PALEOSEISMICITY OF THE SANDIA FAULT ZONE, ALBUQUERQUE, NEW MEXICO

Program Element II: Evaluate Urban Hazard and Risk.

Final Technical Report
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1. ABSTRACT

This study mapped and named 4 strands of the newly-named "Tram Station strand" of the Sandia fault zone, which is restricted to the Sandia Heights embayment of the Albuquerque-Sandia piedmont. We identified three possible trench sites on sub-strands B, C, and D of the Tram Station strand, but only had enough funding to trench the best-preserved trace (sub-strand B). Therefore, the paleoseismic parameters calculated must be viewed as very incomplete, given the fact that only 1 of 4 sub-strands was trenched, and that the entire Tram Station strand is only one of at least 4 named strands of the Sandia fault zone (the others being the Tramway Boulevard. East Embudo, and West Embudo strands).

As a working hypothesis, we assume 1.6 m as a first approximation of MRE displacement across the Tram Station strand of the SFZ. According to Wells and Coppersmith (1994), historic normal-fault earthquakes that have created fault scarps with a maximum and an average height of 1.6 m correlate with earthquakes of moment magnitude M6.75 and M6.91, respectively (Wells and Coppersmith, 1994). Normal fault ruptures the same length as the Sandia fault (27.8 km) are typically associated with earthquakes of M6.77 (Wells and Coppersmith, 1994), which closely matches the magnitude suggested by 1.6 m being the maximum displacement per event.

We cannot compute a recurrence interval for sub-strand B because our trench exposes evidence for only a single faulting event, the MRE. All we can say from this trench is that the elapsed time since the MRE on sub-strand B, the best-expressed sub-strand of the Tram Station strand of the SFZ, has been about 53-67 ka.

Likewise, we cannot compute a closed-cycle geologic slip rate for sub-strand B, based only on the occurrence of a single 1.6 m displacement event at 53-67 ka. If the next earthquake occurred tomorrow and released a similar 1.6 m of slip, the resulting closed-cycle slip rate would be 0.024-0.030 mm/yr. This value, although a maximum for this strand, still falls well short of the slip rate estimate for the SFZ cited in the USGS Quaternary Fault and Fold Database of "less than 0.2 mm/yr".

2. INTRODUCTION

2.1 Purpose and Scope of Study

This report summarizes trenching and dating results on the Sandia fault zone (SFZ) from November of 2002, in a continuing effort to characterize the mid-late Quaternary activity of normal faults in the Rio Grande rift near and in Albuquerque, New Mexico. In particular, this study continues efforts begun in FY96 to trench faults that displace early- to middle-Pleistocene alluvial surfaces of the Rio Grande valley that now stand about 100-150 m above the Rio Grande (Fig. 1). To date (March 2006) this 2002 study is the only detailed paleoseismic study performed on the Sandia fault zone (see Appendix 1).

The fault scarps of the SFZ trend north-south and face west, traversing the head of a middle Pleistocene pediment at the base of the Sandia Mountains. During November 2002 we spent 2 weeks excavating, logging, and sampling one trench and one arroyo bank on the northern end of the SFZ near the base station of the Sandia Tram (Fig. 2). The trench was oriented east-west and transected a vegetation lineament on the northern side of the access road to the Tram.

This lineament projected to the best-preserved fault scarp of the fault zone that lay south of the access road, but which was untrenchable for logistical reasons.

The goal of this trenching investigation was to reconstruct the chronology of surface-faulting events on the SFZ since the abandonment of the middle Pleistocene pediment as a depositional surface.

2.2 Significance of the project

Prior to this study, no detailed paleoseismic work had been performed on the main part of the SFZ (Machette et al., 1998, p. 157), although the fault had been mapped at 1:24,000 scale by Connell (2000) and Reid et al. (2000). As a result, Machette et al. (1998, p. 134-135) cite the slip rate on the SFZ fault as “unknown; probably <0.02 mm/yr”, and timing of the most recent paleoearthquake as “middle and late Quaternary (<750 ka).” There were no data on recurrence intervals. This project used trenching to attempt to measure the age of most recent paleoearthquake, recurrence intervals, and the mid-late Quaternary slip rate. Those data are then compared to similar data for the faults on the western side of the rift (County Dump, Calabacillas, E. Paradise, Zia) which have been more intensively studied since 1996.

2.3 Tectonic Setting

The Albuquerque-Belen Basin is one of the largest structural depressions in the Rio Grande rift, measuring 135 km in N-S dimension and up to 60 km wide (E-W dimension) (Kelley, 1977). The basin is bounded by the steep range fronts of the Sandia and Manzano-Los Pinos Mountains on the east and by the Lucero and Ladrone Mountains on the southwest. In a gross sense the Albuquerque Basin is an asymmetric east-tilted half graben. In 1994 Russell and Snelson (1994a,b) proposed that the west-dipping master fault in the northern graben, termed the Rio Grande master fault (RGMF), underlay the Holocene floodplain of the Rio Grande River and became listric at a depth of ca. 10 km. The fault on the eastern rift margin, the Sandia fault zone, was thought to be mainly abandoned by middle Quaternary time. The numerous east-dipping faults found west of the river on the Llano de Albuquerque (County Dump, Zia, Calabacillas, and Sand Hills fault zones) were interpreted to be antithetic to the Rio Grande master fault.

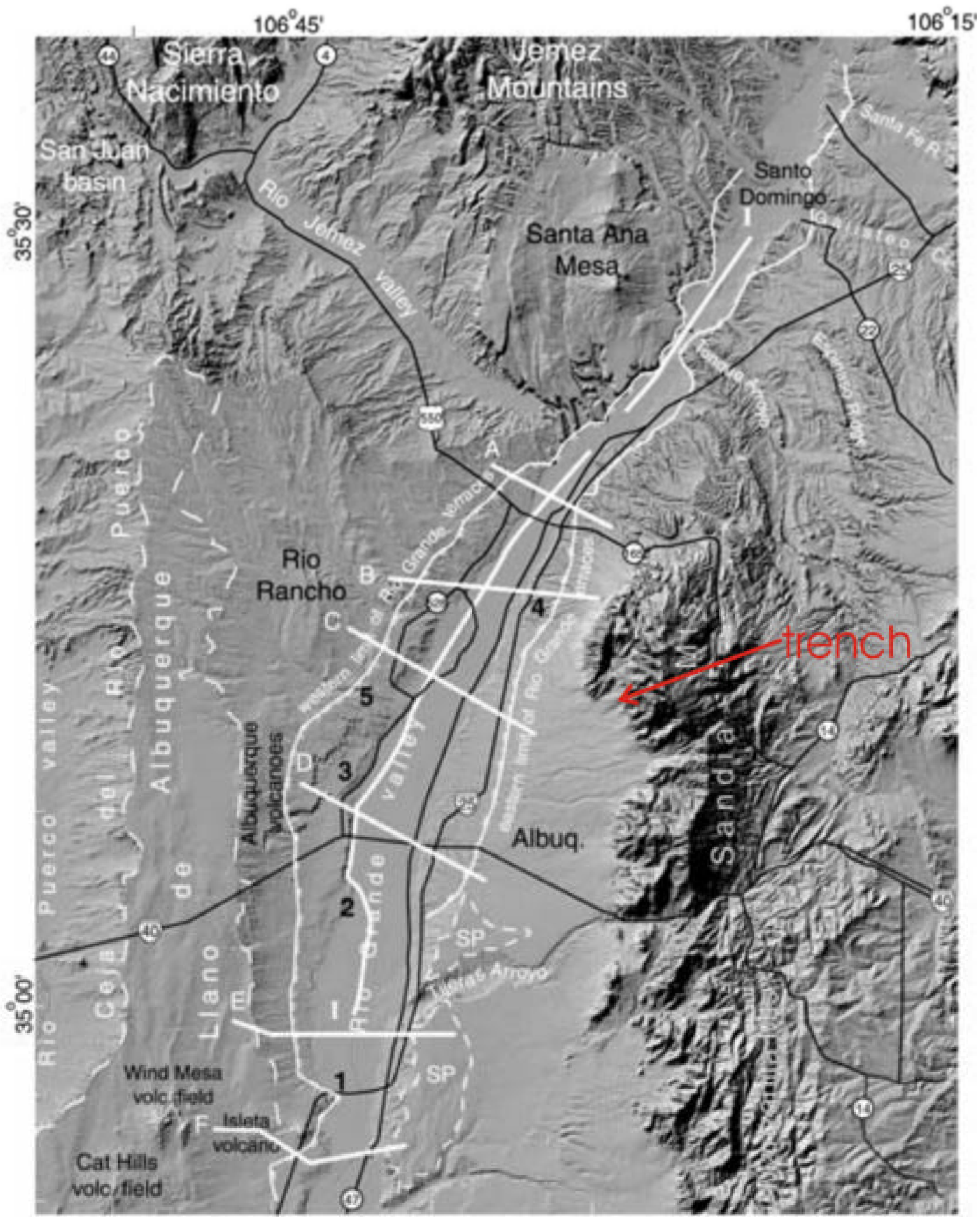

Fig. 1. Shaded relief image of the northern part of the Albuquerque Basin (derived from U.S. Geological Survey 10-m DEM data) illustrating the approximate locations of terrace risers (hachured lines), the Sunport surface (SP), and stratigraphic sections (1-5) and cross section lines (A-F) from Connell and Love, 2001.

