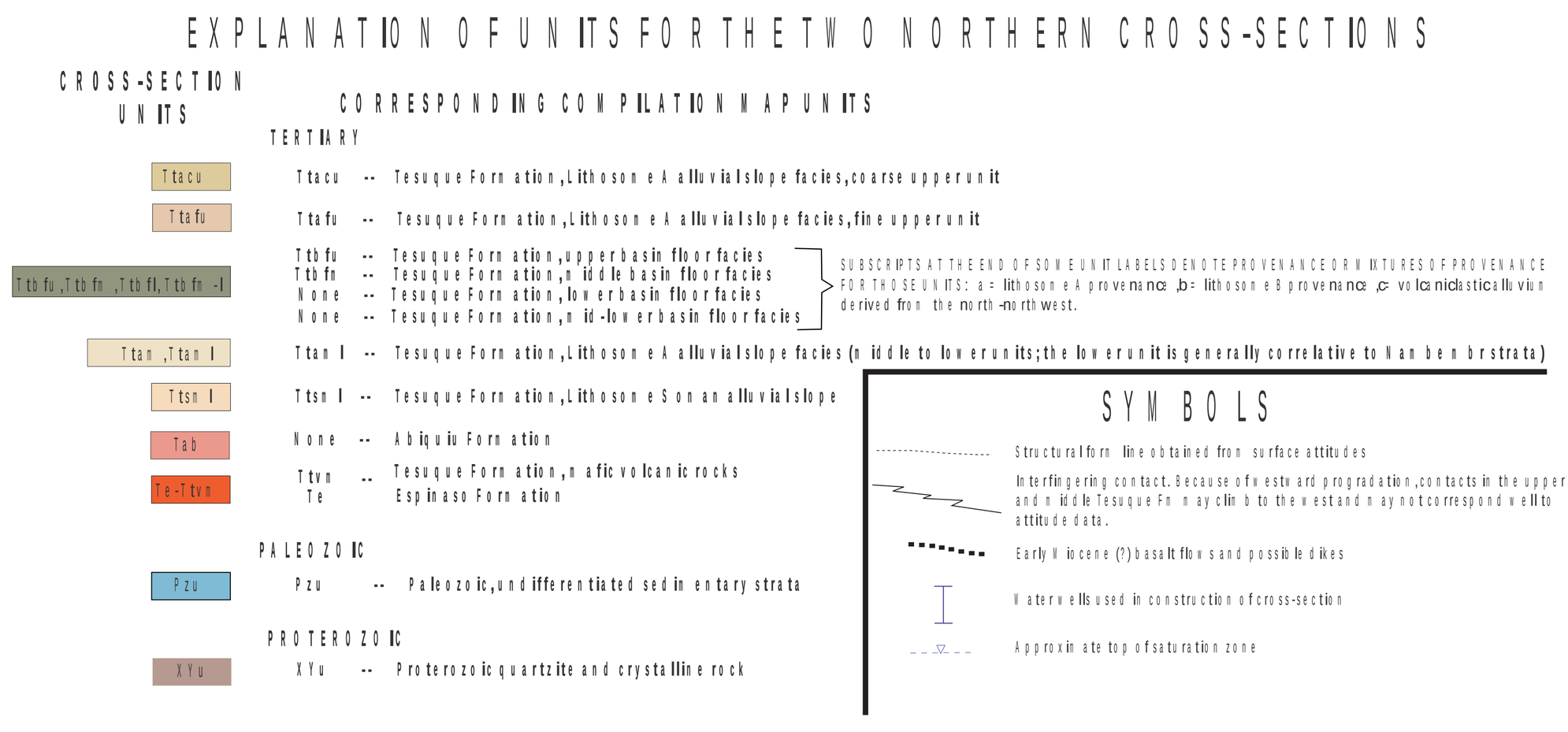
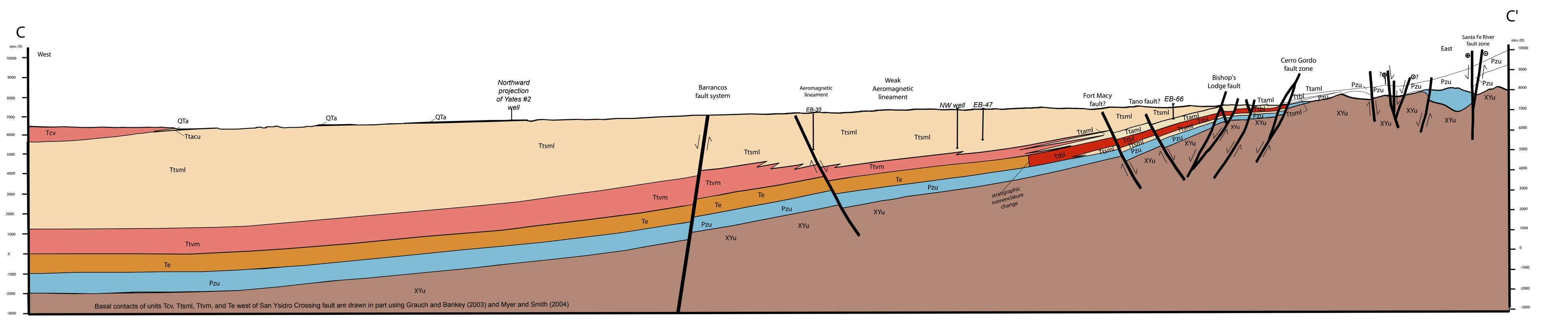
