Final Technical Report

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Award Title: Late Quaternary Evolution of the East-Central San Gabriel Mountains Frontal Fault System

Author and Affiliation:
Dr. Jonathan A. Nourse, Professor and Chair
Department of Geological Sciences
3801 W. Temple Avenue
California State Polytechnic University
Pomona, CA 91768
e-mail: janourse@csupomona.edu
Telephone: (909) 869-3460

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Abstract

Alluvial deposits and debris flows preserved between modern-day San Dimas and San Antonio drainages record progressive uplift and exposure of distinct crystalline bedrock units that accompanied southward migration of the east-central San Gabriel Mountains frontal fault system during Late Quaternary time. Our mapping and geochronology study, initiated after wildfires of 2003, focused on Quaternary gravels presently stranded on the hanging wall of the active, north-dipping Sierra Madre thrust. These gravels are spatially restricted to the Potato Mountain Block, which is separated from precipitous Sunset Ridge by the north-dipping Evey Canyon thrust.

Two major units are recognized from stratigraphic field relationships and consistent provenance signals preserved in pebbles and cobbles. The older unit is subdivided into three geographic domains: eastern and western fluvial terraces associated with San Antonio and San Dimas drainages, and a central expanse of alluvial fans exposed over the intervening area. The terraces preserve basal nonconformities elevated 10-50 m above the modern stream channels. Clasts are derived predominantly from Sunset Ridge, with a minor proportion eroded from more northerly, upstream bedrock sources that include Pelona schist and Proterozoic augen gneiss. The older alluvial fans, composed almost entirely of Sunset Ridge clasts, are elevated as much as 80 m above base level. The younger unit consists of red debris flows derived principally from iron-rich Potato Mountain bedrock sources. It overlies a paleosol developed at the top of the older unit.

Observed provenance relationships are consistent with progressive transfer of slip from the Evey Canyon thrust to the Sierra Madre thrust. Early displacement on the Evey thrust (recorded by clasts derived from Sunset Ridge) was succeeded by activation of the Sierra Madre thrust (and the emergence and erosion of Potato Mountain).

Results are pending from samples of both units collected for cosmogenic dating. These ages will help constrain the Late Quaternary uplift rate related to slip on the Sierra Madre thrust and the sinistral-reverse San Antonio-San Jose Fault system that intersects the frontal fault. In a future project, we plan to conduct gravity and seismic refraction surveys seek to precisely locate the traces of these active faults that are obscured by Holocene alluvial fan deposits.

Report Narrative

Introduction

I worked intensively with student assistants Jeffrey Pepin and Audra Hanks to unravel the late Quaternary uplift history of the east-central San Gabriel Mountains through study of a sequence of gravels exposed in the hanging wall of the Sierra Madre thrust (Figures 1 and 2). We mapped these gravels and nearby bedrock exposures in likely source regions, conducted pebble counts and provenance analyses, and interpreted stratigraphic relationships in terms of an unroofing model. Midway through the study we hosted Dr. Lewis Owen and graduate research assistant Kate Hedrick on a field excursion to collect appropriate samples for OSL and ^{10}Be-^{26}Al cosmogenic dating. Eleven geochronology samples were prepped in the laboratory and then sent to Owen's lab for further processing.

Meanwhile, my students and I made a series of four presentations (three posters and one talk) at professional conferences. These presentations are cited in the Bibliography; the Appendices include PDF documents of two posters. My students gained much from this research experience. Jeff Pepin will be attending graduate school at New Mexico Institute of Mining and Technology next fall. Audra Hanks has one of the highest GPAs our 68 Geology majors. She is compiling a digital GIS data base of this project for her senior thesis, to be presented next June prior to graduation.

Below is a regional fault map showing location of the study area in relation to major Quaternary faults of interest to the southern California Earthquake Hazards academic community:

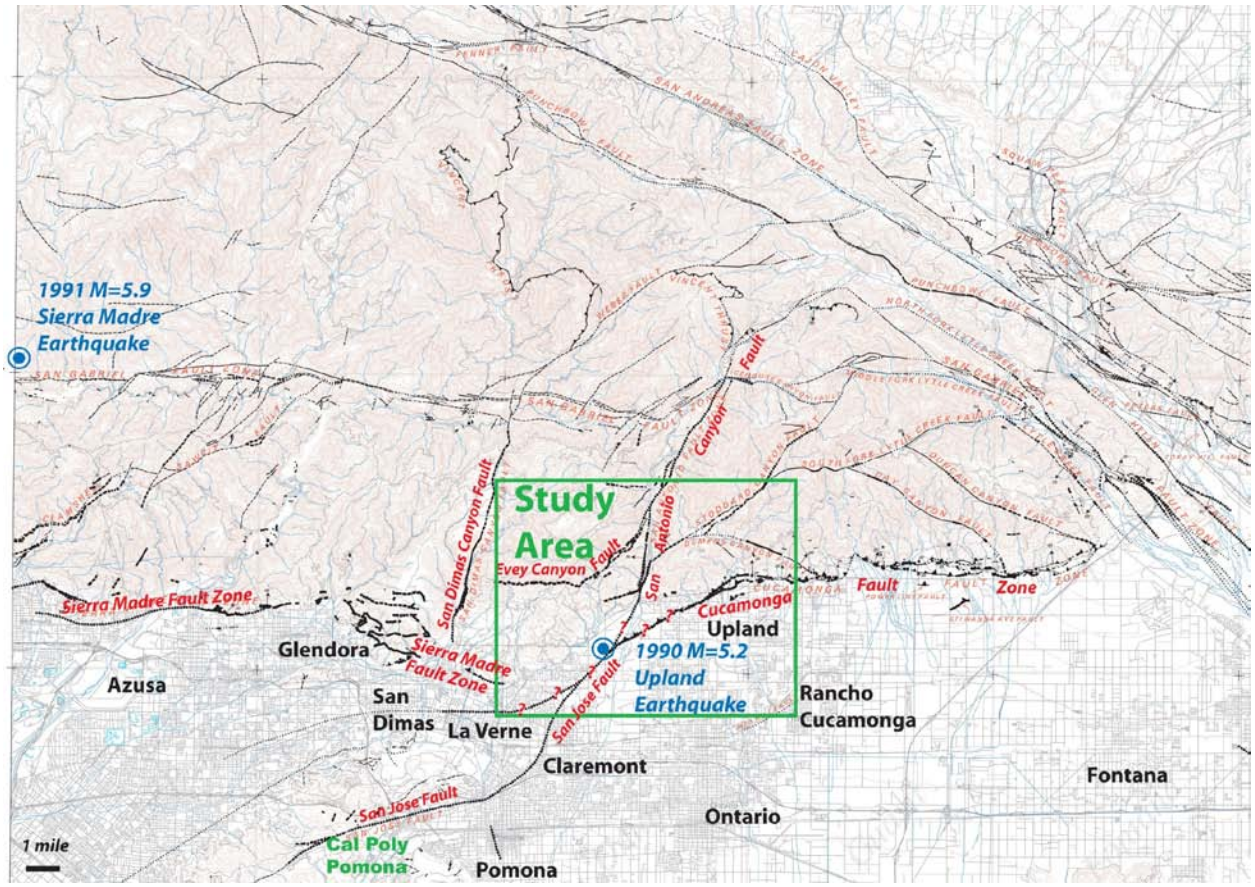


Figure 1. Fault map of the east-central San Gabriel Mountains (modified from Morton and Miller (2003), showing location of the study area relative to recent earthquake epicenters and cities. Faults discussed in proposal are labeled with bold red text.