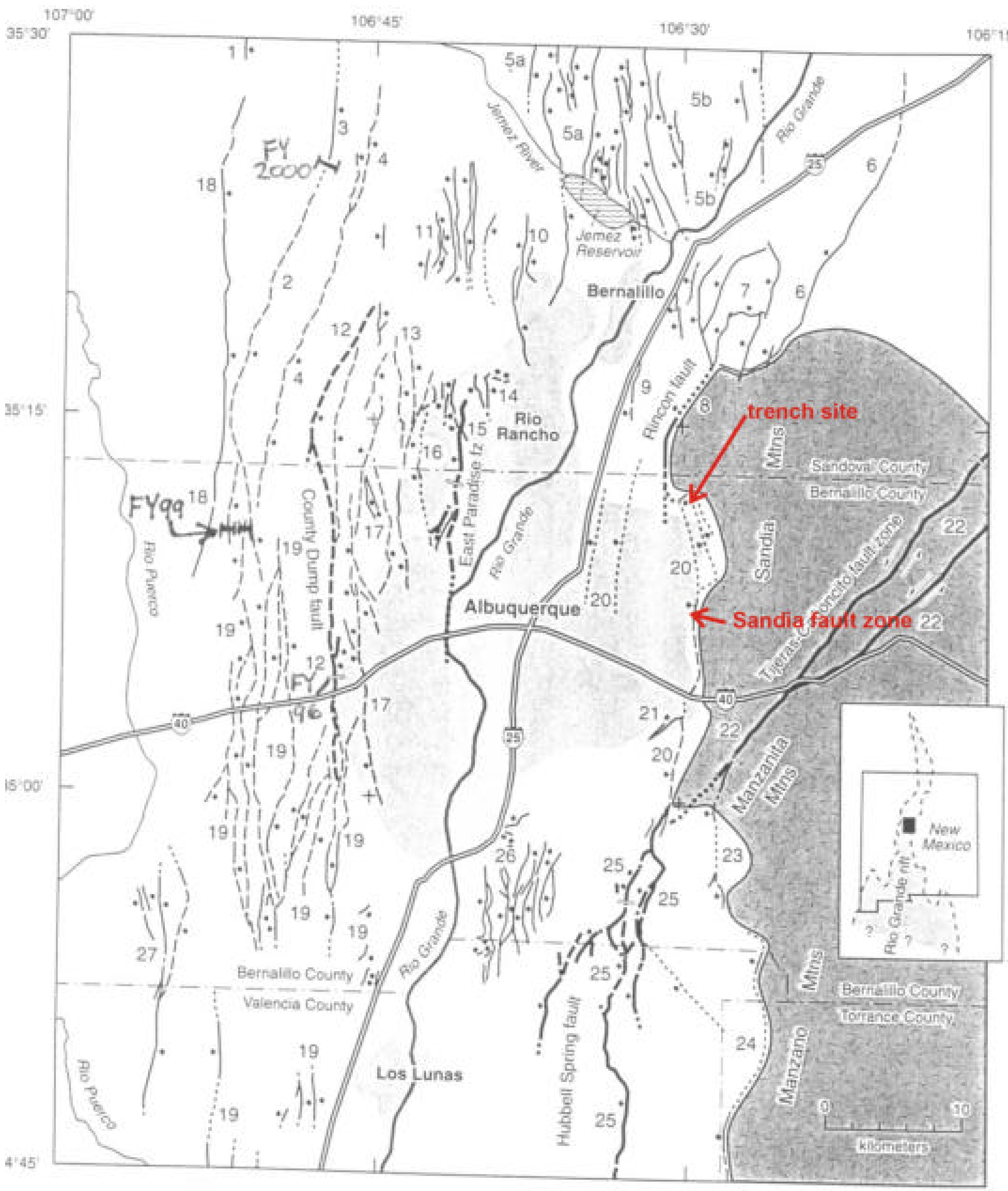

Fig. 2. Quaternary faults and generalized geology of the Albuquerque Basin. Faults with surficial evidence of late Quaternary movement are shown by heavy lines; those without such evidence are shown by thin and dashed lines (based on Machette et al., 1998). Pre-Cenozoic bedrock is shown in gray. Sandua fault zone and trench site shown in red. Previous NEHRP trench sites are labelled FY96 (1996 County Dump fault), FY99 (Calabacillas fault), and FY2000 (Zia fault).

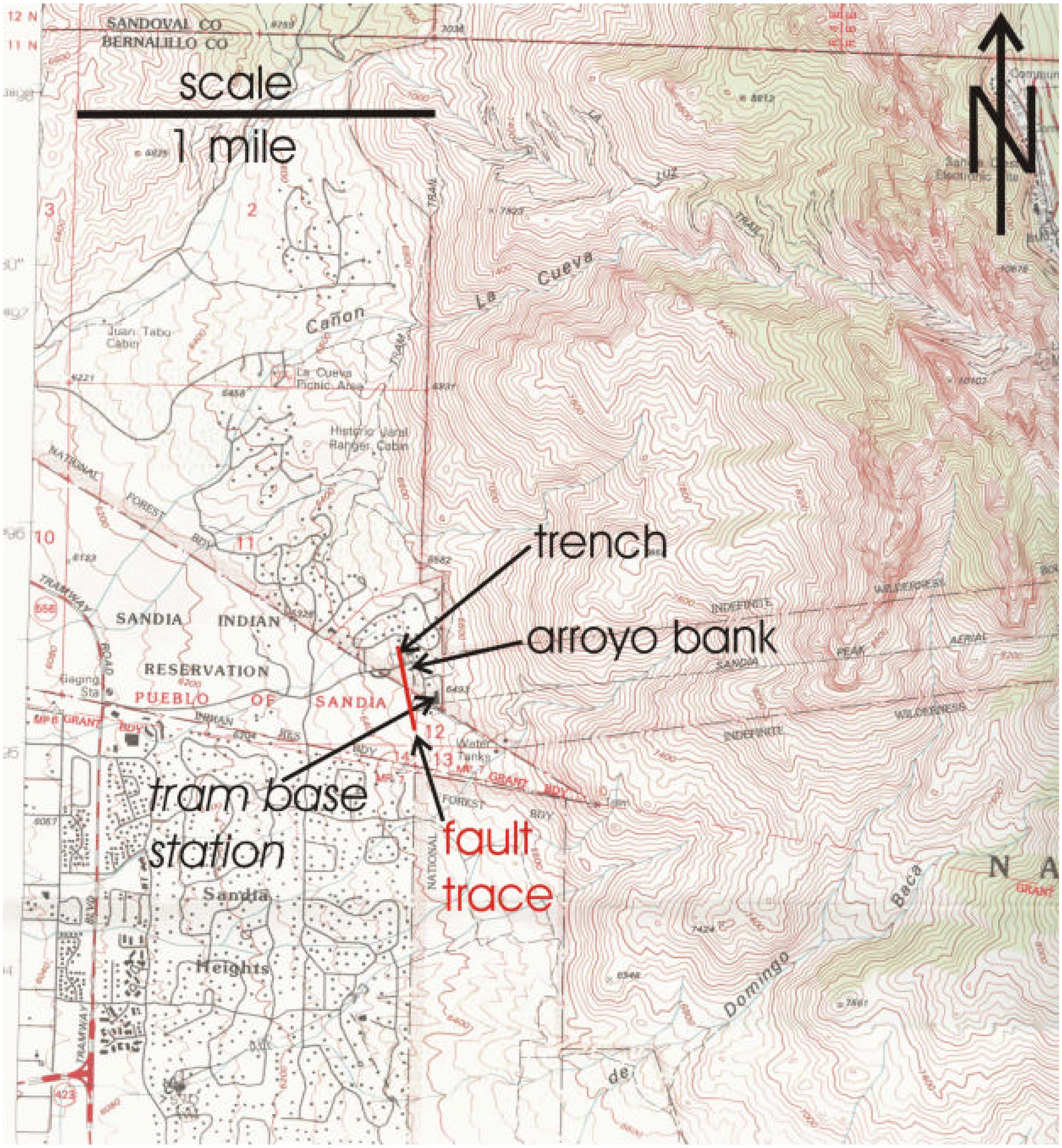

Fig. 3. Close-up map of fault trace and trench site at the Sandia Tramway base station site. Base map from Sandia Crest and Alameda 7.5' quadrangles.

3. METHODS

The trench was excavated by a small rubber-tired backhoe to the width of the 0.9 m-wide bucket (i.e., a narrow slot cross-section), and shored with hydraulic aluminum shores. The southern wall of the trench was cleaned by manual scraping, then a series of horizontal stringlines were attached to the trench wall, spaced 1 m apart, that served as control for the manual trench logging. The wall was logged by the manual method (McCalpin, 1996, p. 70) at a scale of 1:20. Mapping units were defined either as stratigraphic units or as soil horizons developed on stratigraphic units.

Mapping conventions: The unconsolidated map units defined on trench logs include both parent materials unaffected by soil formation (e.g., unit 25), and parent materials that have been affected by soil formation (e.g., unit 25Ck2). In the latter group the map units are soil horizons defined by changes in soil horizon properties, rather than by a change in parent material sedimentology. Horizons were recognized and named according to the definitions of SCS (1994) and Birkeland (1999). In each map unit abbreviation the parent material number (1=oldest) forms the first part of the unit designation and the soil horizon abbreviation (if applicable) forms the next part of the map unit designation. The final part of the map unit designation indicates whether the soil horizon is part of a buried soil (i.e., not the surface soil) and if so, the number of the buried soil, with "b1" indicating the uppermost (youngest) buried soil. Thus, the map unit designation "10Kb1" indicates that the parent material is unit 10 (sand), the soil horizon is a K horizon (strongly calcified), and the K horizon is part of the 1st buried soil counting down from the ground surface. This same naming convention is used throughout the trench logs.

4. SANDIA FAULT STUDY SITE

Our trench was located on sub-strand B of the newly-defined Tram Station strand of the SFZ, about 200 m northwest of the base station building for the Sandia Aerial Tramway. This strand is the easternmost strand of the SFZ and thus lies closest to the Sandia range front. This location was chosen because it was one of the few undeveloped parcels of land in the entire SFZ that was privately owned, and permission to trench could be obtained on a short time frame. Sites to the north on the Tram Station strand were in completed residential subdivisions, whereas sites to the south were in the Sandia Pueblo (Indian reservation) or in the Sandia National Forest (USDA).

