Tectonic Controls on Alluvial Fan Dissection in the El Paso Mountains

A Senior Project

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By

Michael Gaffney

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ABSTRACT:

The localized dissection of alluvial fans along the western El Paso Mountains is under question. A relatively minor, south dipping normal fault, previously unmentioned in scientific literature, cuts across Quaternary terraces and alluvial fans in the piedmont of the El Paso Mountains. The linear trend of footwall uplift and the pattern of stream incision into the footwall adjacent to the linear trend of footwall uplift reveal that fan dissection is a result of base level fall caused by ongoing tectonism along the El Paso fault system. The regional importance is discussed as the timing of faulting reveals relatively recent uplift of the El Paso Mountains, and a model of extensional strain partitioning is argued for to account for this uplift in the tectonically complex Garlock Fault Zone.

INTRODUCTION:

The study location is in Red Rock Canyon State Park, which is close to the boundary between the Sierra Nevada mountain range and the Mojave Desert (Fig. 1). The precise study area is in the southern part of Red Rock Canyon State Park along the mountain front of the El Paso Mountains (Fig. 2). The focus is on the western extent of the El Paso Mountains because the alluvial fans are more dissected here than they are along the rest of the range (Fig. 3).

Regional Tectonics:

The El Paso Mountains are located at the intersection of the Sierra Nevada mountain range, the Basin and Range Province, and the Garlock fault (Fig. 2). The El Paso Mountains western boundary is the Sierra Nevada Fault Zone (Dibblee, 2008). The El Paso Mountains are bounded to the south by the El Paso Fault, which appears to be a dip-slip splay of the Garlock fault with minimal to no sinistral slip (Loomis and Burbank, 1988). The El Paso fault system trends roughly 065°. The northern branch of the Garlock fault system is roughly 2.5 km south of the El Paso fault at the location of the study area and trends roughly 060° in this area (Dibblee, 2008). The Garlock fault is an intracontinental transform fault system along which 48 to 64 km of sinistral slip displacement have occurred (Davis and Burchfiel, 1973). The Garlock fault separates the Mojave Block to the south from the predominantly east-west extension of the Basin and Range Province to the north where the study area lies (Loomis and Burbank, 1988).

The El Paso Mountains trend northeast and are discordant to the majority of north-south trending mountain ranges in the Basin and Range Province. The El Paso fault developed to accommodate dextral offset of the Blackwater fault and regional clockwise oroclinal bending after 3.8 Ma when the Garlock fault became a wide, multi-stranded fault zone (Andrew et al., 2014). The entire Garlock Fault Zone is still active, however, rates of slip for the El Paso fault are not discussed in existing literature (for example, Andrew et al., 2014, and references therein). The El Paso fault system is a solely dip-slip fault, and it is possible that it accommodates strain divergence associated with the Garlock fault system. Such strain partitioning along major transform faults has been previously documented (Lettis and Hanson, 1990; Page et al., 1998). A previously unmapped normal fault just south of the El Paso fault cuts through the Quaternary alluvial fans of the El Paso Mountains (Fig. 4). This fault is herein named the Redrock fault. Whether the Redrock fault relates to the localized alluvial fan dissection is under question because localized stream incision into fans can indicate relatively recent faulting.

Models for Incision on Alluvial Fans:

Without any disturbance to a drainage system, a fan-feeder stream will downcut uniformly and the locus of deposition will uniformly shift downfan (Bull, 1977). While this scenario is possible, it is uncommon in nature. More common in nature is alluvial fan dissection as a function of base level fall either because of climatic shift or tectonics (Harvey, 2002). Tectonism can influence the gradient or base-level of a fan via offset along faults or regional uplift (Harvey, 2002). Tectonic base-level change will temporally be independent of climatic change, and can have spatial variability if the rate of propagation of tectonically induced regional dissection fluctuates (Harvey, 2002). Climatic factors influence sediment supply and discharge thereby influencing critical stream power and the threshold of degradation versus aggradation on fans (Bull, 1977; Bull, 1979; Harvey, 2002). Climatic influence on base level can occur as a result of two mechanisms for an inland fan: 1) change in the level of a lake at the toe of the fan; 2) climatically induced incision of a main river causing base level change for tributary-junction alluvial fans. Additionally, changes in sediment supply can occur concurrently with changes in base level (Harvey, 2002).