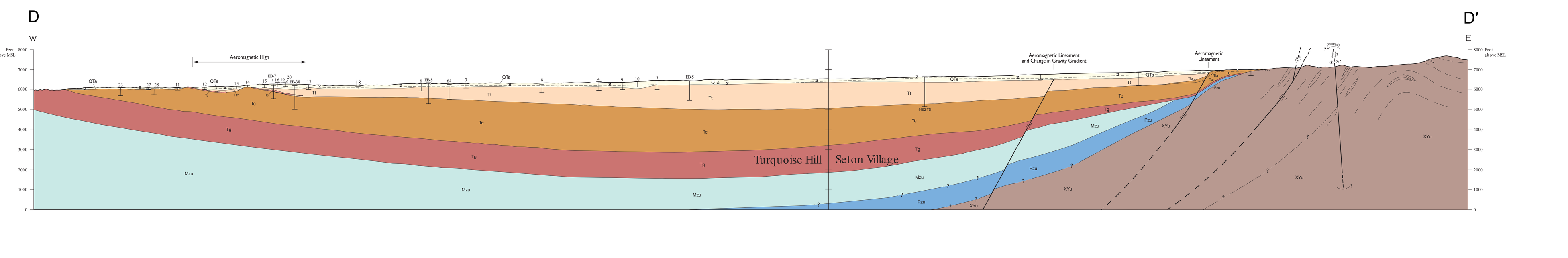
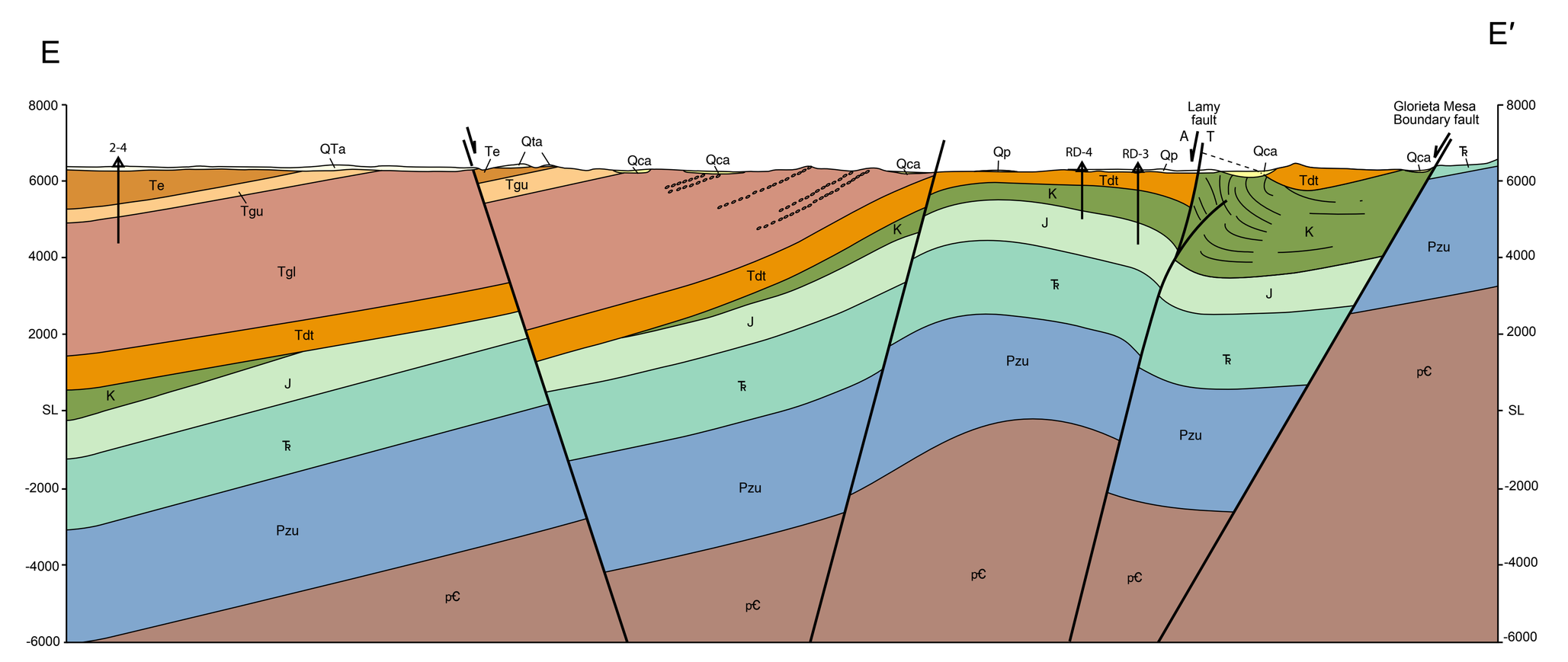