4.1 Local geomorphology and geology

The SFZ lies at the western base of the Sandia Mountains, at the head of a broad pediment that slopes westward to the Rio Grande. The base of the range front is not very linear, compared to many other active range fronts in the Rio Grande rift and Basin and Range province. Instead, the range front is typified by embayments and protruding ridges of Sandia Granite (Precambrian, Mesoproterozoic, ca. 1.4Ga). The largest embayment is lies in the northeast corner of the piedmont, is 4 miles long and 1 mile deep, extending from Jaral Canyon on the north to Embudito Canyon on the south. We informally call this the Sandia Heights embayment, after the subdivision of the same name. The Sandia Granite suffers from granular disintegration and the production of abundant grus and corestones. It weathers along joints into subrounded, exfoliating masses that in places resemble stacks of giant boulders. As a result of this spheroidal-type weathering, the ground surface and slopes of the lower range front are covered with meter-scale

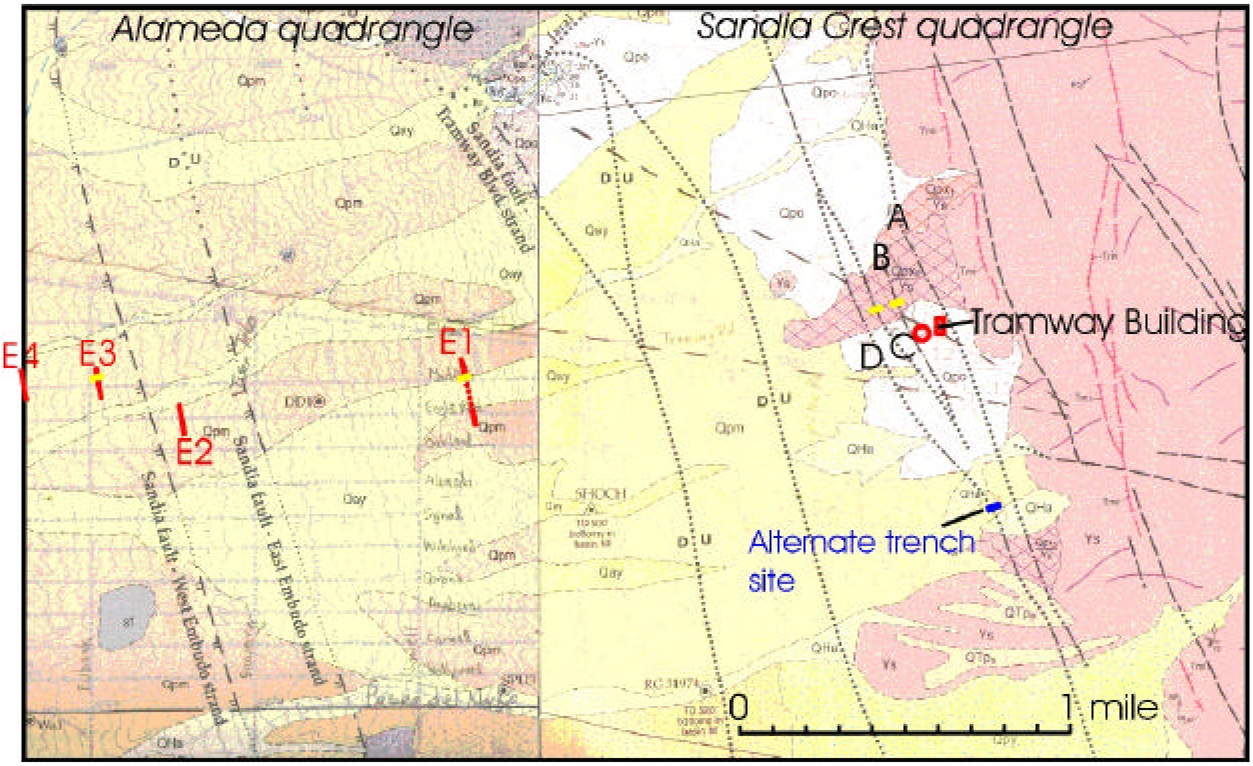

Fig. 4. Geologic maps of the study area. Geology of Alameda quad from Connell (2000); geology of Sandia Crest quad from Read et al. (2000). We use the fault strand names of Connell (2000) as shown for his 3 named strands of the SFZ (from west to east, West Embudo strand, East Embudo strand, Tramway Boulevard strand). In this report we informally name the four easternmost fault strands (A-D) of the greater SFZ as the "Tram Station strands" of the SFZ. The trench described in this study is shown by the yellow bar on fault strand B. Other untrenched alternate sites are shown on strand C (yellow bar) and strand D (blue bar), 0.5 miles south of the Tram Station building on National Forest property. The Alameda quadrangle also shows trench sites proposed for Year 2 of this trenching study (yellow bars on strands E1 and E3, at left), which unfortunately was not funded by NEHRP.

rounded to subrounded boulders (corestones), as is the proximal part of the piedmont Quaternary alluvium.

According to Connell (2000), most of the proximal piedmont crossed by the SFZ is underlain by upper to middle Pleistocene pediment gravels (map unit Qpm in Fig. 4) along most of the Sandia range front. This deposit is described by Connell (2002) as follows:

Qpm: Middle eastern-margin piedmont alluvium,undivided (upper to middle Pleistocene)*— Poorly to* *moderately consolidated deposits of very pale-brown to strong-brown and light-gray (7.5-10YR) sand and silty to clayey sand,and gravel. Inset against older eastern-margin piedmont alluvium (Qpo), unconformably overlies the Edith Formation (Qre),and is inset by younger stream alluvium (Qay). Gravel clasts are predominantly subangular granite and schist with minor subrounded limestone derived from the western front of the SandiaMountains and Rincon Ridge. Slightly to moderately dissected deposit surface exhibits subdued constructional bar-and-swale topography on interfluves.Weakly developed soils exhibit Stage II to III+carbonate morphology and minor to moderate clay film development. Locally divided into two subunits.Variable thickness,ranging up to 140 ft (43 m).*

However, at its northern end the SFZ undergoes a major stepover to the west, with the range front stepping westward about 2 km to the base of Rincon Ridge, and a smaller fault trace extending NNW up Juan Tabo Canyon. This stepover creates a westward step in the range front of the Sandia Mountains, and creates the northern side of the Sandia heights embayment (Fig. 5). Within the embayment, including our trench site, most of the proximal piedmont is underlain by older pediment gravels (map unit Qpo on Fig. 4). This deposit is more dissected by erosion than is unit Qpm, and is described by Connell (2002) as follows:

Qpo: Older eastern-margin piedmont alluvium (middle to lower Pleistocene)—*Consolidated deposits of yellowish-brown (10YR),poorly sorted and stratified,gravel and sand with minor, thin silty-clay interbeds. Gravel clasts are predominantly subangular granite and schist with minor subrounded limestone. Granite clasts are commonly pitted, and schist clasts are typically weathered and split. Variable thickness ,ranging to at least 60 ft (18 m).*

As shown in Fig. 6, gullies incised into deposit Qpo by more than about 2 m are typically flowing on Sandia Granite. Therefore, the unit is quite thin in parts of the Qpo outcrop area west of the the Tram Station. However, on the downthrown sides of sub-strands B and C, the thickness of Qpo is greater, reaching at least 3.5 m at our trench site on sub-strand B.

The oldest Quaternary deposit on the proximal piedmont near the trench site is very old pediment gravels that mantle protruding ridges up to 60 ft high underlain by Sandia Granite (Qpx2/Ys on Fig. 4). One such ridge lies about 200 m north of our trench site, and the western tip of the 60 ft-high ridge is truncated by fault strand B, the same strand as trenched in this study. Although the steep west-facing end of this truncated ridge forms a 60 ft-high (18.3 m) fault scarp, the scarp is covered with meter-size and larger granite boulders, making trenching impractical.

Our trench site and nearby arroyo exposure lie within map unit Qpo just NW of the Sandia Tram Base Station (Fig. 4). Within this area the "Tram Station strand" of the SFZ is composed of sub-strands A, B, C, and D (Fig. 5). Strands A and D are mainly marked by vegetation lineaments, but sub-strands B and C display topographic relief in places (Figs. 6-9). We identified several possible trench localities on sub-strand C (Figs. 6-7), where there appeared to be a significant amount of vertical displacement. However, due to budget limitations we could only trench a single strand. Our preferred strand was sub-strand B, which creates a west-facing scarp directly west of the Tram Station parking lot, and also truncates the western end of the Qpx2 ridge. Unfortunately, the west-facing scarp lay in a gully system and appeared to be partly exhumed, so was abandoned as a trench site because we felt that the colluvial wedge record may have been removed. Instead, our final trench site was located across the sub-strand B lineament on the north side of Tramway Road, on a direct line between the exhumed scarp and the truncated Qpx ridge.

The trench site lay at the eastern end of a large (50 m x150 m) graded area, in which the depth of grading decreased to the east and transitioned to fill at the eastern margin. Prior to our investigation as much as 1 m of fill had been placed atop Qpo alluvium on the downtrhown side of the fault, but the upthrown side may have undergone up to 0.5 m of cut. Despite this drawback, we chose the site because the landowner would give permission for trenching (because the ground had already been disturbed), and we were confident that this was a fault strand with