METHODS

Geomorphologic observation and surficial field mapping were utilized to complete the research project. Observation of the geomorphology of stream terraces and surface features on the alluvial fans was critical in understanding the Redrock fault structure as there is only one outcrop on the mountain front where map units are offset by faulting (Fig. 4). The morphology of soil calcic horizons were assessed using the model of Machette (1985). The stage of calcic soil development was used to estimate the age of mapped alluvium. This is possible because carbonate accumulates consistently depending on the climate (Machette, 1985). The climate most similar to Cantil that Machette utilized is Las Cruces, New Mexico; therefore, age estimates for carbonate deposits will be based on this warm, semiarid region (Machette, 1985).

The surficial field mapping helped determine the fan and terrace morphology and the geologic structure. Grain sizes of the alluvium were determined in the field with a grain size comparator. The heights of terraces were collected using a measuring tape where outcrops were accessible. The trend of the Redrock fault, as well as ridge lines and dips of bedding were measured using a Brunton compass.

RESULTS

Map Units:

The geology of the western El Paso Mountains consists of Tertiary wacke sandstone and the Quaternary alluvium that compose the piedmont of the range, and Cretaceous aphanitic granophyre intrusive bodies, Cretaceous foliated granite, Precambrian to Paleozoic quartzite conglomerate and hornfels, as well as Cretaceous hornblende diorite that compose the basement of the piedmont and the uplands of the range. These different bedrock compositions are relatively well intermixed, outcropping adjacent to one another at multiple locations in the western El Paso Mountains. Although the hornblende diorite only outcrops at one location roughly a kilometer east of the study site, there is a sufficient amount on the alluvial fan surfaces to infer a large presence somewhere in the range, possibly during past times.

The Tertiary wacke Sandstone, Tr, overlies the basement rocks and underlies the Quaternary alluvium across the alluvial fan surface. Tr is a lithified, massive, wacke sandstone with lighter and darker tan beds that dip 15° to 30° to the north and are interbedded with up to tens of centimeters thick, brown, relatively resistant wacke sandstone beds. All clasts are subangular to subrounded, but the more resistant sandstone has smaller and a lesser abundance of clasts. The surface of Tr is erosional with an unconformity between Tr and the terrace Qt-2.

Qt-1 is composed of uplifted relict alluvial fan sediments. Limited exposures of Qt-1 reveal moderately-well lithified, poorly sorted, matrix supported clasts in a coarse sand matrix. Qt-1 is an erosional remnant, so the height above the channel is unclear. A degraded stage 4 calcic horizon is locally developed in Qt-1 erosional remnants; therefore, it is estimated to be older than 3.5 to 0.75 million years old (Machette, 1985).

Qt-2 is composed of interfingering beds of planar laminated sand, massive sand with rare, matrix supported clasts, and beds composed predominantly of imbricated, matrix supported, medium gravel sized clasts in a sand matrix. There is an overall fining upward trend and clasts are poorly sorted with a highly variable composition ranging up to boulder sized. The base of Qt-2 is exposed on the footwall, but the terrace surface is smooth due to erosion. Therefore, a better example of its minimum thickness is on the headwall where the top of the terrace is roughly 30 meters above the active channel. Qt-2 is also estimated to be 3.5 and 0.75 million years old with a degraded stage 4 calcic horizon.

Qt-3 is a stream terrace composed of massive sand and gravel with discontinuous lenses of matrix supported clasts of variable size and composition. The terrace is predominantly 1.2 m thick; however, the thickness is variable from 0.69 to 1.83 m with the thickness generally increasing to the south due to burial by colluvium derived from the terrace riser separating Qt-2 and Qt-3. Qt-3 has stage one calcic horizon development; therefore the terrace is at most 10,000 years old. Finally, Qa is the active stream channel that is composed of sand and clasts that range from pebbles up to boulders which have a highly variable composition.