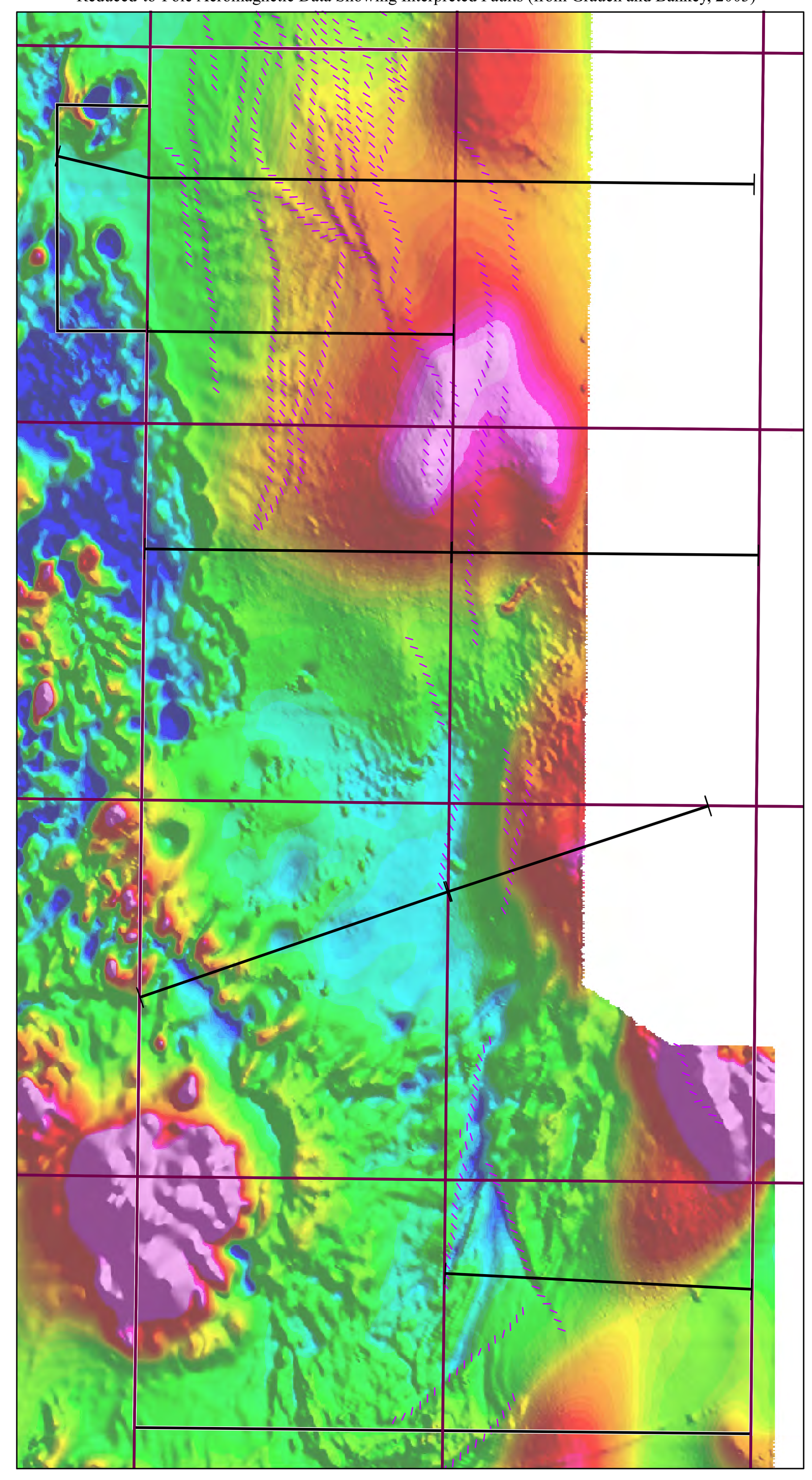








Reduced-to-Pole Aeromagnetic Data Showing Interpreted Faults (from Grauch and Bankey, 2003)



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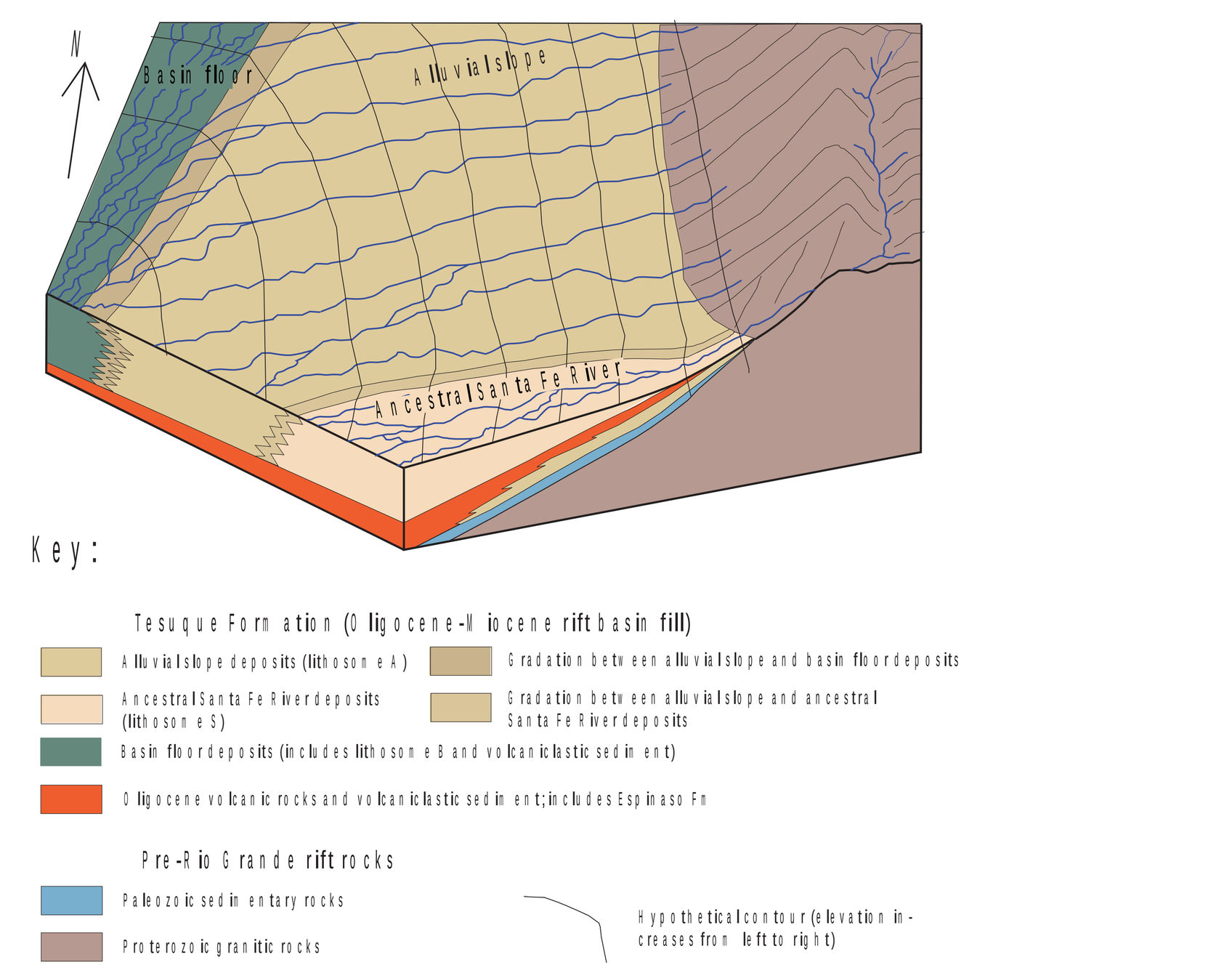