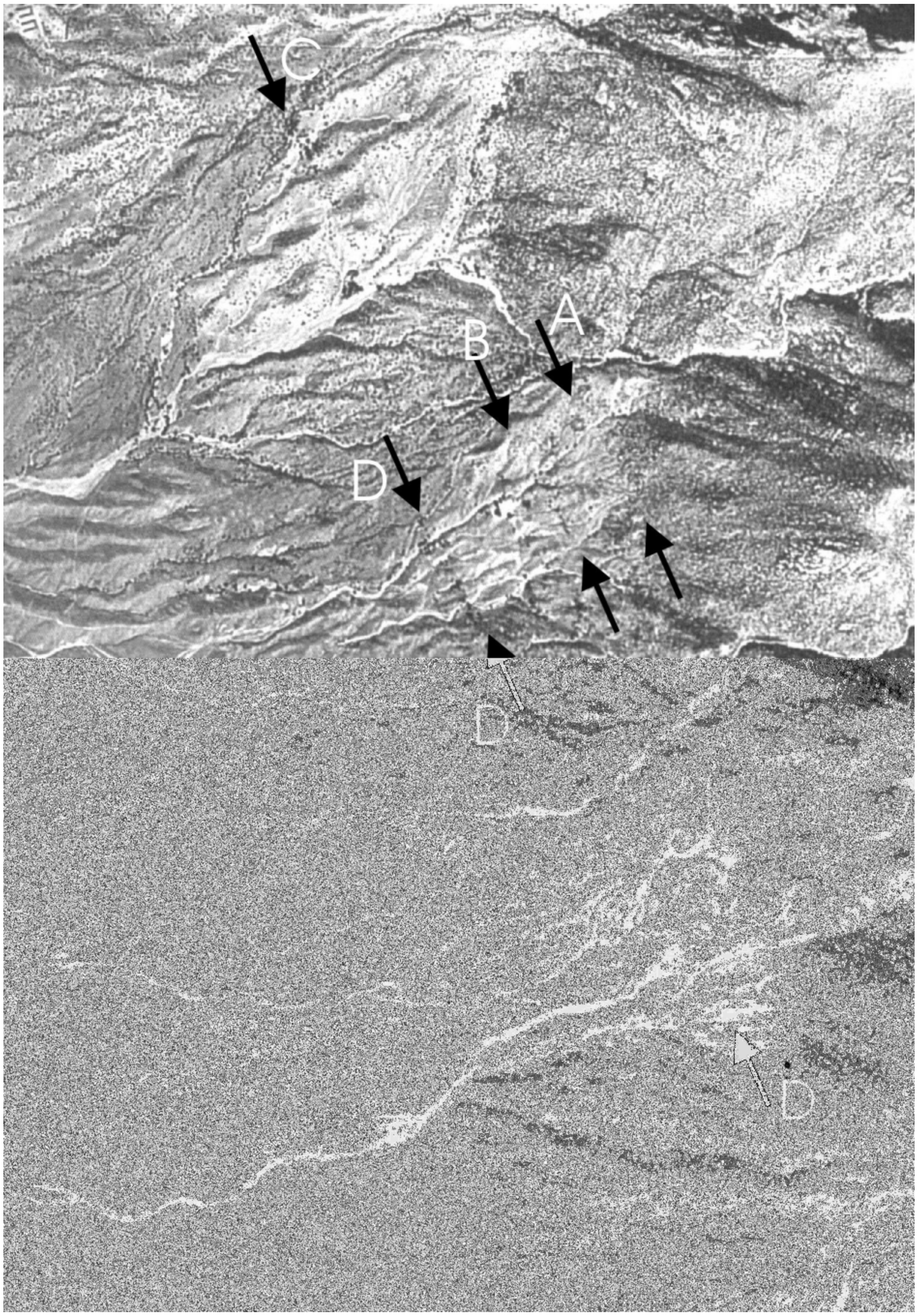

Fig. 5a. Earliest known aerial photograph of the Sandia range front-piedmont junction, showing fault strands A-D of the Tram Station strand of the SFZ (compare to Fig. 3). Photo taken Oct. 1, 1934, original scale 1:20,000. The area where all 4 strands exist (center of photograph) is the present site of the Sandia Tramway Base Station. Land to the north and south of the Station is now an expensive residential subdivision, where the fault scarps have been integrated into the yard landscaping. Note the high, dissected ridge at the tips of arrows labeled A and B. This ridge is the oldest pediment remnant mapped by Read et al. (2000), with an estimated age of Pliocene to early Pleistocene. The western end of the pediment ridge is truncated by fault strand B, which requires a vertical displacement of at least 20 m.

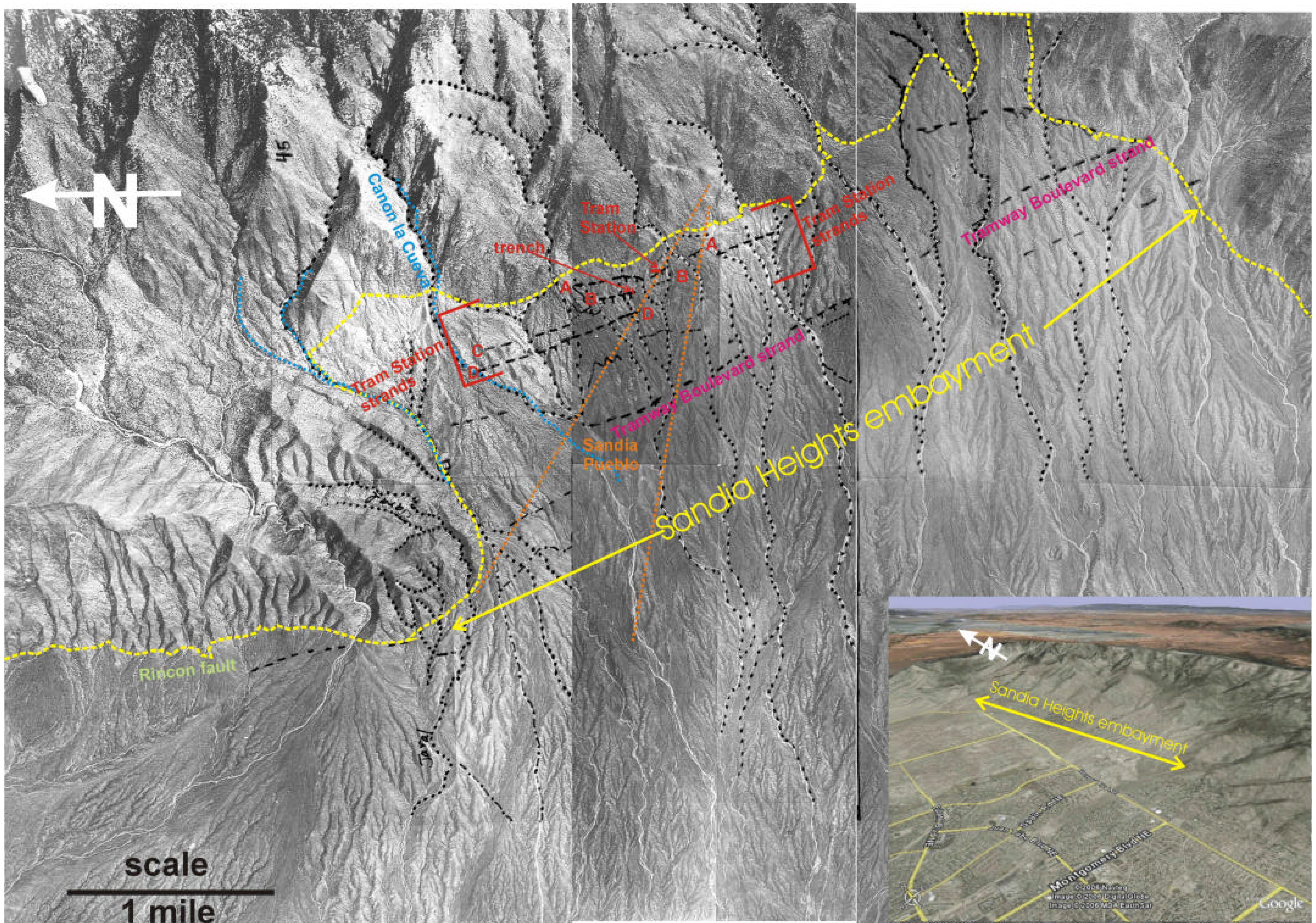

Fig. 5b. Annotated photomosaic of 1937 airphotos, showing the Sandia Heights embayment in notheastern Albuquerque (see Inset, lower right). Base of the Sandia Mountains range front shown by yellow dashed line. Fault scarps (dashed black lines with ticks), lineaments with topographic relief (dashed black lines), and lineaments without relief (dotted black lines) of the Tramway Boulevard strand and the Tram Station strands of the SFZ are shown. Dash-and-dot lines follow ephemeral drainages. The Tram Station building and our November 2002 trench are shown in red.

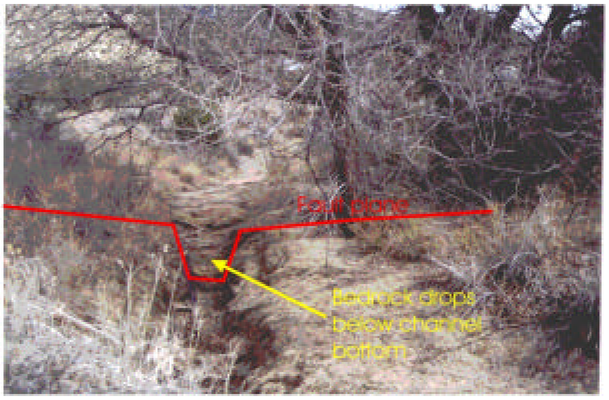

Fig. 6. Fault strand C of the SFZ (red line) where it crosses the gully north of the Tram Station. View looking east. East of the fault the gully flows on Sandia Granite, but bedrock drops below the gully bottom at the fault. Cottonwood trees at right are rooted in the fault plane, and form a lineament that crosses deposits of several ages, as mapped by Read et al. (2000). Photo by J.P. McCalpin, March 1, 2001.

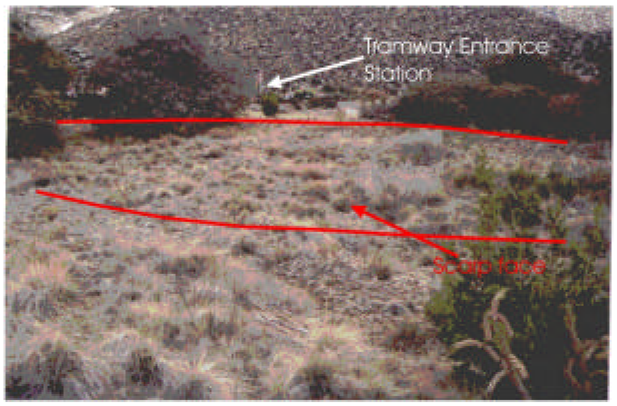

Fig. 7. Fault scarp of strand C of the SFZ (between red lines), north of the gully in Fig. 6, but south of Tramway Road. Proposed trench site is in center of photograph. The upthrown block of this strand is a wide, grassy meadow, underlain by locally-derived grussy alluvium. Shallow bedrock is exposed at the foot of the scarp, just out of the photo at the bottom. Photo by J.P. McCalpin, March 1, 2001.

Fig. 8. Fault scarp of strand B of the SFZ (between red lines), north of Tramway Road. View looking east. The planar surface in the foreground has been graded. The fault scarp has been dissected, and the upthrown block carved into several pediment remnants. Our final trench site was located just to the right of the arrow tip. Photo by J.P. McCalpin, March 1, 2001.