Geological Mapping Endeavors

We mapped most of the Potato Mountain Block and the south portion of the Sunset Ridge Block (Figure 2) at a scale of 1:12,000 during winter, spring and summer of 2012. During this time we also collected the bedrock and pebble samples described in the next section of this report. From field and map relationships we were able to distinguish two older Quaternary units of presumed late Pleistocene age. Map unit Qft on Figures 2 and 3 represents the prominent fluvial terraces exposed in cuts of the Mt. Baldy Road. Map unit Qaf represents an old exhumed alluvial fan surface exposed on the Potato Mountain block directly south of the westerly-trending segment of the Evey fault. This unit was accessed from fire roads in Claremont Wilderness Park. We mapped the boundaries of both Quaternary units and their nonconformable contacts with crystalline bedrock (see details Appendix 1).

We also mapped two colluvial units that stratigraphically overlie the older Quaternary units. The older of these deposits is a red debris flow unit, mapped as

Qrcv on Figure 3. This unit is composed almost entirely of clasts derived from the Potato Mountain Block, and owes its red color to oxidation of iron-rich phyllites and biotite gneisses that form proximal bedrock sources. A younger colluvial unit of likely late Holocene age is ubiquitously exposed on the west side of San Antonio Canyon. This unit is distinguished as Qcv in Appendix 1. Some of the colluvium is very young, deposited after the fires of 2003.

Also mapped during this period were details of the crystalline bedrock units exposed on Sunset Ridge. Access to this area was afforded by the Sunset Ridge fire road. The geologic map of Appendix 1 contains this important information. We recognized early on that bedrock exposures on Sunset Ridge probably represent an important component of the clasts observed in the older Quaternary gravel deposits.

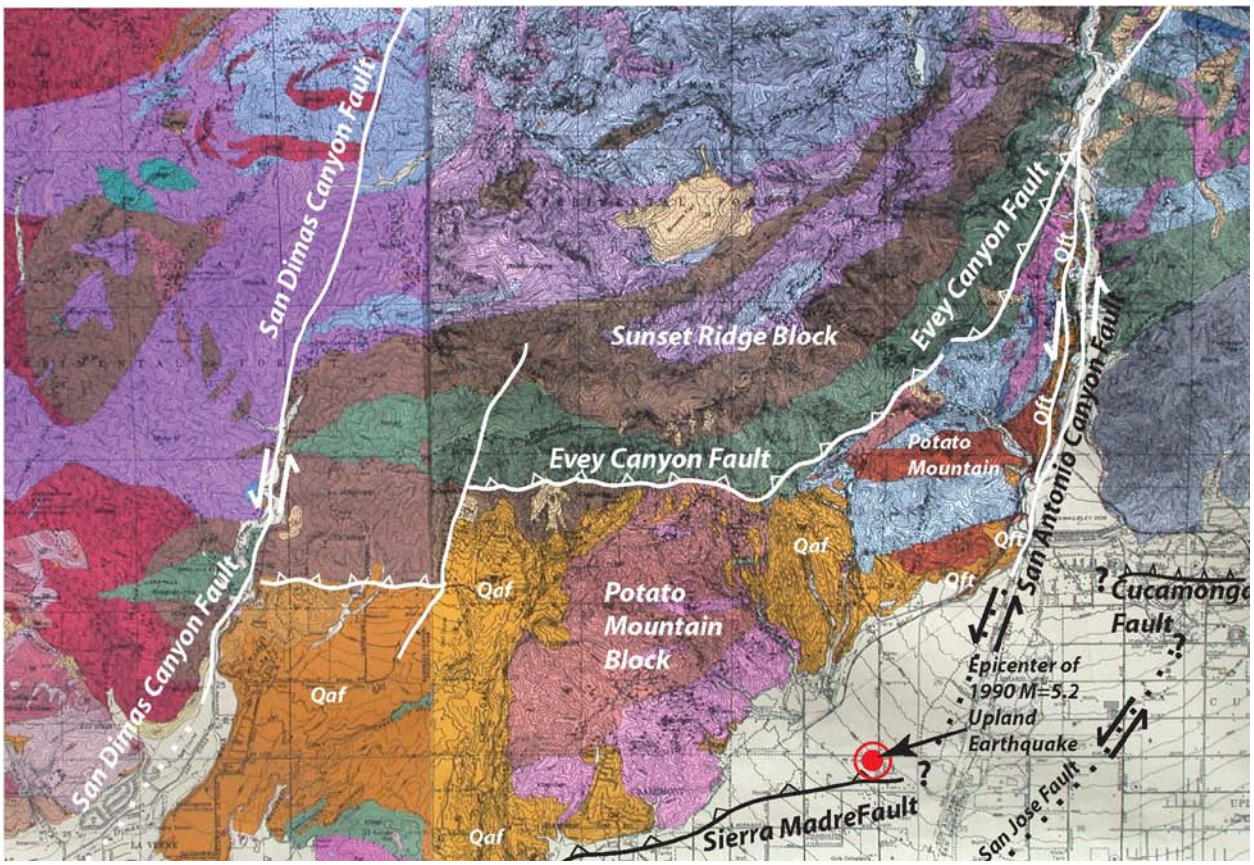


Figure 2. Geologic map of the southern Mt. Baldy quadrangle and southeastern Glendora quadrangle (modified from Nourse et al., 2002 and Nourse, 2002a, 2002b), showing key faults, Quaternary sediments, and crystalline bedrock in the study area. Quaternary units of the Potato Mountain block are colored light orange-yellow.