DISCUSSION

The Ancha Formation: Textural Subdivisions and Lower Contact

Daniel J. Koning

Introduction

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 (Oligocene-Miocene) in the Santa Fe embayment, north-central New Mexico (Spiegel and Baldwin, 1963). The Ancha Formation 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). 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. 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).

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 higher 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 east towards the mountain front. These particular piedmont deposits are similar to alluvial slope sediment described in the Tesuque Formation by Smith (2000a), Smith and Kuhle (2000), Koning (2002), Koning et al. (2002a), and Koning (2003). South of Santa Fe, 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 strata 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 to fine, gravel-sand deposits 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.

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 the 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 north of the ancestral Santa Fe River. 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. Much 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.

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.

Basal contact of the Ancha Formation

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.

The Tesuque Formation

Daniel J. Koning

The Rio Grande rift in north-central New Mexico is largely filled with late Oligocene – late Pliocene clastic sediment derived from flanking uplifts. In the southern Española Basin, these deposits are almost entirely composed of the Tesuque Formation, which was subdivided into members (i.e., Nambe, Skull Ridge, and Pojoaque Members) by Galusha and Blick (1971) on the basis of extensive paleontological investigations and numerous volcanic ashes in their study area north of Tesuque Pueblo. In the absence of these fossils and ashes these member-rank units are not readily recognizable in most of the map area nor do they seem to have consistently distinctive textural, cementation, or channel characteristics relevant to a regional geohydrologic study. As a result, our compiled map does not distinguish these members. A lithosome / provenance approach to the internal stratigraphy of the Tesuque Formation seems more appropriate, particularly if hydrostratigraphic units are considered in this important aquifer.

The term "alluvial slope" has been used to classify or describe piedmont environments, including the southeastern Española Basin, where surface flow (typically unsteady) is relatively confined within shallow, parallel stream channels over much of the width of the piedmont (Smith, 2000a). In the map area, particularly in the medial and distal parts of the alluvial slope, there is much sediment that does not appear to have been deposited in a recognizable channel. These particular deposits are commonly in tabular to broadly lenticular, very thin to thick beds of silty to clayey sand (and minor sandy silt), and are referred to by us as "extra-channel sediment". Extra-channel sediment is interpreted to have been deposited on either localized depositional lobes on an alluvial slope or else in very broad channels, as opposed to overbank deposits where sediment was deposited primarily by vertical settling from suspension. In outcrop, coarser channels of sand and gravel are commonly inset into the extra-channel deposits. Alluvial slopes generally lack debris flows and planar sheetflood deposits that are common in alluvial fan deposits, and have more evidence of relatively persistent channelized flow across much of the alluvial slope (Smith, 2000a).

The differentiation of six map units in the Tesuque Formation in large part follows the recognition of three depositional environments in the Tesuque Formation. Two of these depositional environments correspond with previously established lithosomes. Specifically, the alluvial slope depositional environment corresponds with lithosome A of Cavazza (1986) and ancestral Santa Fe River deposits corresponds with lithosome S of Koning et al. (2003). (lithosome A of Cavazzaa, 1986, and lithosome S of Koning et al., 2004). Middle Miocene basin floor deposits (unit Ttbfm) consist of lithosome B of Cavazza (1986). However, upper Miocene basin floor deposits (unit Ttbfu) near Buckman well field consist of mixed provenance fluvial sediment (i.e., lithosome B and a volcaniclastic unit derived from the north-northwest). Below, we describe the six map units in detail according to their respective depositional environments.

Alluvial slope deposits (lithosome A)

Granite-rich gravel and arkosic sand, silt, and mud deposited on an alluvial slope flanking the western Sangre de Cristo Mountains, the latter located on the east margin of the basin. Provenance is the western front of the southern Sangre de Cristo Mountains (south of Truchas Peaks), These are further subdivided on the basis of gross texture

Ttacu – Coarse alluvial slope deposits of the upper Tesuque Formation

Diagnostic features
This unit is composed of pebbly sandstone to sandy pebble-conglomerate channel deposits, with subordinate extra-channel deposits of slightly muddy, very fine- to very coarse-grained sandstone. Gravel composition is almost entirely granitic and the sand is arkosic. The composition and westward paleoflow data are very consistent with lithosome A of Cavazza (1986). It was probably deposited on the medial alluvial slope.

Hydrogeologic significance
The predominance of channels implies a relatively high degree of channel connectivity, and the overall coarse texture suggests relatively high permeability. However, various amounts of calcium carbonate cement and clay matrix within the channels may result in lower permeabilities than inferred from the overall gross texture. Much of this unit probably lies in the unsaturated zone. At the surface, the unit generally erodes to produce relatively thick colluvium, and badland topography is relatively uncommon. This colluvium, in addition to the gross coarseness of the unit, may enhance the unit's potential in recharging the aquifer.