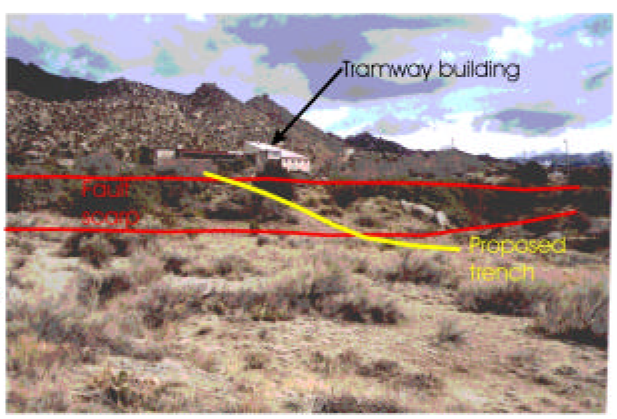

Fig. 9. Fault scarp of strand B of the SFZ (between red lines), south of Tramway Road. The Tram Station building is visible at center. Originally-proposed trench line is shown in yellow. Based on field reconnaissance, this part of the scarp was not disturbed during construction of the tramway parking lot (red circle on Fig. 4), which lies to the right of the Tram Station building.

vertical displacement (and thus possibly, colluvial wedges), as opposed to merely a lineament following a fracture.

A third potential trench site was located about 0.5 mile south of the Tram Station (Fig. 10) where sub-strand D formed a 1-2 m-high scarp in map unit Qpm. This site was not trenched because there was no access to it, and it was felt unlikely that US Forest Service would permit the degree of ground disturbance necessary to access the site and trench there.

Fig. 10. Fault scarp of strand D of the SFZ (between red lines), looking east from a location about 0.56 miles south of the Tramway Station. Yellow line shows proposed alternate trench site; see Fig. 4. The geomorphic surface offset here was mapped as a mid-Pleistocene fan by Read et al. (2000), but scattered bedrock outcrops show that the fan deposits are thin. This scarp is in the National Forest. Photo by J.P. McCalpin, March 1, 2001.

4.2 Trench Site

The trench in this study was excavated across Scarp B about 15 m north of Tramway Road. The purpose of the trench was to expose down-faulted pediment alluvium and possibly scarp-derived colluvial wedges that would provide age constraints on the latest faulting event. Prior to trenching, Sandia Heights Water and Sanitation District personnel ran a pipe-locating survey to locate a buried water line that was thought to cross the fault trace diagonally to the NW. After they spray painted the ground over the inferred location of the buried pipe, we laid out an eat-west trench alignment that avoided it. Then we began trenching into the inferred upthrown block of sub-strand B, and quickly encountered weathered, grussy, but clearly in-situ Sandia Granite, as expected.

However, after the trench had been advanced about 8 feet, the backhoe encountered the buried water line (Fig. 11). The water line lay atop weathered Sandia Granite and beneath fill. We continued excavating westward, beneath the pipe, and west of the pipe the top of bedrock began to decline steeply. By the time that the trench was 10 feet west of the pipe, the entire 3.5 m depth of the trench was in unconsolidated Quaternary deposits. We interpreted this steep decline in the top of bedrock to represent the fault of sub-strand B. However, due to the presence of the "live" water pipe we felt we could not continue excavating, without risking rupturing the pipe and depriving an entire subdivision of water service.

Therefore, from the midpoint of the initial trench we dug a perpendicular trench 10 feet to the south (Fig. 12), and then continued excavating the final trench westward. The initial trench

Fig. 11. Photograph of the initial trench, showing the NW-trending water line exposed in the trench. View is to the west.

Fig. 12. Photograph of the eastern half of the initial trench (foreground), the perpendicular trench (right center), and the final trench (upper right). View is to the south.

was then immediately backfilled without being logged, before the water line suffered any distress.

The perpendicular trench and the easternmost 5 m of the final trench are in the upthrown block (footwall) of sub-strand B. The footwall is composed of gray, weathered Sandia Granite cut by numerous steeply west-dipping shear bands (Fig. 13). In the trench log Sandia Granite is unit 1.

Fig. 13. Photograph of the south wall of the final trench, at its easetrn end on the fault footwall. The entire footwall is composed of Sandia Granite (gray-and-white speckled rock) cut by numerous west-dipping shear zones (light brown to tan, fine-grained zones).

4.2.1 Stratigraphy

In the fault zone and hanging wall of sub-strand B we defined 17 Quaternary depositional units and 5 soil horizons (Fig. 14 and Appendix 2). The depositional units are dominantly granitic pebble gravel with varying amounts of grussy sand matrix (10 of the 17 units) and are inferred to represent pediment alluvium deposited by the ephemeral streams that cross the proximal piedmont. Five of the gravel units (units 6, 9, 12, 15, and 16) are well sorted and weakly to moderately stratified. These units are interpreted as channel alluvium of ephemeral streams. Five of the gravel units (units 2, 3, 4, 14, and 18) are poorly sorted and unstratified. We interpret these units as debris flows. The remaining 7 units (units 5, 7, 8, 10, 11, 13, 17) are massive sands, some of which contain thin stringers of coarser sand or fine gravel. We interpret these massive sands as dominantly eolian, but reworked by rillwash processes where stratified.

Units 4-18 dip gently westward, roughly parallel to the modern ground surface and to the westward slope of the Qpo pediment surface. These units lie with angular unconformity upon units 2-4, which dip moderately eastward, toward the mountains. Units 2-4 lie atop Sandia Granite and atop the major fault zone in the center of the trench.

Annotated Field Log of Nov. 2002 Trench Across the Tramway Boulevard Strand of the Sandia Fault Zone, Albuquerque
Logged by Jim McCalpin and Crew

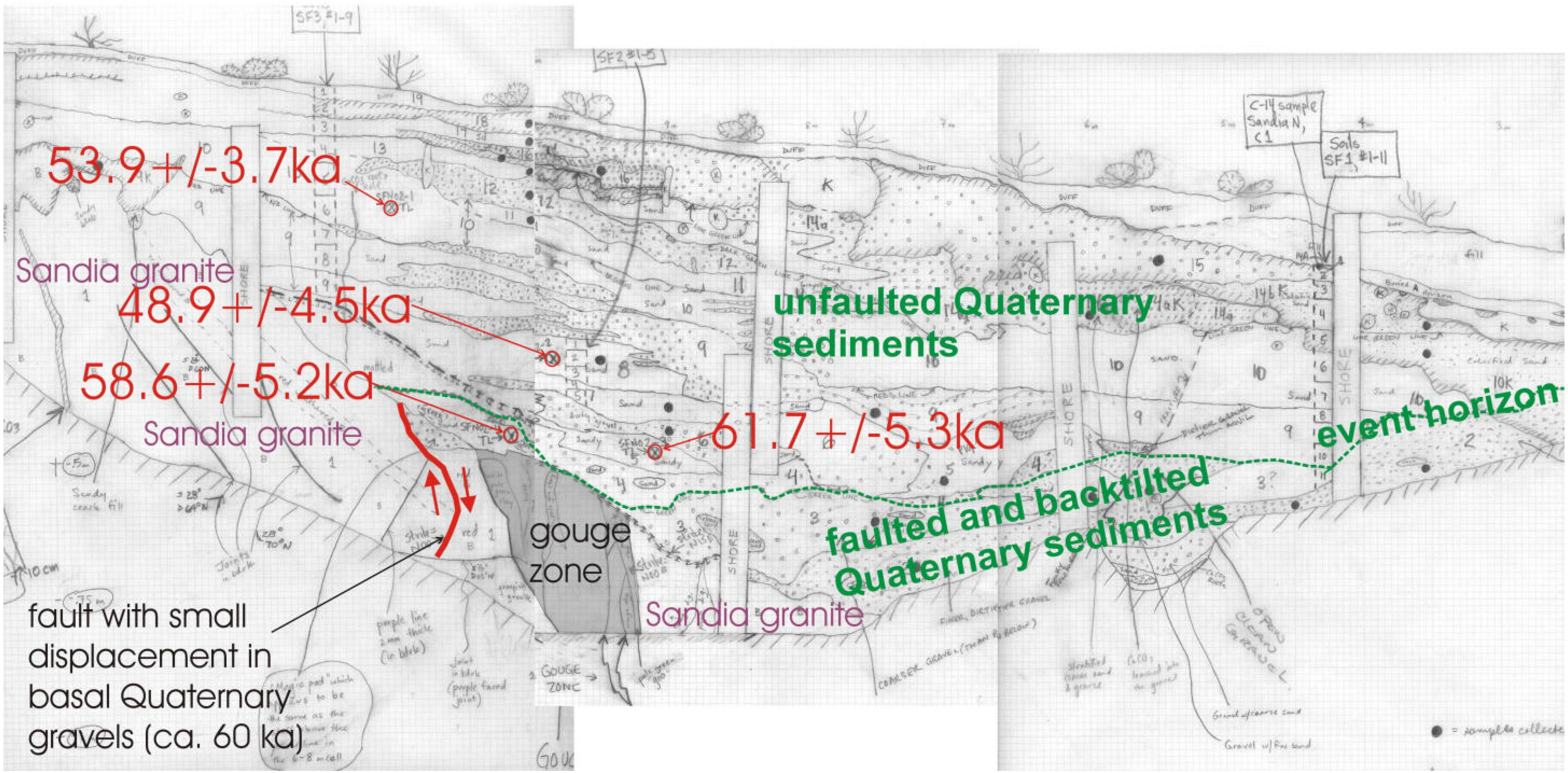

Fig. 14. Log of trench across sub-strand B of the Tram Station strand of the SFZ. OSL ages shown in red. The event horizon (green dashes) separates backtilted units 2-3 from horizontal units 4-19.

4.2.2 Soils

The degree of surface soil development in the trench yields an independent estimate of the age of the alluvial deposits and the geomorphic surface. The surface soil does contain a K horizon with stage I-II morphology, but the soil may also have been periodically thinned by erosion. Therefore, we computed the total weight of pedogenic carbonate in the profile (Table 1) in 3 vertical profiles. Profiles SF1 and SF2 form a continuous vertical sequence in the thickest section of Quaternary deposits, while profile SF3 lies near the south end off the trench in a thinned section of alluvium.