Structures:

The Redrock fault strikes 047° and dips 36°, and it cuts across the alluvial fans at the piedmont of the El Paso Mountains (Fig. 5). The Redrock fault is exposed in one outcrop and offsets Qt-2 at the outcrop, revealing a minimum offset of 5.5 m (Fig. 4). Along this outcrop, Tr is uplifted and exposed on the footwall and Qt-2 is down-dropped with no Tr exposed on the hanging wall. There is a zone of gouge and breccia up to 15 cm thick where there are angular clasts of up to 13 cm within the fault gouge that aligns with the 047° strike of the Redrock fault. This outcrop is where strike and dip measurements were recorded. Farther east, the trace of the fault is interpreted from the location of channels that are incised into the alluvial fan, and topographic features that align with the strike of the Redrock fault as measured at the aforementioned outcrop. The fault trace is absent with no topographic expression of the fault where it projects into the El Paso Mountains in the northeast part of the study area.

Topography

North of the fault trace the alluvial fans have varying degrees of dissection with gullies tens of meters deep into Tr, and south of the fault trace there are no gullies. The alluvial fans are undissected east of where the fault trace projects into the mountain front. The morphology and geologic composition of the alluvial fans is drastically different north of the fault trace compared to the south and east because in the southeast there is no incision and, Tr is unexposed.

The Redrock fault strikes 047° at the outcrop where it is well exposed (Fig. 4). The topographically highest parts of alluvial fans north of the fault trend 350° to 010°. These are discordant with the trend of topographic highs of the erosional remnants of uplifted Qt-1, which trend between 020° and 050°: uplifted mounds of Qt-1 trend roughly 040° and are aligned with the Redrock fault from the outcrop exposure. The western-most mapped Qt- 1 has a ridge line that trends 046°, and is discordant with adjacent, unincised, alluvial fan surfaces. Furthermore, the erosional remnants of uplifted Qt-1 have surfaces that project upfan slightly steeper into the sky with a slope of 18°, which is steeper than the surfaces of the adjacent fans that have a slope of 13°. There is a swale directly south of the 046° trending ridgeline. The swale is 12 m deep.

On Qt-2 adjacent to and northeast of Qa, there is a roughly 10-15 m deep depression directly above the fault scarp where the hanging wall is exposed in the outcrop (Fig. 4).

DISCUSSION

Possible Factors Causing Fan Incision

Climate Controls

Climatic influence on base level of an inland fan either occurs due to change in the level of a lake at the toe of the fan or climatically induced incision of a main river causing base level change for tributary-junction alluvial fans. There is a dry lake just south of Redrock Randsburg Road called Koehn Lake (Fig. 5). Historical fluctuation of lake levels can be ruled out as a factor causing fan incision because the fans are unincised south of the study area to the edge of the dry Koehn Lake (Fig. 5). Furthermore, the climatic effect on tributary-junction alluvial fans due to incision of a main river can be dismissed because no other fans east of the Redrock fault throughout the El Paso Mountains are dissected.

Tectonic Base Level Fall

In the context of the strike of the Redrock fault, the topographic lineaments formed in alluvial fans (Qt-1), and the topography of Qt-2 terraces reflect tectonism. The eastern Qt-2 has a depression with at least ten meters of vertical offset directly above the fault exposure (Fig. 4). The Qt-2 to the west has a planar surface, but the slope of the terrace surface increases exactly where the fault projects southwestward from the exposure in Figure 4 (Fig. 5). Combined with the incision that is unique to the north of the fault as well as the western mountain front, it is concluded that the fan incision is due to active tectonism. The fault is contributing to mountain uplift, so base level is falling relative to the mountain and the incision north of the fault is the response. It is expected that in the case of a single fault on a mountain front, the effects would be primarily on the proximal fan area instead of triggering incision in the distal zone (Harvey, 2002).

Implications for Regional Tectonics

Based on the ages of Qt-1 and Qt-2, the most recent faulting across the alluvial fans and uplift of Qt-1 occurred between 3.5 ma and 10 ka. This is consistent with the model proposing that the El Paso fault formed 3.8 ma (Loomis and Burbank, 1988). The Redrock fault and the El Paso fault sustain the extensional uplift of the El Paso Mountains. It is possible that both the Redrock fault and the El Paso fault reflect strain partitioning from extension oblique to the Garlock fault. Therefore, some degree of vertical offset caused by oblique divergence along the Basin and Range – Mojave Desert Block contact is accounted for with these normal fault systems that have uplifted the El Paso Mountains block. This explains the discordance of the El Paso Range with other mountains that are part of the Basin and Range Province.