Ttafu — Fine alluvial slope deposits of the upper Tesuque Formation

Diagnostic features
Generally composed of extra-channel and overbank deposits of silty very fine- to fine-grained sandstone with subordinate siltstone and mudstone; channels of pebbly sandstone and sandy-pebble-conglomerate comprise about 3-30% of the unit. Gravel is granitic, sand is arkosic, and paleoflow data are to the west – consistent with lithosome A of Cavazza (1986). Unit Ttafu grades laterally into basin floor facies, and in the vicinity of the Buckman well field it very likely grades laterally eastward into the coarse upper unit of the Tesuque Formation. This unit is recognized by its predominance of fine extra-channel and overbank deposits,. Tephra beds comprised of coarse white ash or coarse, dark gray, basaltic(?) ash are locally present. These coarse tephra differ from the fine white and gray ashes found in the distal alluvial slope sediment lower in the Tesuque Formation. Deposited on the distal alluvial slope.

Hydrogeologic significance
The gross fine texture of this unit, and relatively common weak cementation, may result in lower permeability than the coarse upper unit of the Tesuque Formation. Channels are also likely to be less connected than in the coarse upper unit.

Ttaml — Undifferentiated alluvial slope deposits of the middle to lower Tesuque Formation

Diagnostic features
Generally extra-channel sediment of silty sandstone with minor overbank sediment of siltstone, mudstone, and claystone. Channel sediment is generally minor to subordinate, except near (within about 5 km) of the modern mountain front, and consists of pebbly sandstone and sandy pebble-conglomerate (subordinate cobbles) in channel complexes up to ~ 2 m thick. Southwards, the unit grades laterally into lithosome S over a wide distance (about 1-3 km). In the distal to medial alluvial slope facies, numerous white and gray, fine ashes are preserved; these fine ashes serve to distinguish this unit from the coarse and fine alluvial slope deposits of the upper Tesuque Formation (Ttacu and Ttafu). The granitic clast composition, arkosic sand, and westward paleoflow data are very consistent with lithosome A of Cavazza (1986). The proportion of coarse channel and finer extra-channel and overbank sediment varies across this unit; it is interpreted that the unit includes distal, medial, and proximal alluvial slope depositional environments.

Hydrogeologic significance
The gross finer texture of this unit (exept near the mountain front) may result in lower permeability than the coarse upper unit of the Tesuque Formation and lithosome S. Channels are also likely to be less connected than these two other units.

Basin floor deposits (lithosome B and mixed provenace)

Floodplain mud, silt, and very fine to fine sand together with sandy to gravelly channels deposited on a basin floor.

Ttbfu — Basin floor deposits of the upper Tesuque Formation

Diagnostic features
Floodplain deposits consisting of planar-laminations to planar-very thin to medium beds of claystone, siltstone, and very fine- to fine-grained sandstone., with minor (10-25%) thick channel complexes of sand and gravelly sand. Deposited on a basin floor by a southward-flowing fluvial system of mixed provenance. Near the Buckman well field, clasts are mainly volcanic, with minor Paleozoic clasts characteristic of lithosome B of Cavazza (1986). In contrast to the basin floor facies, the adjacent distal alluvial slope facies to the east (Ttafu) has much greater proportions of silty sand extra-channel sediment, and the channel gravel and sand are granitic and arkosic, respectively.

Hydrogeologic significance
This unit comprises the bulk of the aquifer serving the Buckman well field. Because the floodplain deposits in outcrop are composed primarily of siltstone and claystone, with only minor (<25%) sand and gravelly sand channel deposits, groundwater occurs in a series of somewhat disconnected confined and semiconfined aquifers. The sand channel deposits in the Buckman area have permeabilities, based on air permeameter measurements, of approximately 1 to 10 ft/d (John Sigda, written communication). The degree of channel connectivity determines the overall transmissivity of the aquifer(s) and is an important parameter to consider in a geohydrologic study.

Ttbfm — Basin floor deposits of the middle Tesuque Formation (Lithosomes B & C)

Diagnostic features
Floodplain sediment consisting of planar-laminations and planar-very thin to medium beds of mudstone, siltstone, claystone, and very fine- to fine-grained sandstone, with minor broad channel complexes of fine to medium sandstone. Deposits lack gravel, but correlate along-strike to lithosome B, gravel-bearing strata to the north. The unit has relatively distinctive grayish sand that has an approximate ratio of 1:1 of dark lithics and greenish quartz grains compared to potassium feldspar. Unit is commonly weakly consolidated and erodes to form strike-valleys. Unit grades laterally eastward and southward into distal alluvial slope facies (map unit Ttaml). It is inferred that paleoflow direction was to the southwest, consistent with paleflow data by Cavazza (1986) and Koning (2002) for lithosome B. When compared to correlative strata to the north and upper fluvial basin floor sediment near Buckman (map unit Ttbfu), the basin floor deposits near Pojoaque are finer grained. It is very likely that these older basin floor deposits become even finer-grained to the southwest (in the subsurface)..

Hydrogeologic significance
This unit is inferred to have low permeability because it is mostly composed of fine floodplain and possibly local lacustrine sediment. The unit probably becomes even finer grained, and less permeable, in the subsurface to the southwest. These basin floor deposits likely have the lowest groundwater yields of all the map units in the study area. Delineating the three-dimensional extent of this unit in the subsurface is important in considering the overall productivity of the aquifer underlying the northern portion of the map area.

Ancestral Santa Fe River deposits (lithosome S)

Pebbly sand channel sediment together with subordinate fine sand, silt, and mud floodplain and extra-channel sediment. These were deposited by a large westward-flowing paleo-drainage that exited the Sangre de Cristo Mountains near Santa Fe.