The fine sediments in which the soils have formed have not been derived from weathering of granite, rather they are a mixture of sands and silts which were probably aeolian deposits. The source of these deposits was likely the broad ephemeral streams flowing from the Sandia Mountain front. These deposits have been reworked by fluvial processes as indicated by the intermixing of gruss gravels into the deposits.,

Profile SF1 contains 13.5 g of total carbonate. We assume that the granitic parent material possessed no carbonate upon deposition, however, the aeolian deposits may have had an inherited calcium content. The C horizon sediments have very low calcium carbonate contents so we assume that total carbonate also equals total pedogenic carbonate. Profile SF2 contains 1.1 g of pedogenic carbonate, and profile SF3 contains 10.1 g of pedogenic carbonate. The cumulative pedogenic carbonate in profiles SF1 and SF2 (14.6 g) may be increased over the normal amount expected for this geomorphic surface, due to additional surface water infiltrating at the base of the fault scarp. Profile SF3 is less affected by this footslope factor, so might be more representative.

Previous soils work on the Llano de Albuquerque (Calabacillas fault; McCalpin, in press) shows that the dominant accumulation rate for pedogenic carbonate has been 0.17 g/ka between 32 and 55 ka and 0.35 g/ka between 55 and 151 ka. At the County Dump fault (McCalpin et al, 2006), TL ages define a carbonate accumulation rate of 0.26 g/ka over the time period 4- 82 ka, and of 0.54 g/ka between 82-293 ka. These rates can be compared to those computed elsewhere in the southwestern US (Machette, 1985), and fall closest to cited rates from Las Cruces, NM of 0.25 g/ka for pluvial climates in the Pleistocene, and 0.5 g/ka for interpluvial climates.

Applying the average of the 6 rates cited above (0.35 g/ka), the 10.1 g of pedogenic clay at profile SF3 implies an age of only 29 ka, whereas the combined 14.6 g at profiles 1 and 2 imply an age of 41.7 ka. Both of these ages are somewhat younger than the OSL ages of subjacent strata, which date between 48.9±4.5 ka and 61.7±5.3 ka (section 4.2.4).

Table 1. Soil texture and carbonate data for 3 vertical soil profiles in the trench across sub-strand B, Sandia fault zone.

Soil texture and carbonate data for 3 vertical profiles						Mean		weight
SF1, footwall; SF2, over fault zone; Sf3, hanging wall (thinned)						Bulk Density	thickness	of CaCO3
lab #	base (cm)	% CaCO3	% sand	% silt	% clay		(cm)	(g)
SF1-1	6	7.76	62.7	28.7	8.6	1.3e	6	0.60528
SF1-2	16	18.69	61.6	28.9	9.5	1.29	10	2.41101
SF1-3	26	10.04	53.5	39.4	7.1	1.32	10	1.32277
SF1-4	42	6.65	35.6	54.0	10.3	1.35	16	1.43374
SF1-5	64	24.75	36.4	49.4	14.2	1.29	22	6.996825
SF1-6	84	0.35	48.1	39.5	12.4	1.29	20	0.0903
SF1-7	104	0.67	50.5	38.3	11.2	1.31	20	0.17554
SF1-8	114	0.69	46.7	40.4	12.9	1.29	10	0.0891825
SF1-9	129	0.29	49.1	37.0	13.9	1.43	15	0.06235
SF1-10	144	0.7	50.6	39.1	10.3	1.57	15	0.16485
SF1-11	164	0.41	64.2	31.8	4.0	1.56	20	0.12751
							Total of SF1	**13.479358**
SF2-1	10	0.94	49.1	42.8	8.1	1.73	10	0.16215
SF2-2	20	0.84	44.4	44.6	11.1	1.71	10	0.14322
SF2-3	30	1.85	48.2	41.6	10.1	1.69	10	0.311725
SF2-4	40	1.71	44.1	46.6	9.3	1.69	10	0.28899
SF2-5	50	1.04	42.7	48.5	8.8	1.68	10	0.17472
							Total of SF2	**1.080805**
SF3-1	10	9.06	60.7	24.1	15.2	1.5e	10	1.359
SF3-2	22	10.21	40.3	44.8	14.9	1.57	12	1.917438
SF3-3	45	7.77	37.5	48.3	14.2	1.48	23	2.644908

SF3-4	65	2.87	41.4	41.5	17.1	1.50	20	0.85813
SF3-5	85	4.28	42.6	42.3	15.2	1.44	20	1.23264
SF3-6	107	1.31	57.7	31.2	11.1	1.47	22	0.422213
SF3-7	129	1.5	60.4	29.0	10.6	1.51	22	0.49665
SF3-8	142	2.93	41.9	44.1	14.0	1.52	13	0.5770635
SF3-9	158	2.02	48.0	38.2	13.9	1.69	16	0.544592
							Total of SF3	**10.052635**

The discrepancy between the soil carbonate age estimates and the OSL age estimates can be explained in several ways. First, if erosion has alternated with deposition over the past 50-60 ka at the trench site, part of the soil record (and its associated carbonate) may have been physically removed. In that case, the soil carbonate preserved today is less than it should be considering the age of the deposit. We feel this is the most likely explanation, given the dissection of the pediment surface in the vicinity of the trench. Second, the rate of soil carbonate accumulation during the past 50-60 ka may have been slower than the average rate of 0.35 g.ka that we assumed. With increased elevation the soil is closer to the pedocal/pedalfer boundary which represents the point at which all calcium carbonate is leached from the soil profile. Certainly the mean annual precipitation, and thus flushing of carbonate through the soil column, is greater here at the Sandia range front than on the Llano de Albuquerque or at Las Cruces. Thus we believe that the ages of the soils based on calcium carbonate accumulation rates represent a minimum age of these deposits.

4.2.3 Structure

The main fault zone in the trench is a 2 m-wide zone of Sandia Granite that contains both wide gouge zones and thinner, planar faults. Two gouge zones are most prominent, being subvertical, irregularly shaped, and filled with white to pale green clay gouge (Fig. 14). Both gouge zones are erosionally truncated by the overlying Quaternary deposits. This geometry, and the fact that the gouge was unlikely formed at at depth of only 3.5 m below the ground surface, suggests that these gouge zones are pre-Quaternary structures that may date back to the early evolution of this rift margin.

Interspersed with the gouge zones are several subvertical fault planes that juxtapose different colors of altered Sandia Granite. The easternmost of these faults extends up into the bottom of the Quaternary deposits and appears to displace Sandia Granite against a small triangular remnant of units 2 or 3.

4.2.4 Geochronology

Due to the arid conditions and coarseness of the granitic alluvium, organic material for radiocabon dating was largely absent. This was not seen as a major obstacle, because the deposits of map unit Qpo were thought to be "middle to lower Pleistocene", and thus too old for radiocarbon dating. Instead, we estimate the ages of Quaternary deposits in the trench from luminescence dating and from the amount of secondary pedogenic carbonate in paleosols.

The gravelly alluvium exposed in the trench was considered to be deposited too rapidly to have had its luminescence signal reset to zero during deposition, therefore we did not sample these units. In contrast, the 7 sandy units were inferred to be mainly eolian and were assumed to be well-zeroed. We collected 4 samples from sandy units. The upper 3 samples were from gently west-dipping strata that were apparently undeformed by faulting, i.e. units 10, 8, and 5 (Table 2). These units yielded infrared-stimulated luminescence ages of 53.9±3.7 ka, 48.9±4.5 ka, and 61.7±5.3 ka. These units are slightly out of stratigraphic order, and moreover, are too young to match the inferred "middle to lower Pleistocene" age of the Qpo unit mapped at the trench site by Reid et al. (2000). Based on these ages, the sediments preserved on the hanging wall of fault sub-strand B are more likely correlative to Reid's unit Qpm, which is "upper to middle Pleistocene."

The fourth sample was taken from the small triangular deposit of units 2 and 3? that appear to be in fault contact with Sandia Granite. The sample yielded an age of 58.6±5.2 ka, which overlaps the age of overlying sample SFN02-3 at 1 sigma.

Table 2. Summary of multi-aliquot infrared-stimulated luminescence measurements on the fine silt fraction; detection at 420 nm; errors are one sigma.

Sample	Unit	Depth below ground surface	Dose Rate (Gy/ka)	Equivalent Dose (Gy)	Age (ka)
SFN02-1	10	0.8 m	4.25 ±0.19	229±12	53.9±3.7
SFN02-2	8	1.85 m	4.42±0.21	216±17	48.9±4.5
SFN02-3	5	2.35 m	4.99±0.23	308±22	61.7±5.3
SFN02-4	2 or 3?	2.4 m	5.14±0.20	271±18	58.6±5.2

4.4.5 Interpretation

The angular unconformity between Quaternary units 3 and 4 near the bottom of the trench, and the faulted unit 2-3 correlative over the main fault zone, suggest that units 2-3 have been faulted by the Most Recent fault Event (MRE) on sub-strand B. The displacement during that event is difficult to estimate, because it it not clear whether the small triangular-shaped deposit that is faulted correlates with unit 2 or 3 on the hanging wall. Based on lithologic similarity, it is likely that the gravelly basal part of the triangular deposit correlates with unit 2 on the hanging wall. The vertical separation across the main fault zone between the bottom of the triangular unit and that of unit 2 on the hanging wall is 1.6 m. We consider this a maximum estimate of the net vertical tectonic displacement in the MRE, because much of that 1.6 m is caused by backtilting of unit 2 toward the fault.

The timing of the MRE should be bracketed between IRSL samples 3 and 4, which straddle the inferred Event Horizon of the MRE. However, these 2 samples yielded stratigraphically reversed ages of 61.7 ka above the Event Horizon and 58.6 ka below it, with the ages overlapping at 1 sigma. Based on this overlap, about all we can conclude is that the 1-sigma age range for the MRE is likely about 53-67 ka.