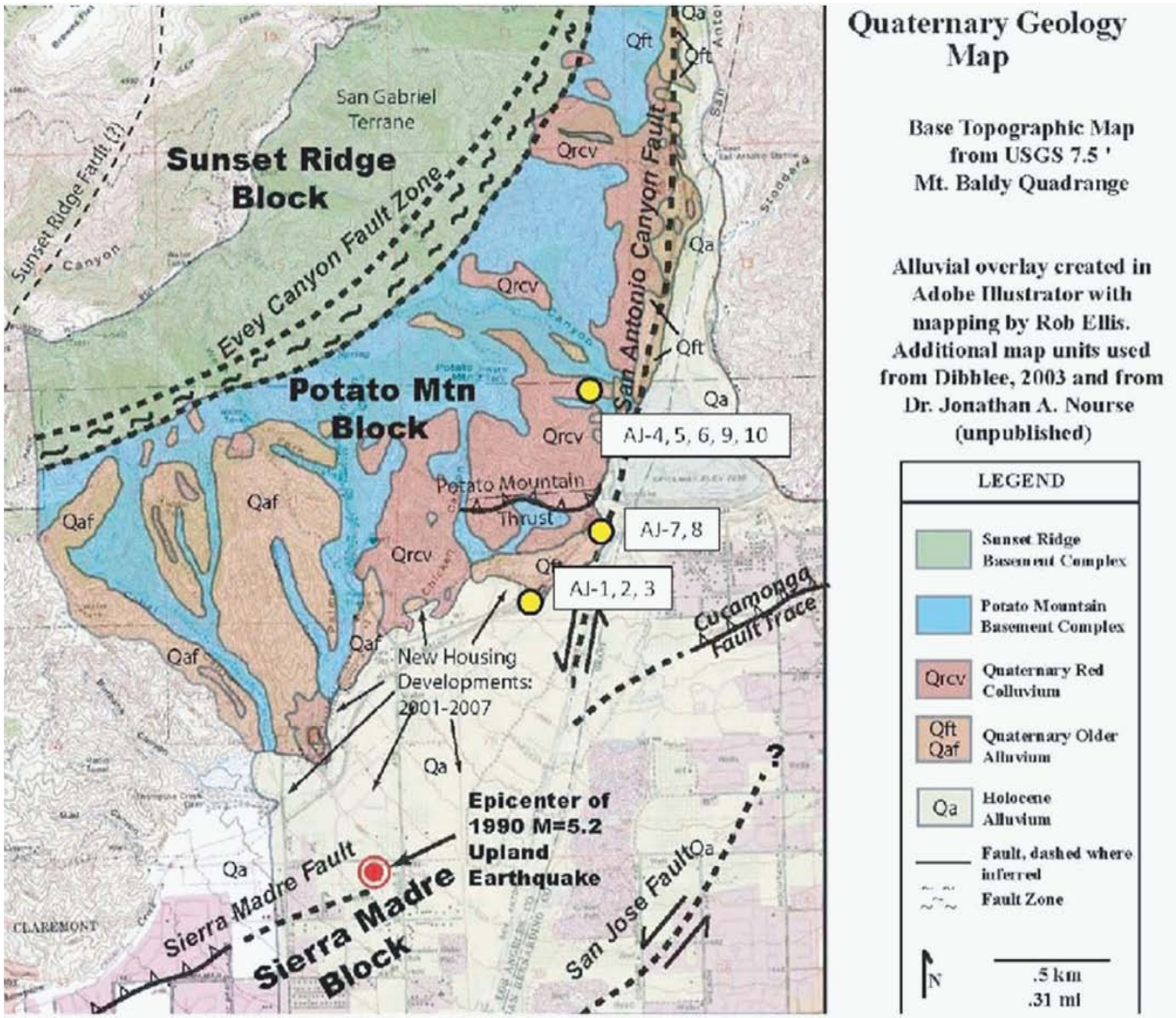
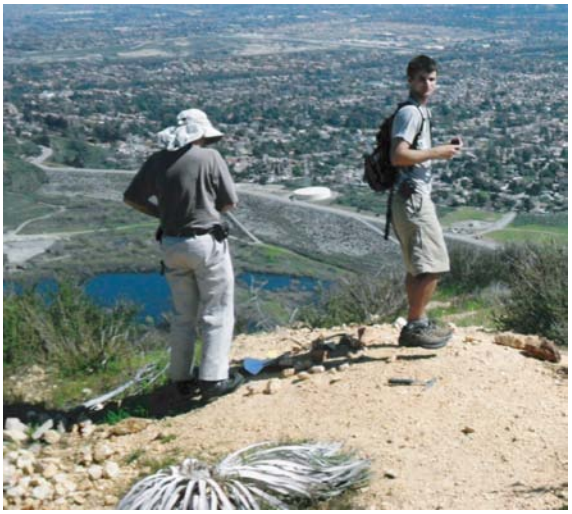


Figure 3. Quaternary geology map of the Potato Mountain block showing distribution of older Quaternary fluvial terraces and alluvial fans overlain by younger colluvium and debris flows (modified from Ellis, 2008). Yellow dots show locations of 10 pebble samples described in Figure 4.

The photographs below show Audra Hanks and Jeff Pepin standing in front of the red debris flow unit (Qrcv), and Jon Nourse and Jeff Pepin mapping on the summit of Potato Mountain with a view of San Antonio Dam to the southeast:



Bedrock and Pebble Sample Collection

In the course of geologic mapping, we collected 8 multi-bag samples of pebbles and cobbles from the three gravel sequences, plus 18 bedrock samples from the Potato Mountain Block and 77 bedrock samples from the Sunset Ridge Block. We also conducted boulder counts in the field from two areas of Evey Canyon: 1) a side drainage incised into the older gravel sequence, and 2) the modern Holocene drainage of Evey Creek. These samples comprise the main data base for provenance studies described in our published results (see Bibliography)

The photographs below show Jeff and Audra collecting crystalline bedrock samples and measuring foliation structure along the Sunset Ridge fire access road:

Laboratory Analyses

Pebble Counts

All samples were brought back to the Cal Poly Pomona Geology Department for laboratory analysis. Each individual pebble or cobble was washed and scrubbed so as to reveal as much mesoscopic composition and texture as possible. There were usually 100 to 200 clasts in a single pebble sample; only two samples had smaller populations of 33 and 45 pebbles.

The students began by studying the bedrock samples and dividing them into various lithotype categories. This was best accomplished in the bright sunlight as shown in the first photograph below. Descriptions of each bedrock sample were tabulated in Excel (Appendix 3). After their eyes were tuned to the many different possible bedrock sources, analysis of the pebble samples began. Each pebble was classified by lithology type and logged in a spread sheet (Appendix 4). Results are shown below in Figure 4 and discussed in more detail in Appendix 5.