CONCLUSION

The normal-slip El Paso fault and the associated El Paso Mountains formed as and along a strand of the Garlock fault due to the formation of the Garlock Fault Zone starting at 3.8 ma (Andrew et al., 2014). Deposition of Tr and Quaternary map units were a result of the uplift of the El Paso Mountains. The Redrock fault is a normal fault that cuts across the piedmont of the El Paso Mountains. Offset fan alluvium indicates a minimum offset of 5.5 m of normal slip from the Redrock fault between 3.5 ma and 10 ka. Based on age estimates from observations of carbonates in terraces, the Redrock fault has not been active during the last 10 ky. The isolated dissection of the alluvial fans is a result of the Redrock fault continuing uplift of the mountain front and dropping the relative base level. The most compelling evidence supporting this conclusion is incision into Tr only north of the fault that extends from a streambank exposure of the fault to where the fault disappears into the El Paso Mountains. The tectonics of the El Paso Mountains is not well documented in existing literature; however, a possible model for the El Paso fault and Redrock fault is that they accommodate strain partitioning resulting from oblique divergence across the Garlock Fault Zone.

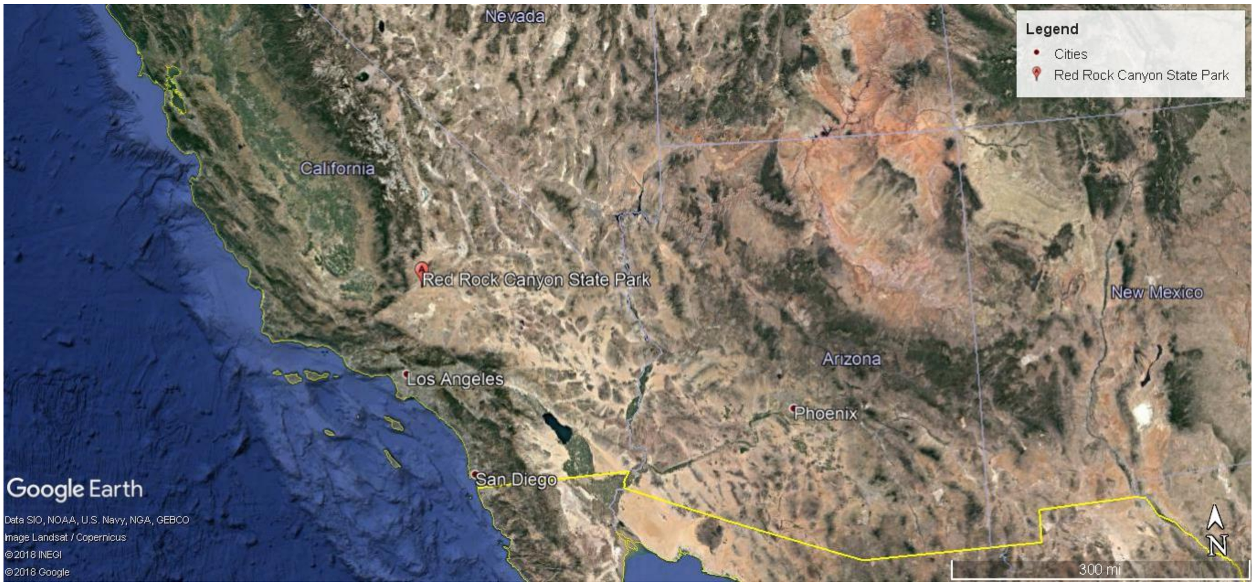

Figure 1: Location of Red Rock Canyon State Park. Imagery sourced from Google Earth.