4.2.6 Implications for Regional Earthquake Hazard

It may seem odd that the slip rate and recency of faulting on the SFZ, which lies at the base of an impressive mountain range and rift margin, is comparable and older (respectively) than for the much less conspicuous faults on the opposite rift margin. The SFZ forms the eastern margin of the rhomb-shaped Calabacillas sub-basin (Fig. 15). The western boundary of this sub-basin is formed by the Calabacillas fault. There is no impressive range front rising from the County Dump, Calabacillas, and Zia faults on the flat Llano de Albuquerque, but all three have more recent MREs and comparable late Quaternary slip rates compared to the SFZ. For example, the latest 4 ruptures on the Calabacillas fault are dated at approximately 14 ka, 32 ka, 77 ka, and 151 ka, compared to the MRE on sub-strand B of the SFZ between 58-61 ka. Thus, there have been two ruptures on one of the western margin faults subsequent to the MRE that occurred on the eastern margin fault (SFRZ).

The answer probably lies in the concept of “seesaw tectonics” proposed by Smith et al. (2001). According to this model, over long periods of geologic time (Ma), the main displacement activity in a rift basin may switch from one margin fault to the opposite margin, thus reversing the polarity of the basin. If we compare the vertical height of fault scarps on early Pleistocene geomorphic surfaces on the SFZ (18.3 m) to those on the similar-age (?) Llano de Albuquerque surface across the Calabacillas fault (27 m), it appears there has been more displacement on the western side of the rift in the past ca. 1.5 Ma. However, the overall topography of the rift at this latititude clearly shows that since the Miocene, the majority of the displacement has occurred on the SFZ. If the current pattern persists in the near future in the Calabacillas sub-basin, we should expect low slip rates and low hazard for the SFZ, and higher slip rates and higher hazard for the Calabacillas fault.

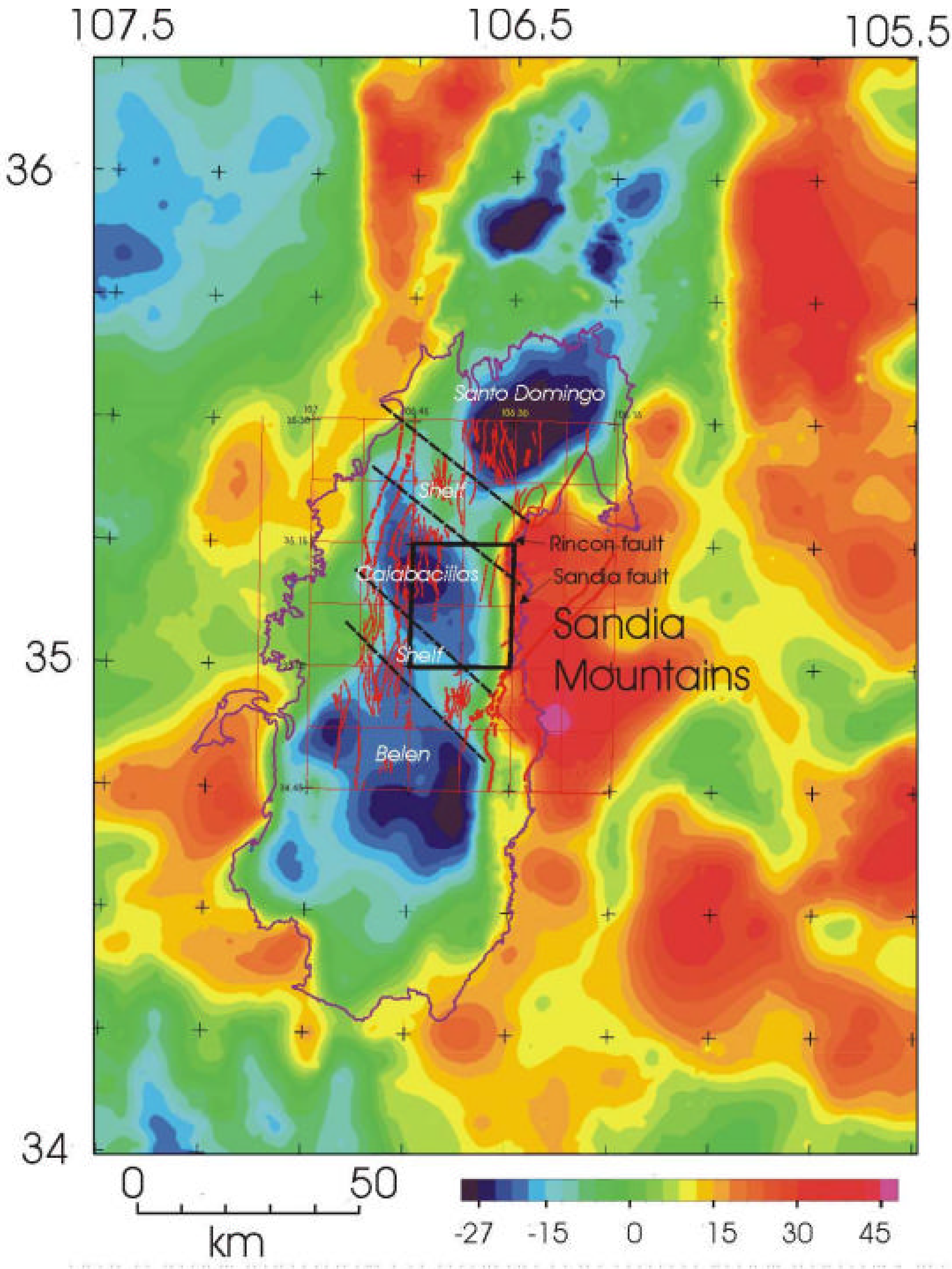

Fig. 15. Gravity map of the Albuquerque-Belen basin (values in mgals), after Grauch (unpub.). Quaternary faults are shown in red. The Sandia fault zone defines the eastern margin of the Calabacillas sub-basin, while the western margin is defined by several fault strands on the Llano de Albuquerque, chiefly the Calabacillas fault.

5. CONCLUSIONS

This study mapped and named 4 strands of the newly-named “Tram Station strand” of the Sandia fault zone, which is restricted to the Sandia Heights embayment of the Albuquerque-Sandia piedmont. We identified three possible trench sites on sub-strands B, C, and D of the Tram Station strand, but only had enough funding to trench the best-preserved trace (sub-strand B). Therefore, the paleoseismic parameters calculated below must be viewed as very incomplete, given the fact that only 1 of 4 sub-strands was trenched, and that the entire Tram Station strand is only one of at least 4 named strands of the Sandia fault zone (the others being the Tramway Boulevard. East Embudo, and West Embudo strands).

5.1 Displacement per Event and Paleomagnitude

The maximum estimate of 1.6 m for displacement during the MRE is perhaps a minimum cumulative displacement estimate for this event, because simultaneous ruptures may have also occurred on parallel sub-strands A, C, or D. Granted, sub-scarp B has the best fault scarp expression of the four sub-strands, and the highest scarps, but simultaneous displacement of sub-meter size cannot be disproven at this time for the other 3 sub-strands, because they have not yet been trenched. As a working hypothesis, we assume 1.6 m as a first approximation of MRE displacement across the Tram Station strand of the SFZ.

According to Wells and Coppersmith (1994), historic normal-fault earthquakes that have created fault scarps with a maximum and an average height of 1.6 m correlate with earthquakes of moment magnitude M6.75 and M6.91, respectively (Wells and Coppersmith, 1994). We can compare these displacement-based values to the magnitudes suggested by the overall length of the fault zone. The Sandia fault zone as strictly defined in the USGS Quaternary Fault and Fold Database (Appendix 1) is 27.8 km long. Normal fault ruptures of this length are typically associated with earthquakes of M6.77 (Wells and Coppersmith, 1994), which closely matches the magnitude suggested by 1.6 m being the maximum displacement per event.

5.2 Recurrence Interval

We cannot compute a recurrence interval for sub-strand B because our trench exposes evidence for only a single faulting event, the MRE. All we can say from this trench is that the elapsed time since the MRE on sub-strand B, the best-expressed sub-strand of the Tram Station strand of the SFZ, has been about 53-67 ka. This age explains why the topographic expression of the Tram Station strand is so poor.

5.3 Slip Rate

Likewise, we cannot compute a closed-cycle geologic slip rate for sub-strand B, based only on the occurrence of a single 1.6 m displacement event at 53-67 ka. If the next earthquake occurred tomorrow and released a similar 1.6 m of slip, the resulting closed-cycle slip rate would be 0.024-0.030 mm/yr. This rate is a maximum slip rate estimate for sub-strand B, because if the next earthquake occurs later than tomorrow, the slip rate would be lower. If there was additional slip on sub-strands A, C, or D (or even on the Tramway Boulevard strand of the SFZ), then the estimates above might be a minimum.

However, it is unlikely that the cumulative slip in the MRE on sub-strands A, C, and D would be greater than that experienced on sub-strand B, or those other strands would have better geomorphic expression today. So, assuming that the slip rate on the Tram Station strands could be as much as 0.048-0.060 mm/yr, these numbers still fall well short of the slip rate estimate cited in the USGS Quaternary Fault and Fold Database of "less than 0.2 mm/yr" (Appendix 1).

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7. ACKNOWLEDGMENTS

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APPENDIX 1

DATABASE ENTRY FOR THE SANDIA FAULT, from the U.S. Geological Survey's Quaternary Fault and Fold Database (http://qfaults.cr.usgs.gov/faults/FMPro)

Complete Report for Sandia fault (Class A) No. 2037

Brief Report || Partial Report

Compiled in cooperation with the New Mexico Bureau of Mines and Mineral Resources

citation for this record: Personius, S.F., compiler, 1997, Fault number 2037, Sandia fault, in Quaternary fault and fold database of the United States, ver 1.0: U.S. Geological Survey Open-File Report 03-417, http://qfaults.cr.usgs.gov.