Bedrock samples organized by lithology type:

Keeping track of all the samples:

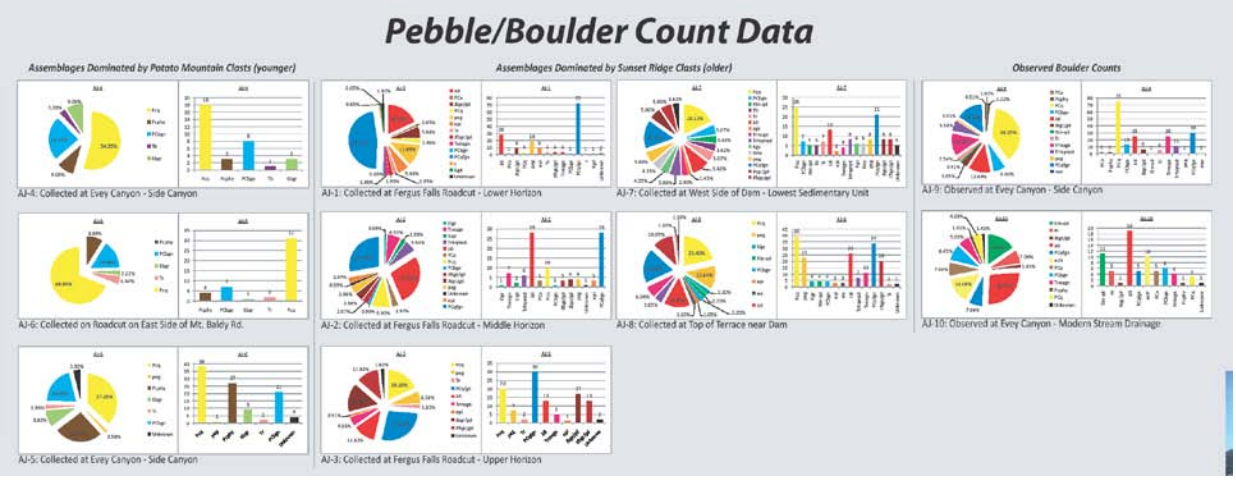


Figure 4. Results of pebble and boulder counts

Petrography

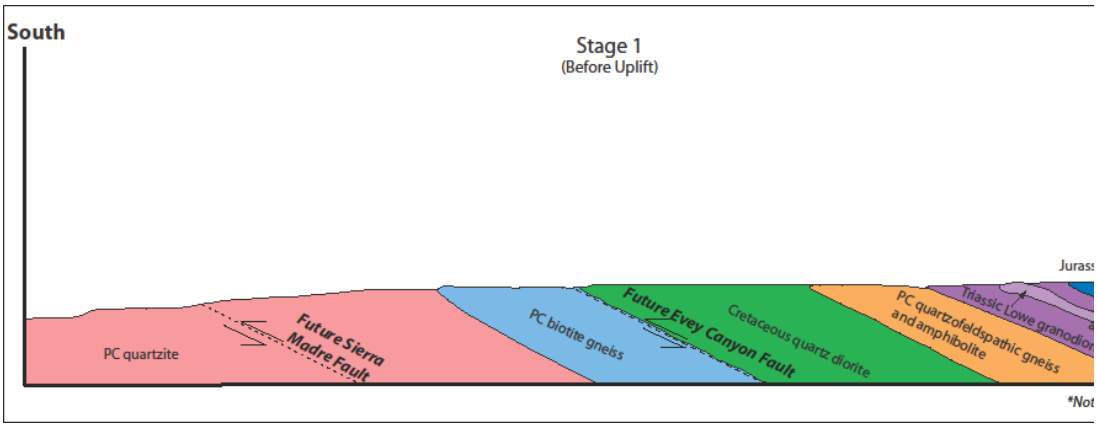
Forty two thin sections were cut from a carefully selected suite of pebbles collected from the older gravel sequences and representative bedrock exposures of the Sunset Ridge block. Audra and Jeff analyzed these sections under a petrographic microscope to test the degree of correspondence of mineralogy and texture. In general, petrographic characteristics of the selected pebbles matched those of the interpreted bedrock sources. The students were able to apply skills previously learned in our Optical Mineralogy class (GSC 325/L) to an interesting rock correlation problem.

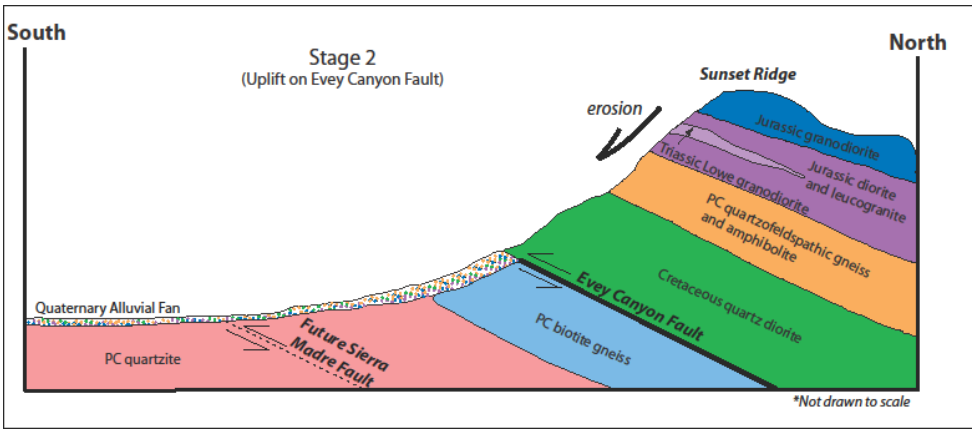
Analysis and Interpretation of Geologic Relationships