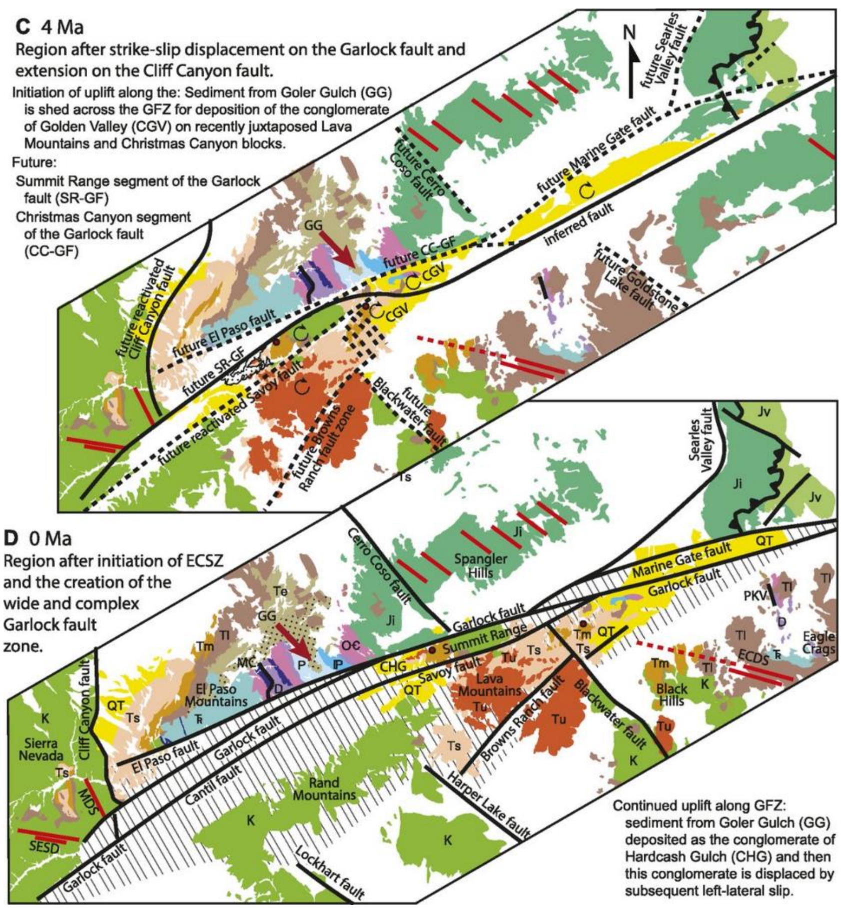

Figure 2: Interpreted time-slice maps with thick black lines denoting faults active before the time-slice and black dashed lines are active after. The diagonal hatching denotes the wide active Garlock Fault Zone. The red-filled dots are the locations of megacrystic dacite lava domes in the Summit Range and Lava Mountains. Blocks with known rotations are shown with a curved arrow in C. Image sourced from Andrew et. al (2014), fig. 13.

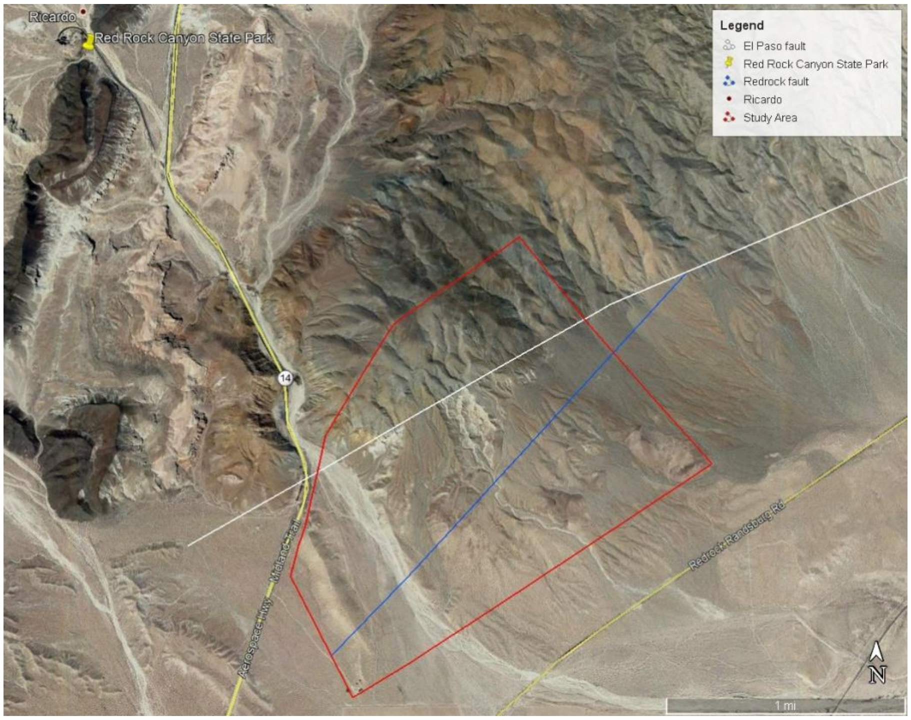

Figure 3: Map of the study area within Red Rock Canyon State Park. Alluvial fan dissection reveals tan sandstone (Tr of Dibblee, 2008) that is noticeably absent from the eastern part of the piedmont. Imagery sourced from Google Earth.