Ttsml — Fluvial deposits associated with the ancestral Santa Fe River on an alluvial slope, middle to lower Tesuque Formation

Diagnostic features
This unit is recognized by its clast composition (granite with 3-40% Paleozoic clasts and 5-30% quartzite), reddish color (compared to less red distal alluvial slope facies), and high-energy-flow deposits in very broad, thick channel complexes that possess very thin to medium, planar to lenticular internal bedding. These deposits were called lithosome S by Koning et al. (2004). The upper contact of the unit is gradational with the coarse upper unit of the Tesuque Formation. Lithosome S is also found below, and just above, the Bishops Lodge Member (not differentiated on the compilation map); here, the clast assemblage is dominated by granite and yellowish Paleozoic limestone and siltstone (more granite than Paleozoics), with only 0-1% quartzite. The gravel of this unit includes much higher percentages of Paleozoic limestone and Proterozoic quartzite than is found in lithosome A to the north, thus indicating that the fluvial system probably extended east across the Pecos-Picuris fault (as also inferred by Smith, 2000b). Because the quartzite clasts proportionally increase up-section, the fluvial system of lithosome S likely increasingly elaborated onto, or cut into, quartzite bedrock as a function of time.

Hydrogeologic significance
The overall coarse texture of this unit, particularly in its eastern extent (near Santa Fe) where it lacks extra-channel and overbank sediment, probably imparts a relatively higher permeability than the other map units. Also, there is a relatively high degree of channel connectivity because of the broad and abundant channel complexes of this unit, particularly in its eastern extent where channel complexes predominate.

Volcanic Rocks in the Tesuque Formation

Volcaniclastic rocks and basaltic lava flows associated with volcanic centers to the east and southeast.

Ttvm – Mafic volcanic rocks in the basal Tesuque formation (upper Oligocene to lower Micocene)
Black to gray, coarse-grained, altered olivine basalt. Near the Sangre de Cristo Mountain front, this unit consists of a single, 1-1.7 m-thick flow,,vesicular and amygdaloidal throughout, that either rests directly on tuffaceous mudstone of the Bishop's Lodge Member or is interbedded with the overlying arkosic sediment of the Tesuque Formation. Near La Cienega, this unit consists of grayish black, porphyritic, olivine-bearing, volcanic flows of basanite, nephelinite, and basalt. These western flows are fine-grained and non-vesicular, and have a cumulative thickness of up to 30 m in the study area. The Cieneguilla basanite has been dated at 25.1 + 0.7 Ma using K-Ar radioisotopic analyses (Baldridge et al., 1980) and 26.08 + 0.62 Ma using recent $^{40}Ar/^{39}Ar$ radioisotopic analyses (Table 1 of Turquoise Hill quadrangle of Koning, 1999; Peters, 2000a).

Ttbl—Bishops Lodge Member of the Tesuque Formation (upper Oligocene?).
White tuffaceous mudstone, gray pebbly volcaniclastic sandstone, and pebble to boulder conglomerate. Clasts of light to dark gray pyroxene (+ biotite) latite as large as 100 cm but typically 5-20 cm. Clast size increases to the south where 50 cm and larger clasts are common in exposures near the Santa Fe River. A slightly reworked ash, 30-40 cm thick, 4 m below the top of the Bishops Lodge interval was dated at 30.45 +0.16 Ma (Peters, 2000b). In places, the Bishops Lodge Member lies directly on Paleozoic rocks, but overlies up to 100 m of non-volcaniclastic Tesuque Formation around Bishops Lodge. Up to 80m thick.

Geologic Structure

Adam S. Read and Daniel J. Koning

Basin Architecture

The general structure of the southern Española Basin can be inferred using geologic mapping, examination of subsurface data, and available geophysical data. In the study area north of the Santa Fe River, the general structure is that of a west-tilted half-graben (Biehler et al., 1991), with the Pajarito fault zone near Los Alamos probably serving as the master fault. Within this half-graben are numerous extension-related structures of interest. In the northeastern Horcado Ranch 7.5-minute quadrangle, there is a significant west-facing monocline with an interpreted 1500 m (4900 ft) of structural relief. This structure continues to the north into what Kelley (1978) referred to as the Barrancos monocline. Beds generally strike north and dip west, but their dip magnitudes change across the monocline as follows: less than 6 degrees west of the Barrancos monocline, 5-15 degrees within the monocline, and 4-12 degrees east of the monocline. Near the crest of the Barrancos monocline is the north-trending, west-down Pojoaque fault that has an estimated throw of 50-150 m. To the west, strands of the Jacona fault zone offset the monocline in an east-down manner.

The area south of the Santa Fe uplands (i.e., the highlands north of the Santa Fe River) is generally referred to as the Santa Fe embayment (e.g., Koning et al., 2002b). The Santa Fe embayment is located east of the major La Bajada fault, which interacts with the Pajarito fault to the north in a complex manner near the lower part of White Rock Canyon. The general geologic structure in the Santa Fe embayment is that of a north-northeast-plunging syncline. This syncline may be displaced by normal faults on its eastern margin, but the existence of a large fault near the western margin of the syncline has never been confirmed. The structural relief of this syncline is estimated to be approximately 1800 m (6000 feet) at the base of the Phanerozoic section along cross section D-D'.

Mountain Front Faults

North of the Santa Fe River, faults within the Proterozoic basement and overlying Paleozoic rocks typically strike north-south. Some are reverse faults and related folds that are interpreted, based on structural style, to have formed during the Laramide. Perhaps some of the monoclinal structures, like the one at Nambe Falls, were initially Laramide structures that were reactivated during rifting.

The largest of the north-south faults is the Santa Fe River Fault, which juxtaposes Madera Group limestones against Proterozoic basement. It is a relatively large displacement fault, with perhaps as much as 300m (1000 ft) of stratigraphic separation. The Aztec Springs syncline lies parallel to this Laramide fault and preserved a thick section of Madera Group rocks from later erosion. Along the Santa Fe River, the fault bends to the southwest. Madera Group limestone is present in scattered outcrops along the valley floor but not on the peaks to the south and east. It is not clear how this fault exits the mountain front or its extent under the Ancha Formation to the west. We show the queried fault merging with the Hondo Fault east of a high gradient in ground water elevations. Geometrically this makes sense given the isolated outcrops of Paleozoic rocks near Seton Village and the lack of evidence for a large transverse fault in the area imaged by the detailed aeromagnetic survey (Grauch and Bankey, 2003).