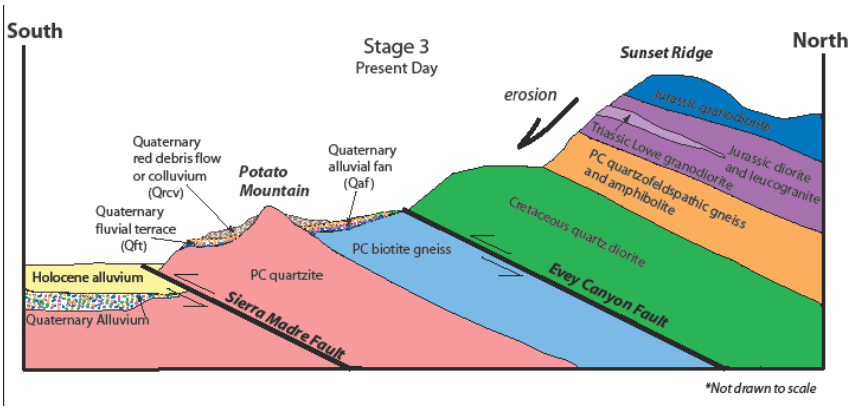
Two major units are recognized from stratigraphic field relationships and consistent provenance signals preserved in pebbles and cobbles. The older unit is subdivided into three geographic domains: eastern and western fluvial terraces associated with San Antonio and San Dimas drainages, and a central expanse of alluvial fans exposed over the intervening area. The terraces preserve basal nonconformities elevated 10-50 m above the modern stream channels. Clasts are derived predominantly from Sunset Ridge, with a minor proportion eroded from more northerly, upstream bedrock sources that include Pelona schist and Proterozoic augen gneiss. The older alluvial fans, composed almost entirely of Sunset Ridge clasts, are elevated as much as 80 m above base level. The younger unit consists

of red debris flows derived principally from iron-rich Potato Mountain bedrock sources. It overlies a paleosol developed at the top of the older unit.

Observed provenance relationships are consistent with progressive transfer of slip from the Evey Canyon thrust to the Sierra Madre thrust. Early displacement on the Evey thrust (recorded by clasts derived from Sunset Ridge) was succeeded by activation of the Sierra Madre thrust (and the emergence and erosion of Potato Mountain). This fault evolution, coincident with development of an unroofing sequence in the Quaternary gravels, is illustrated below:







Geochronology

Field Work and Geochron Sample Collecting

We hosted Dr. Lewis Owen and graduate research assistant Kate Hedrick of University of Cincinnati on a sample collecting endeavor in early November, 2010. The first day was spent scouting the study area for the best candidates for sampling. We expended the second day collecting these samples following protocols taught by Dr. Owen. Samples were selected so as to yield one age for the red debris-flow unit, one isochron age for the fluvial terrace unit, and one depth-profile age for the older alluvial fan surface.

One sample of sand from the red debris flow unit (Qrcv on Figure 3) was collected for Optically Stimulated Luminescence (OSL) dating (Aitken, 1998). This sample is reported as "Jon 1" below. The fluvial terraces exposed in Mt. Baldy road cuts yielded three sites appropriate for determining ^{10}Be-^{26}Al burial ages (Balco and Rovey, 2008). These samples are represented by Jon B1, B2 and B3. Last, after a protracted search we located a site on the exhumed alluvial fan south of the Evey fault (map unit Qaf of Figures 2 and 3) that was ideal for a ^{10}Be-^{26}Al depth profile experiment. We collected samples Jon DP 1 through 5 at this site.

All samples were oven-dried and sieved and weighed at the Cal Poly Pomona Geology Department laboratory. Weighed fractions were mailed to Kate Hedrick at the University of Cincinatti for further sample preparation.

The photograph below shows Lewis Owen collecting OSL sample Jon1 from a sand horizon near the top of the red debris flow unit (map unit Qrcv of Figure 3) exposed near the lower Mt. Baldy Road:

The next two photographs show one of the three burial age sample sites intended to date the exhumed fluvial terraces (Map unit Qft on Figures 2 and 3) exposed above San Antonio Creek along Mt. Baldy Road:

The next two photographs show the exhumed alluvial fan surface on the Potato Mountain block (map unit Qaf on Figures 2 and 3), and the depth profile sampled with Lewis Owen and Kate Hedrick:

Sieved Sample Weights: Jon Nourse Samples

Sample ID	UTM East	UTM North	<2mm >500µm (grams)	<500µm >250µm (grams)	<250µm (grams)
Jon B1	437719	3782898	147.88	140.79	488.59
Jon B2	437732	3781650	719.79	215.03	172.96
Jon B3	437636	3782503	435.91	197.91	179.64

Each of these samples also has a bag of pebbles that was not weighed

Sample ID			>2mm (grams)	<2mm >500µm (grams)	<500µm >250µm (grams)	<250µm (grams)
Jon DP1	*434224*	*3779311*	295.05	256.97	97.62	83.44
Jon DP2	*434224*	*3779311*	385.99	293.81	90.06	109.07
Jon DP3	*434224*	*3779311*	329.45	320.40	93.01	124.70
Jon DP4	*434224*	*3779311*	294.30	252.91	59.54	71.07
Jon DP5	*434224*	*3779311*	237.04	229.02	59.30	73.24
Jon AC1	*434410*	*3778879*	257.40	306.16	220.57	91.25

Jon DP1 contained an extra small bag that has not been sieved and weighs 305.22 grams (including the bag)
datum is NAD27 ConUS

OSL Sample	UTM East	UTM North
Jon 1	436685	3779085

OSL Results

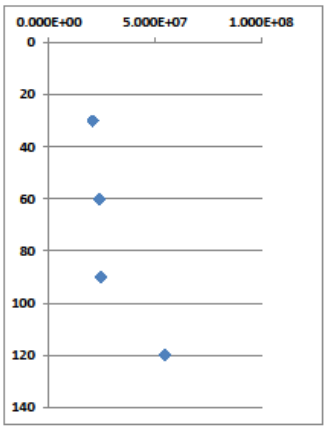
OSL dating is used to determine the time elapsed since a sediment sample was exposed to daylight (Aitken, 1998). The sand sample collected from the red debris flow unit (Qrdf on Figure 3) was analyzed with the OSL method. The results below demonstrate an age of 3.62 Ka ± 0.32 Ka, confirming that this unit was deposited during late Holocene time.

Sample Details			Dose Rate (Gy/ka)			Age(ka)		
	UTM Coords	Depth(cm)	U(ppm)	Th(ppm)	K%	Wt mean(Ka)	Mean(ka)	Mean_Std Err(ka)
JON1	436685E 3779085N	30	3 ± 0.3	14.6 ± 1.46	2.43 ± 0.122	3.012 ± 0.16	3.62 ± 1.2	3.62 ± 0.32

^{10}Be-^{26}Al Results

The burial and depth profile samples were analyzed in the PRIME Laboratory at Purdue University. The deepest depth profile sample (Jon DP5) did not yield enough quartz for analysis. At the time of this writing only the Be results have been returned from the lab. Due to a major backlog in sample processing at the PRIME lab, our Al analyses are still forthcoming. Be concentrations and ^{10}Be/^{9}Be ratios for 8 samples are reported below. The graph shows variation of ^{10}Be/^{9}Be with depth at the depth profile site in map unit Qaf.