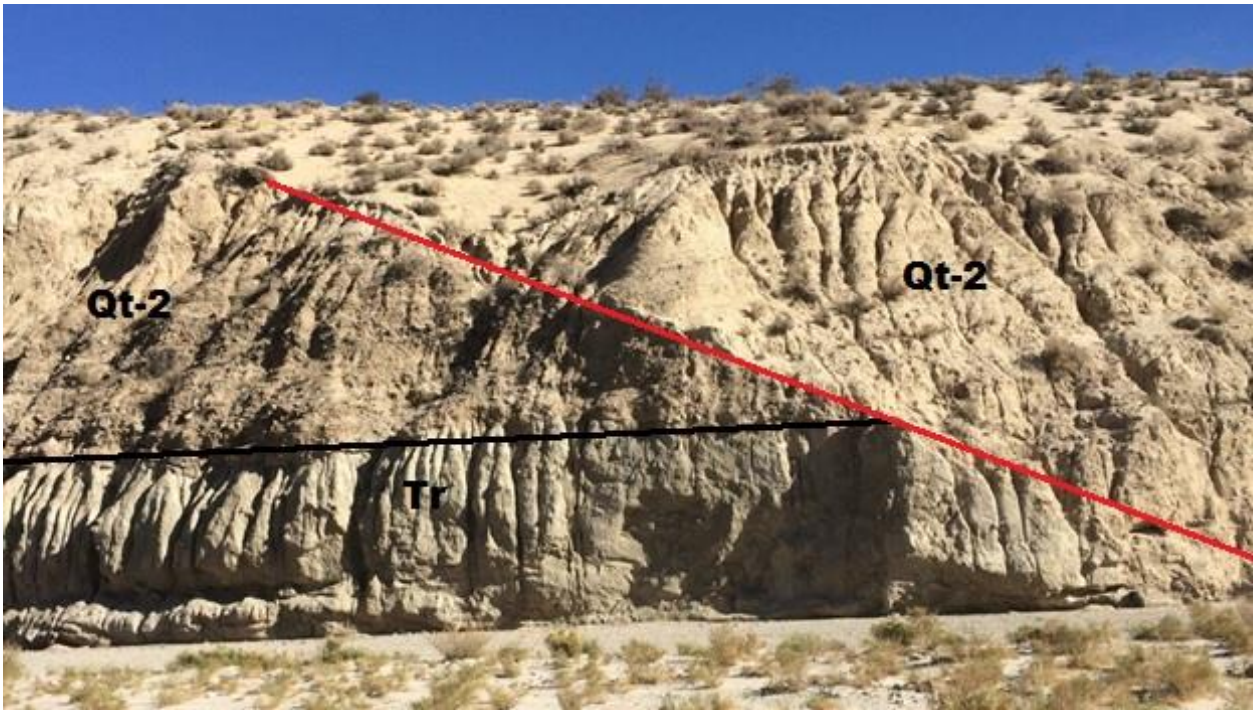

Figure 4: Image of the normal-slip Redrock fault uplifting Tr relative to Qt-2. Small black backpack for scale just left of where the fault disappears into Qa. Fault trace is denoted in red, and the contact between Tr and Qt-2 is denoted approximately in black.