Along Little Tesuque Creek, large outcrops of strongly brecciated Proterozoic rocks appear to be overlain by relatively undeformed Paleozoic rocks (see Spiegel and Baldwin, 1963 p. 29). The implications of these breccias (and other similar breccias in the region) are a current subject of considerable debate (Fankhauser and Erslev, 2004), but they suggest (as F.E. Kottlowski did in Spiegel and Baldwin, 1963) that there may have been pre-Pennsylvanian brittle deformation. The current debate revolves around the magnitude and timing of possible brittle deformation events in the Proterozoic, Ancestral Rocky Mountain, and Laramide Orogenies.

Regional aeromagnetic data suggest significant offset, likely dextral strike slip faulting, of basement rocks along the eastern piedmont of the Santa Fe Range (Kucks, et al., 2001; Grauch, unpublished data; and personal communication 2004; Daniel et al., 1995). However, while the Tesuque Formation is faulted along much of the piedmont, it appears to have only minor offset by these (likely repeatedly reactivated) structures. The faults that do cut the Tesuque Formation, particularly west-down faults, appear to take the form of faulted, west-facing monoclines (see cross sections). Where these faulted monoclines exist some distance away from the mountain front, they create structural benches characterized by domains with shallower dips that steepen to the west across the monoclines. One such bench is formed by a broad north-south structure manifested by a west-facing monocline and numerous faults within 2-3 km to the west of the present-day mountain front. This unnamed structure appears to extend as far south as northern Santa Fe, and exposes Paleozoic rocks near Nambe Dam. These benches, and the structures that cause them, may be important hydrologically for both shallow and bedrock aquifers (particularly those within the Paleozoic section).

Basin bounding faults, basement faults, and breccia/fracture zones probably play a significant role as recharge conduits into the basin, as well as within bedrock aquifers. Fracture zones that cut transversely across the Sunlit Hills east of Eldorado are composed of numerous, closely spaced, vertically dipping fractures. Many of these fracture zones appear to be minor left-lateral structures. They almost certainly extend some distance into the basin and in places, appear to influence the location of streams.

Intrabasinal Faults

Several major faults and related structures offset and deform the Tesuque Formation within the basin. The deformation zones of all faults have clay cores along much of their length in addition to deformation bands and cataclasite zones. Also, cementation is commonly stronger in the immediate hanging wall or footwall of the fault (compared to cementation of strata away from the fault). These features may result in the faults acting as groundwater barriers along part or most of their length. Hydrologic data indicate that some mapped faults (and interpreted faults based on aeromagnetic surveys – Grauch and Bankey, 2003) are indeed associated with major anomalies in groundwater levels and probably result in compartmentalization of the Tesuque Formation aquifer.

Aeromagnetically interpreted faults from Grauch and Bankey (2003) are shown on the map plates as hashed purple lines and are shown for reference with a small-scale version of their aeromagnetic data on this sheet. In many cases, these aeromagnetically inferred faults coincide with mapped faults. This reflects a convergent evolution of both field mapping and interpretation of the aeromagnetic data during collaborative work on this project. In some cases (particularly on the Horcado Ranch quadrangle) the aeromagnetically interpreted structures are offset from the mapped faults. This discordance is likely either related to where magnetic properties are most in contrast at depth (perhaps suggesting subsurface fault geometry) or due to multiple strands of these faults that were unrecognized on the surface. In areas within the Tesuque Formation where surface investigation has not identified aeromagnetically interpreted faults, we did not add them to the map. Where these aeromagnetically interpreted faults are completely covered by the Ancha Formation, we chose to add them as inferred (concealed) faults to the compilation. In addition, we infer several other faults in the Eldorado area based on our examination of the aeromagnetic data, projections of mapped faults, and gravity studies (Biehler, 1999).

An aeromagnetic high near the northeast corner of the Santa Fe 7.5-min.quadrangle was interpreted as a buried and faulted bedrock high, or alternatively as a fault controlled intrusion by Grauch and Bankey (2003). We feel there is support for both interpretations based on observations of faulted monoclinal structures to the north and the occurrence of strongly silicified Tesuque Formation sediments in that vicinity (Borton, 1979) – the latter which may be the result of hydrothermal circulation above a buried volcanic center. Accordingly, we have drawn a speculative geometry for this feature on cross section (C-C').

References

Baldridge, W.S., Damon, P.E., Shafiqullah, M., and Bridwell, R.J., 1980, Evolution of the central Rio Grande rift, New Mexico: New potassium-argon ages: Earth and Planetary Science Letters, v. 51, p. 309-321.

Biehler, S., 1999, A geophysical evaluation of the subsurface structure of the Eldorado Subdivition, New Mexico, *unpublished report* for the Eldorado Area Water and Sanitation District.

Biehler, S., Ferguson, J., Baldridge, W.S., Jiracek, G.R., Aldern, J.L., Martinez, M., Fernandez, R., Romo, J., Gilpin, B., Braile, L.W., Hersey, D.R., Luyendyk, B.P., and Aiken, C.L., 1991, A geophysical model of the Española Basin, Rio Grande rift, New Mexico: Geophysics, v. 56, no. 3, p. 340-353.

Blair, T.C., 1987, Sedimentary processes, vertical stratification sequences, and geomorphology of the Roaring River alluvial fan, Rocky Mountain National Park: Journal of Sedimentary Research, v. 57, p. 845-862.

Blair, T.C., 1999, Sedimentary processes and facies of the waterlaid Anvil Springs Canyon alluvial fan, Death Valley, California: Sedimentology, v. 46, p. 913-940.