Sample Number	Qz wt (g)	Be carrier wt (g)	10Be/ 9Be	error	# of Be-9 atoms	# of Be-10 atoms	error
JonB1	15.7308	0.3534	9.97E-15	6.09E-15	2.57332E+22	1.631E+07	*9.961E+06*
JonB2	15.0270	0.3563	9.87E-15	5.75E-15	2.59444E+22	1.705E+07	*9.920E+06*
JonB3	15.6672	0.3566	8.01E-15	5.07E-15	2.59662E+22	1.328E+07	*8.399E+06*
JonDP1	15.5510	0.3550	1.24E-14	4.67E-15	2.58497E+22	2.068E+07	*7.768E+06*
JonDP2	15.6804	0.3536	1.46E-14	4.23E-15	2.57478E+22	2.390E+07	*6.954E+06*
JonDP3	15.6125	0.3563	1.46E-14	4.11E-15	2.59444E+22	2.434E+07	*6.827E+06*
JonDP4	12.6459	0.3580	2.66E-14	5.06E-15	2.60682E+22	5.482E+07	*1.043E+07*
JonAC1	15.4771	0.3514	4.69E-14	7.66E-15	2.55876E+22	7.749E+07	*1.266E+07*



At this point we can say that the Be ratios are very low (about twice background levels). This means that there is not a lot of inherited Be in the sediment, which will result in a large uncertainty. Because Al ratios are typically 3-6 times that of Be, we should be able to determine ages as soon as we receive the Al data, albeit with somewhat large errors.

To calculate the burial age of the terrace gravels along Mt. Baldy Road (map unit Qft on Figures 2 and 3) we will apply the "Isochron method" of Balco and Rovey (2008). Figure 7 below (copied from their paper) gives an example of the method:

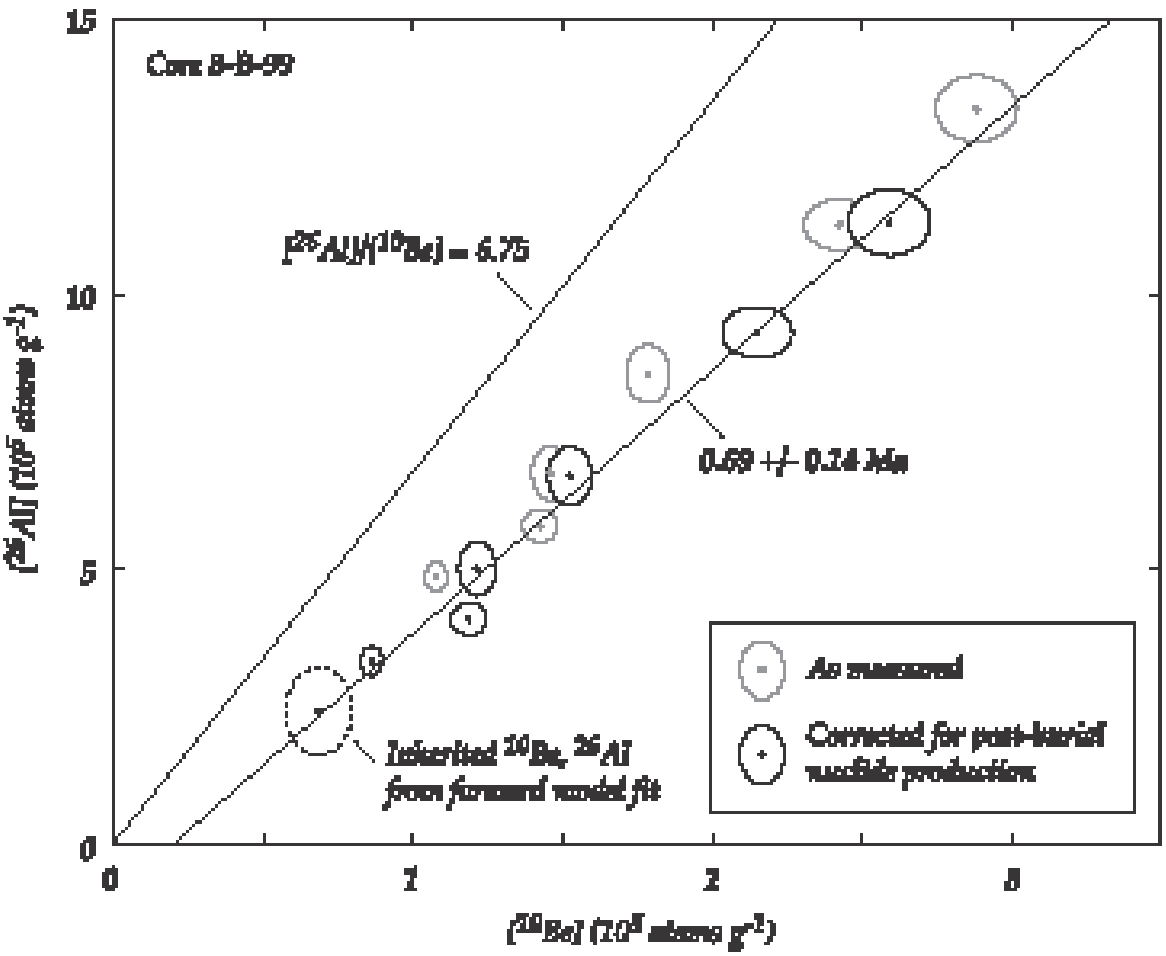


Fig. 7. Isochron method applied to the paleosol in borehole 3-B-99 in eastern Nebraska described in Balco and others (2005c). In this and subsequent figures, the light gray ellipses are 68% confidence ellipses for the raw ^{26}Al and ^{10}Be measurements on paleosol quartz. The black ellipses reflect correction of the measured data to remove nuclide production after burial, as described in the text. The dark line is the isochron that best fits the corrected data, from which we infer the burial age of the paleosol. The light line has a slope given by the production ratio $P_{26}(0)/P_{10}(0)$ for comparison. In this figure only, the dotted ellipse shows the inherited ^{26}Al and ^{10}Be concentrations calculated (independently of the isochron method) by forward model optimization in Balco and others (2005c). These lie on the isochron, indicating consistency between the two methods.