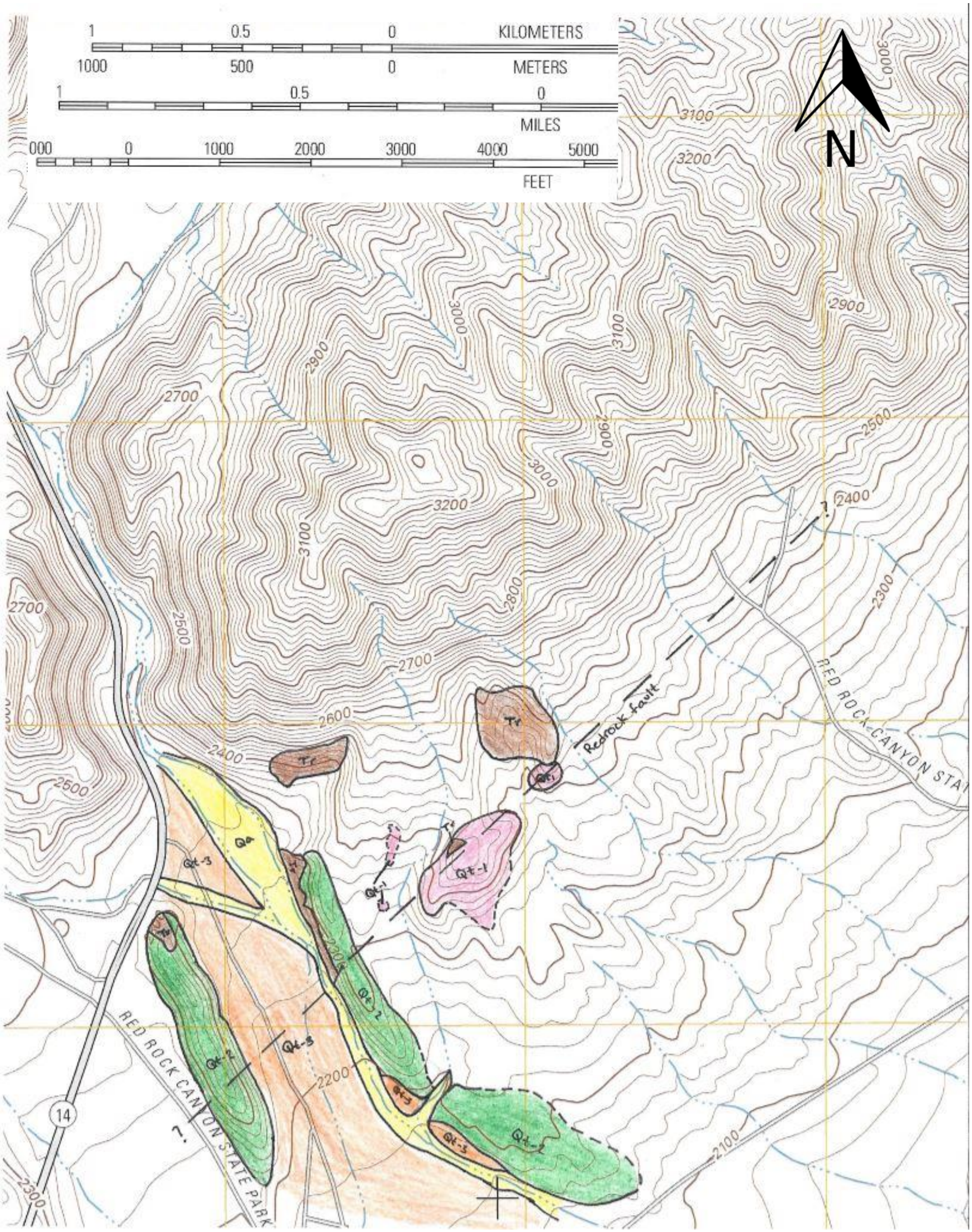

Figure 5: Surficial geology field map. Map legend is below on page 17.

MAP LEGEND

(yellow)	Qa	Active stream channel.
(orange)	Qt-3	Terrace composed of weakly consolidated sand with discontinuous lenses of matrix supported clasts.
(green)	Qt-2	Terrace composed of interfingering beds of laminated sands, massive sands with less abundant clasts, and imbricated clasts in a sand matrix
(red)	Qt-1	Relict fan surface composed of moderately well lithified , poorly sorted, matrix supported gravel clasts in a coarse sand matrix.
(brown)	Tr	Massive, pebbly wacke sandstone composed of light and dark tan strata interbedded with thin, brown resistant wacke sandstone strata.
– – – –	Redrock fault	The fault trace is dashed because the exact location is assumed except for the exposure adjacent to Qa where strike and dip were recorded.