Blair, T.C., and McPherson, J.G., 1994, Alluvial fans and their natural distinction from rivers based on morphology, hydraulic processes, sedimentary processes, and facies assemblages: Journal of Sedimentary Research, v. A64, p. 450-489.

Borton, R.L., 1979, Enigmatic quartzite piles of the La Tierra-Las Dos Subdivisions area, Santa Fe County, New Mexico, New Mexico Geological Society Guidebook, 30th Field Conference, Santa Fe Country, p. 289-291.

Bull, W.B., 1972, Recognition of alluvial-fan deposits in the stratigraphic record, *in* Rigby, J.K., and Hamblin, W.K., ed., Recognition of Ancient Sedimentary Environments: Soc. Econ. Paleont. Mineral. Spec. Publ., v. 16, p. 63-83.

Cavazza, W., 1986, Miocene sediment dispersal in the central Española Basin, Rio Grande rift, New Mexico, USA: Sedimentary Geology, v. 51, p. 119-135.

Daniel, G.G., Karlstrom, K.E., Williams, M.L., and Pedrick, J.N., 1995, The reconstruction of a middle Proterozoic orogenic belt in north-central New Mexico, U.S.A., New Mexico Geological Society Guidebook, 46th Field Conferece, Geology of the Santa Fe Region, p. 193-200.

Fankhauser, S.D., and Erslev, E.A., 2004, Unconformable and cross-cutting relationships indicate major precambrian faulting on the Picuris-Pecos fault system, Southern Sangre de Cristo Mountains, New Mexico, New Mexico Geological Society Guidebook, 55th Field Conference, Geology of the Taos Region, 2004, p. 206-219.

Galusha, T., and Blick, J.C., 1971, Stratigraphy of the Santa Fe Group, New Mexico: Bulletin of the American Museum of Natural History, v. 144, 127 p.

Grauch, V.J.S., and Bankey, V., 2003, Aeromagnetic Interpretations for Understanding the Hydrogeologic Framework of the Southern Española Basin, New Mexico: United States Geological Survey, Open File Report 03-124, 39p.

Kelley, V.C., 1978, Geology of the Española Basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Geologic Map GM-48, scale 1:125,000.

Koning, D.J., 2002, Geologic map of the Española 7.5-minute quadrangle, Santa Fe County, New Mexico: New Mexico Bureau of Geology?? and Mineral Resources, Open-file Geologic Map OF-GM-54, scale 1:24,000.

Koning, D.J., 2003, Geologic map of the Chimayo 7.5-minute quadrangle, Rio Arriba and Santa Fe counties, New Mexico: New Mexico Bureau of Geology?? and Mineral Resources, Open-file Geologic Map OF-GM-71, scale 1:24,000.

Koning, D.J., and Hallett, R.B., 1999, rev. Jan-2003, Geologic map of the Turquoise Hill 7.5-minute quadrangle, Santa Fe County, New Mexico: New Mexico Bureau of Geology?? and Mineral Resources, Open-file Geologic Map OF-GM-41, scale 1:24,000.

Koning, D.J., Nyman, M., Horning, R., Eppes, M., and Rogers, S., 2002a, Geology of the Cundiyo 7.5-min. quadrangle, Santa Fe County, New Mexico, New Mexico Bureau of Geology and Mineral Resources, Open-file Geologic Map OF-GM 56, scale 1:24,000.

Koning, D.J., Connell, S.D., Pazzaglia, F.J., and McIntosh, W.C., 2002b, Redefinition of the Ancha Formation and Pliocene-Pleistocene deposition in the Santa Fe embayment, north-central New Mexico: New Mexico Geology, v. 24, no. 3, p. 75-87.

Koning, D.J., Smith, G.A., and Lyman, J., and Paul, P., 2004a, Lithosome S of the Tesuque Formation: hydrostratigraphic and tectonic implications of a newly delineated lithosome in the southern Española Basin, New Mexico: U.S. Geological Survey, Open-File Report 2004-1093, p. 17.

Koning, D.J., Smith, G.A., and Aby, S., 2004b, Third-day supplemental road log, Penasco to Espanola: New Mexico Geological Society, 55th Field Conference, Guidebook, 99-107.

Kucks, R.P., HIll, P.L., and Heywood, C.E., 2001, New Mexico Aeromagnetic and Gravity Maps andData:A Web Site for Distribution of Data, version 1.0, U.S. Geological Survey, Open-File Report, 01-0061, available at: http://pubs.usgs.gov/of/2001/ofr-01-0061

Peters, L., 2000a, $^{40}Ar/^{39}Ar$ geochronology results from tephra and basalt clasts: report by New Mexico Geochronological Research Laboratory (NMGRL) for Sean Connell of New Mexico Bureau of Mines and Mineral Resources, Internal Report # NMGRL-IR-123, 4 p. plus figures, tables, and appendices.

Peters, L., 2000b, $^{40}Ar/^{39}Ar$ geochronology results from from Tephra Found in the Bishop's Lodge Member: report by New Mexico Geochronological Research Laboratory (NMGRL) for Gary A. Smith of the University of New Mexico, Internal Report # NMGRL-IR-76

Smith, G.A., 2000a, Recognition and significance of streamflow-dominated piedmont facies in extensional basins: Basin Research: v. 12, p. 399-411.

Smith, G.A., 2000b, Oligocene onset of Santa Fe Group sedimentation near Santa Fe, New Mexico (New Mexico Geological Society, Spring Meeting abstract): New Mexico Geology, v. 22, p. 43.

Spiegel, Z., and Baldwin, B., 1963, Geology and water resources of the Santa Fe area, New Mexico: U.S. Geological Survey Water-Supply Paper 1525, 258 p.

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Plate1b: Cross Sections and Supporting Information to Accompany the Generalized Geologic Map of Part of the Southern Española Basin Santa Fe County, New Mexico

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November 29, 2004

All cross sections are 1:5000 with no vertical exaggeration