To calculate the age of the exhumed alluvial fan surface in Claremont Wilderness Park (map unit Qaf on Figures 2 and 3) we will apply the curve matching technique for depth profiling as described in Balco and Rovey (2008). Figure 4 below (copied from their paper) explains the concept:

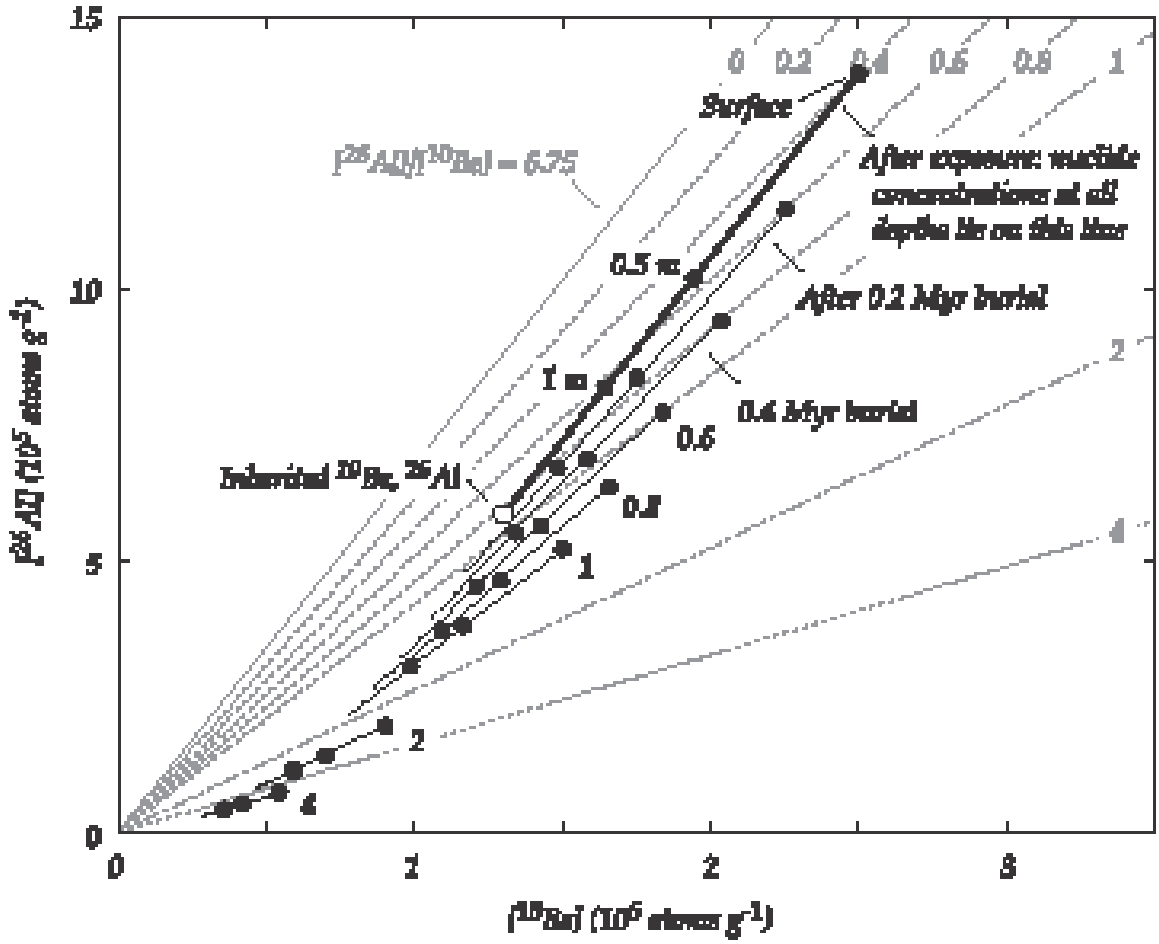


Fig. 4. The idea of a ^{26}Al-^{10}Be burial isochron. Quartz in a soil starts out with some arbitrary concentrations of inherited ^{26}Al and ^{10}Be (open circle). Nuclide concentrations increase during exposure and soil formation, to a greater extent at shallower depths. After a time, the nuclide concentrations in quartz at different depths will lie along a line whose slope is given by the production ratio (the uppermost dark line). During subsequent burial (at infinite depth in this example), all nuclide concentrations decrease, and the slope of the line connecting nuclide concentrations at different depths in the soil decreases (thinner dark lines). The slope of the line does not depend on the inherited nuclide concentrations, only on the duration of burial. The light lines in the background are contours of the simple burial age—that assumes zero inheritance—inferred from a single sample. Comparing these with the burial isochrons highlights the fact that, when inherited ^{26}Al and ^{10}Be have a low ^{26}Al/^{10}Be ratio, the simple burial age always overestimates the actual burial age.

Future Intentions

As soon as the ^{26}Al data comes back from the PRIME lab, the analyses will be coupled with the ^{10}Be data we have in hand already to calculate: 1) burial ages of the exhumed fluvial terrace along the Mt. Baldy Road (map

unit Qo1 of Appendix 1), and 2) a best-fit surface exposure age for the depth profile collected from the alluvial fan surface at the base of Sunset Ridge in Claremont Wilderness Park (map unit Qaf of Appendix 1). These results will provide the first ever ages for two prominent older gravel sequences exposed along the San Gabriel mountain front. The age data can then be used to constrain uplift rates of the Potato Mountain block, and estimate slip the rate of the Sierra Madre fault segment between San Antonio and San Dimas canyons.

Using newly acquired equipment at Cal Poly Pomona, we plan in the future to conduct gravity and seismic refraction surveys and micro-earthquake triangulation studies to precisely locate the traces of these active faults that are obscured by Holocene alluvial fan deposits. These faults include the Sierra Madre fault and southwest ends of the Stoddard Canyon, San Antonio Canyon and San Dimas Canyon faults

Bibliography

Publications Directly Related to Proposal Results

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Appendixes

Appendix 1: Geologic Map of Quaternary Sediments and Bedrock along the East-Central San Gabriel Mountain Front

Appendix 2: Explanation of Geologic Map

Appendix 3: Categorized Sample List (Bedrock and Pebble Samples)

Appendix 4: Pebble Counts September 30, 2010

Appendix 5: May 2011 GSA Poster; (a similar version was presented at southern California Academy of Sciences conference two weeks earlier; a preliminary version was presented at the November 2010 Southern California Council on Undergraduate Research conference)

Mapped, edited, and published by the Geological Survey
Revised in cooperation with California Department of Water Resources

Control by USGS, NOS/NOAA and Los Angeles County

Topography by photogrammetric methods from aerial photographs taken 1952 and planetable surveys 1933. Field checked 1954
Revised from aerial photographs taken 1966. Field checked 1967

Polyconic projection. 1927 North American Datum
10,000-foot grids based on California coordinate system, zones 7 and 5
1000-meter Universal Transverse Mercator grid ticks, zone 11, shown in blue

To place on the predicted North American Datum 1983 move the projection lines 2 meters north and 84 meters east as shown by dashed corner ticks

Red tint indicates areas in which only landmark buildings are shown

Certain land lines are omitted because of insufficient data

GN MN 0°23' 7 MILS 13½° 240 MILS

UTM GRID AND 1988 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

Areas covered by dashed light-blue pattern are subject to controlled inundation

There may be private inholdings within the boundaries of the National or State reservations shown on this map

Purple tint indicates areas of urban extensions

SCALE 1:24 000

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY
DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

South Mt. Baldy 7.5 Minute Quad: Explanation of Geologic Map Units

(descriptions by J. Nourse, 2011)

Rock and Soil Units

Qa Late Holocne alluvium, generally restricted to modern drainages. Unconsolidated, moderately sorted braided stream deposits composed of rounded boulders to medium sand.