APPENDIX

Tr, Tertiary Ricardo Formation: Lithified, massive, pebbly wacke sandstone composed of light and dark tan strata interbedded with brown resistant wacke sandstone strata. Both the light and dark strata have a mud matrix. However, the light tan strata have less of this mud matrix, and that is the only distinction between the light tan and dark tan beds. Both are composed of matrix supported clasts that range up to -8 phi, but clasts are predominantly -5 phi. Clasts are angular to subrounded, and the clast composition is primarily granitic. The light and dark tan beds are predominantly composed of 2.0 phi sand, and dip 15° to 30° to the north. The light and dark tan sandstone is weathered and rills are developed over the entire surface of the outcrop. The light and dark tan sandstone beds are predominantly a meter thick. The brown resistant pebbly wacke sandstone beds are only tens of centimeters thick, they protrude a few centimeter out of the outcrop relative to the light and dark, less resistant beds. There are no rills on the brown resistant pebbly wacke sandstone beds. This more resistant sandstone has a lower abundance of clasts. The median diameters of the clasts only are as large as -5 phi, but are predominantly -3 phi. This brown pebbly sandstone is moderately well sorted with grains ranging from -1 phi to 2.5 phi, but are predominantly 0.0 phi. The contact between Tr and Qt-2 is wavy with tens of meters of relief. This is displayed along the Qa cut stream bank. The faulted Tr exposed along the largest channel in the study area varies in thickness from roughly 6 to 12 meters. *Tr is unconformably overlain by Qt-2*

Qt-1, Quaternary terrace 1 (oldest): Qt-1 composes a relict fan surface and sediment underlying that surface that is moderately-well lithified, poorly sorted, matrix supported gravel clasts in a coarse sand matrix. The sand matrix is poorly sorted with grains ranging from 1.0 to 4.0 phi, angular to subangular sand. The clasts composition is predominantly hornblende-bearing diorite, which only appears as float west of the fault as the closest outcrop is roughly two kilometers northeast of the study area. Qt-1 is also composed of gravel clasts with granitic and tuff compositions. The clasts are poorly sorted and subangular. The clasts range from -2 to -6 phi, but are predominantly -5 phi. A stage four degraded petrocalcic horizon is present near the surfaces of Qt-1 alluvium. Outcrops that have well developed petrocalcic soils are rare, but one outcrop reveals a 125 cm thick calcium carbonate cemented, predominantly coarse sand and angular gravel clast conglomerate. Uplifted mounds of Qt-1 trend roughly 040° and are aligned with the projection of the Redrock fault (trending 047°) from where it is well exposed along the largest drainage in the study area to the El Paso Range beyond the piedmont. The individual ridge-like mounds are elongate and trend between 020° and 050°.

Qt-2, Quaternary terrace 2: Interfingering beds of planar laminated sand, massive sand with rare, matrix supported clasts, and beds composed predominantly of imbricated clasts in a sand matrix. There is an overall fining upward throughout Qt-2. There are petrocalcic lenses of up to 5 m in length and 0.15 m thick and dispersed throughout adjacent fractures. Clasts inset on the surface of Qt-2 are coated in calcium carbonate and there are surface clasts of purely laminated calcium carbonate. Clasts are poorly sorted ranging up to boulders, but are predominantly -4 phi. Clasts are subangular to subrounded and compositions are highly variable: schist, slate, tuff, vesicular basalt, and granitic clasts. The sands are angular to subrounded and poorly sorted ranging from -1.0 phi to 3.0 phi, but are predominantly 2.0 phi. It also has a stage four degraded petrocalcic horizon. The surface at this unit is 30 meters above the adjacent, active channel.

Qt-3, Quaternary terrace 3 (youngest): Qt-3 consists of massive, weakly consolidated sand with discontinuous lenses of matrix supported gravel clasts. Clasts are poorly sorted ranging in median diameter up to 8 phi, but the typical clast size is -3 phi. Clasts are angular to subangular.

The sand is poorly sorted and ranges from -1.0 phi to 3.0 phi, but is predominantly 1.5 phi. There is calcium carbonate accumulation in cracks, and in thin discontinuous lenses that are laterally up to a meter and only .10-.20 m thick. A stage one calcic soil is formed in Qt-3 surfaces. The terrace thickness is variable but increases to the south. Terrace heights above the adjacent channel vary from 0.69 m to 1.83 m. The increase to the south is predominantly a function of erosion from the adjacent Qt-2.

Qa: Active stream channel. The streambed is predominantly sand and gravel clasts that have median diameters ranging up to boulders.

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