Synopsis:	The Sandia fault forms the steep western flank of the Sandia Mountains, and the eastern margin of the Albuquerque-Belen basin in the vicinity of Albuquerque. Little geomorphic evidence of Quaternary faulting is found along the trace of the Sandia fault, but the presence of a steep mountain front and a few possible fault scarps on unconsolidated deposits indicates that the Sandia fault has probably been active in the Quaternary. The concealed fault strands west of the main range front are mapped on the basis of subsurface well and geophysical data; they appear to offset upper Santa Fe Group sediments.
	Name Comments: The Sandia fault is series of structures responsible for most of the uplift of the west flank of the Sandia Mountains; various traces of the Sandia fault have been mapped by Ellis (1922 #1294), Kelley (1954 #1222; 1977 #1106), Kelley and Northrop (1975 #1308), Connell (1995 #1291), GRAM Incorporated and William Lettis and Associates, In (1995 #1430), and Connell (1997 #1765). We include several north trending intrabasin fault strands that lie to the west of the main Sandia range front in this discussion of the Sandia fault. **Number Comments:**
State(s):	New Mexico

County(s):	Bernalillo Sandoval
AMS sheet(s):	Albuquerque view map
Physiographic province(s):	Basin and Range province
Geologic setting:	The Sandia fault forms part of the eastern margin of the Rio Grande rift and the Albuquerque basin in the vicinity of Albuquerque.
Reliability of location:	Poor. Compiled at 1:100,000 scale. *Comments:* Most published maps show the Sandia fault as dotted (concealed) along most of its trace; map traces are from Kelley and Northrop (1975 #1308), Connell (1995 #1291; written commun., 1997), GRAM Incorporated and William Lettis and Associates, Incorporated (1995 #1430), and Connell (1997 #1765).
Length (km):	27.8 *Comments:* The fault zone includes numerous faults that have a cumulative length of 59.3 km.
Average strike:	N4°E
Sense of movement:	Normal *Comments:*

Dip:	55° W *Comments:* Dip measurements are from a shallow fault exposure just north of Tijeras Arroyo (Kelley and Northrop, 1975 #1308; Lambert and others, 1982 #1397).
Paleoseismology studies:	
Geomorphic expression:	The range front adjacent to the northern end of the Sandia fault, from Rincon Ridge south to Embudito Canyon (Domingo Baca segment of Connell, 1995 #1291) is deeply embayed; from Embudito Canyon south to Tijeras Canyon, the Sandia range front is steep, linear, and characterized by dissected faceted spurs and ridges. South of Tijeras Canyon to its intersection with the Tijeras-Cañoncito fault system [2033], the Sandia Range front is again embayed. A few small fault scarps have been mapped intermittently on middle Pleistocene alluvial-fan deposits at the northern and southern ends of the Sandia fault (Connell, 1995 #1291; GRAM Incorporated and William Lettis & Associates Incorporated, 1995 #1430; Gustafson, 1996 #1299), but most of the trace is buried by younger fan deposits. The intrabasin faults west of the main range front have little or no geomorphic expression (Connell, 1995 #1291; written commun., 1997).
Age of faulted surficial deposits:	A few small scarps are preserved on middle Pleistocene alluvial fan deposits along the Sandia Mountain front (Connell, 1995 #1291; GRAM Incorporated and William Lettis & Associates Incorporated, 1995 #1430; Gustafson, 1996 #1299), but most strands included in the Sandia fault only offset upper Santa Fe Group sediment (Connell, 1997 #1765).
Year of historic deformation:	
Most recent prehistoric deformation:	Middle and late Quaternary (<750 ka) *Comments:* The Sandia fault offsets probable early Pleistocene upper Santa Fe Group sedimentary rock north of Tijeras Arroyo (Kelley and

	Northrop, 1975 #1308; Lambert and others, 1982 #1397). Evidence for younger movement exists at the southern end of the Sandia fault near Arroyo del Coyote, where GRAM Incorporated and William Lettis and Associates, Incorporated (1995 #1430) have mapped short fault scarps and described a fault exposure in middle to late Pleistocene alluvial fan deposits, and at the northern end of the Sandia fault where Connell (1995 #1291) mapped short fault scarps on middle Pleistocene fan deposits.
Recurrence interval:	*Comments:*
Slip-rate category:	Less than 0.2 mm/yr *Comments:* No detailed studies of fault offset or age of offset deposits are available; slip-rate category is based on lack of prominent fault scarps and low rates of slip on other faults in this part of the Rio Grande rift.
Compiled or modified by and affiliation:	Stephen F. Personius, U.S. Geological Survey, 1997
References:	#1291 Connell, S.D., 1995, Quaternary geology and geomorphology of the Sandia Mountains piedmont, Bernalillo and Sandoval Counties, central New Mexico: Riverside, University of California, unpublished M.S. thesis, 414 p., 3 pls. #1765 Connell, S.D., 1997, Cenozoic geology of the Tijeras 7.5-minute quadrangle, Bernalillo County, central New Mexico: New Mexico Bureau of Mines and Mineral Resources Open-File OF-425, 11 p. pamphlet, 1 sheet, scale 1:24,000. #1294 Ellis, R.W., 1922, Geology of the Sandia Mountains: University of New Mexico Bulletin 108, Geology Series, v. 3, no. 4, p. 44. #1430 GRAM Incorporated, and William Lettis & Associates Incorporated, 1995, Conceptual geologic model of the Sandia

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APPENDIX 2

UNIT DESCRIPTIONS, TRENCH on sub-strand B

1—Sandia Granite (local basement rock)

2-- poorly sorted gravel (with one large granite clast); better sorting at top of unit, then bottom; Clumps or wads of very poorly sorted material (silt/fine sand to gravel). Harder at 4.5 m than at 3.5 m. At 7.25 m, very weakly stratified (dip 17E, with stringers of clean gravel; ALLUVIUM.

3-- Poorly sorted gravel; unstratified; contains blobs and pods of sand; units 2-3 dip east toward the fault plane, in opposition to the slope of the piedmont, but all overlying units are subhorizontal or west-dipping; the angular unconformity at the top of unit 3 is thought to mark the Event Horizon of the Most Recent Faklting event; ALLUVIUM

4-- loose, orange staining above -1.25 m station; below -1.25 m station unit is somewhat harder; ALLUVIUM

5-- Sand with small stringers of gravel that dip 20E; contains small blebs of carbonate; ALLUVIUM

"Yellow Blob"-- well sorted clean sand with some well sorted coarser sand stringers; ALLUVIUM

6-- Clean gravel, cross-bedded; hard; contains stringers; ALLUVIUM

7-- Sand, very hard, massive, with random clasts and some coarse sand stringers; purple staining on the ped faces; EOLIAN?

8-- Sand; softer than unit 7; generally massive; contains pea gravels and coarse sand pods; EOLIAN?

9-- Clean gravel with small sand stringers; loose to semi-firm; channel-shaped stratification (trough crossbedding); ALLUVIUM

9K-- soil K horizondeveloped on unit 9; calcified massive sand with pea gravels and granite clasts; abundant cicada burrows; PALEOSOL

10-- Brownish silty fine sand; noncalcareous; EOLIAN?

10K--soil K horizon developed on unit 10; stage III calcium carbonate impregnating a silty fine sand; PALEOSOL

11-- Sand; generally massive; somewhat hard (firm); EOLIAN

12-- Gravel, loose, random (not stratified); ALLUVIUM

13K-- soil K horizon developed on unit 13; sand impregnated with stage III carbonate; PALEOSOL

13-- Sand, generally massive; firm; EOLIAN

14A-- A horizon of pre-grading surface soil, developed on unit 14; SURFACE SOIL HORIZON

14bK-- soil K horizon developed on unit 14b; stage III calcium carbonate impregnating a silty fine sand; PALEOSOL

14a-- Sand with fine gravel; moderately firm; EOLIAN

15-- Sand and gravel; some areas stratified, others not; calcified; ALLUVIUM

16-- Gravel, stratified, loose; dips 7W; ALLUVIUM

17-- Sand, massive; carbonate filaments; relatively soft (knife sinks in); EOLIAN

18-- sand and gravel; poorly sorted; unstratified; relatively hard; calcified; ALLUVIUM

19-- Duff; loose, many roots; DISTURBED MATERIAL

APPENDIX 3: Descriptions of Soils in the Sandia fault trench

Soil SF1
A/C. 0-6 cm A thin veneer of sand with some fine alluvial gravels, structureless, slightly sticky, slightly plastic, sandy loam.

Ak . 6-16 cm. Sandy loam, moderately developed medium sub angular blocky structure, slightly sticky, slightly plastic. Disseminated calcium carbonate

2Bk1. 16-26 cm. Sandy loam with fine gruss. Moderately developed fine angular blocky structure, slightly sticky, slightly plastic. Stage II calcium carbonate nodules.

2Bk2. 26-42 cm. Silt loam, massive, slightly sticky, slightly plastic, Stage I disseminated calcium carbonate.

2Bk3. 42-64 cm. Silt Loam, massive, slightly sticky, slightly plastic, Stage II calcium carbonate disseminated.

2Ck1 64-129 cm Loam with gruss gravels, massive, slightly, sticky, slightly plastic, slight calcium carbonate reaction

2 Ck2 29-164 cm. Gravelly sandy loam, massive, slightly sticky, slightly plastic, slight calcium carbonate reaction.

Soil SF 2 (A buried soil found under SF 1)
3Bk1 0-10 cm. Gravelly sandy loam, massive, slightly sticky, slightly plastic, slight calcium carbonate reaction.

3Bk2. 10-20 cm. Gravelly loam, massive, slightly sticky, slightly plastic, slight calcium carbonate reaction.

3Ck1 20-50 cm. Gravelly loam, massive, slightly sticky, slightly plastic, moderate calcium carbonate reaction. Stage I

Soil SF3
Ak 1. 0-10 cm. Gravelly sandy loam, loose, structureless, slightly sticky, slightly plastic
Stage I disseminated Calcium carbonate.

Bk1 10-45 cm. Gravelly loam, moderately medium blocky structure, slightly sticky, slightly plastic, Stage I nodules calcium carbonate.

Bk2 45-85 cm. Gravelly loam, massive, slightly sticky, slightly plastic, disseminated calcium carbonate.

Ck1 85-129 cm. Gravelly sandy loam, massive, non sticky, non plastic, slight calcium carbonate reaction.

Ck2 129-158 cm. Gravelly loam, massive, non sticky, non plastic, slight calcium carbonate reaction