Qt Holocene talus breccia and other angular colluvium, poorly consolidated and generally unvegetated.

Qcv Holocene or late Quaternary colluvial deposits, undifferentiated. Parts of this unit represent debris flows deposited after the wildfires of 2003.

Qo Older Quaternary alluvial terraces, with basal unconformities intermittently preserved as much as 100 m above modern-day San Antonio Creek. Gently inclined bedding with dip direction toward axis of moder San Antonio Canyon or down-canyon. Basal layers composed of rounded cobbles and boulders are typically overlain by finer alluvium. May interfinger with Qls deposits.

Qof Older Quaternary alluvial fan deposits and debris flows containing subangular to subrounded clasts of PCgn, TRqd-di, and Kqd derived from the steep mountain front north and northeast of the Evey fault. These deeply incised sediments rest upon bgn, Klbgr, and ms units in the hanging wall of the Sierra Madre thrust

Q_L; Qls Sizeable Quaternary landslide with anomalous vegetation and characteristic geomorphology. Poorly sorted angular debris flows or colluvial wedges, moderately consolidated, may be heavily vegetated.

Tr Tertiary rhyolite porphyry dikes and sills. Dacite and quartz latite varieties are less common. Distinguished by prominent subspherical quartz phenocrysts, with biotite composing the sparse mafic phase. Ar40/Ar39 analyses indicate a latest Oligocene age (P. Weigand, unpublished data). Geochemically identical (Nourse and others, 1998) to porphyritic biotite granite of Telegraph Peak, which yields latest Oligocene to Early Miocene ages (May and Walker, 1989 {U/Pb}; Miller and Morton, 1977 {K/Ar}; P. Weigand, unpublished data {Ar40/Ar39}). Most occurrences not shown at 1:24,000 scale to avoid clutter.

ORTHOGNEISSES OF ONTARIO RIDGE, GLENDORA RIDGE, AND MOUNT SAN ANTONIO:

JKp Late Cretaceous(?) or Late Jurassic(?) weakly to moderately foliated pegmatite, aplite, or leucocratic biotite granite dikes. Intrusive into Jurassic and older lithologies from San Gabriel Canyon to San Antonio Canyon. Most dikes not mappable at 1:24,000 scale.

Kgr, Klbgr, Klgr Late Cretaceous fine to medium grained leucocratic biotite granite, weakly foliated. Intrudes as small stocks, dikes and sills into Ktn, bbmy, and ms units on Ontario Ridge (May and Walker, 1989) and west of Lower San Antonio Canyon. May be the source of pegmatite unit described above.

Kbbmy Late Cretaceous "black belt" mylonite exposed east of lower San Antonio Canyon (Hsui, 1961; May, 1986; May and Walker,1989). Protoliths include cg, ms, m, q, bgn, and Ktn. This north-dipping shear zone separates footwall cg from hanging wall Ktn and ms.

Ktn, Kqd, Kgd Late Cretaceous(?) medium grained, porphyritic hornblende-biotite tonalite or quartz diorite or porphyritic hornblende-biotite granodiorite, moderately to weakly foliated. Occurs on Mt. San Antonio, Ontario Ridge , and Glendora Ridge. Sample from Stoddard Road dated at ca. 80 Ma ({U/Pb}; May and Walker, 1989). Porphyritic granodiorite on south wall of Icehouse Canyon contains K-feldspar

phenocrysts up to 4cm long. Regionally extensive quartz diorite sill defines synform underlying Sunset Ridge and Glendora Ridge. Kqd exposed north of the San Gabriel fault on the south face of Mount San Antonio and Bear Canyon contains abundant xenoliths of TRbhqmzd and TRqd-di. Intruded by Kgr and pegmatite.

Jbgd Jurassic(?) moderately to well foliated, medium grained biotite granodiorite or less common quartz monzonite, commonly porphyritic with 1-2cm lavender K-feldspar phenocrysts. Intrudes finer grained TRqd-di unit. Contains common pCagn and pCgn xenoliths. Hornblende-bearing varieties occur at structurally high levels of Sunset Peak and eastern Glendora ridge. Similar to mid-Jurassic granodiorite dated on Pleasant View Ridge (Powell et al., 1983).

TRqd-di Triassic or Jurassic(?) biotite+/- hornblende quartz diorite or diorite, fine to medium grained, poorly to moderately foliated, commonly recrystallized. Spatially associated with the Triassic Mt. Lowe intrusive suite. Some phases are intruded by TRbqm. Contains abundant pCgn and pC agn-bagn-pbgd xenoliths. Rarely contains irregular bodies of poorly foliated gabbro or pyroxenite, medium to coarse grained. This gabbroic unit may be strongly recrystallized, with mafic minerals replaced by biotite.

TRbqm-TRbhqmzd Triassic Mt. Lowe intrusive suite, generally well foliated. Subdivided into leucocratic biotite quartz monzonite, commonly porphyryitic with megacrystic K-feldspar augen ("pigeon eggs") 2-6cm long and hornblende+/-biotite quartz monzodiorite ("dalmationite") with prominent 0.5-1cm hornblende phenocrysts. Spatially associated with TRqd-di and Kqd units. Dated at 215-218 Ma {U/Pb} in the central San Gabriel Mountains by Silver (1971) and Barth et al., 1990).

pCagn Paleoproterozoic coarse grained biotite granite augen gneiss, with flattened or isoclinally folded K-feldspar augen up to 8cm long. Similar to samples dated {U/Pb} in the western San Gabriel Mountains at ca. 1.65-1.7 Ga (Silver, 1971; Barth et al. 1995). Some varieties are leucocratic with K-feldspar composing greater than 60% of the rock volume. Intruded by TRqd-di, Jbgd, and pegmatite units.

pCbagn Paleoproterozoic medium grained granite augen gneiss, rich in recrystallized biotite, commonly displaying tight to isoclinal folds. K-feldspar augen typically 0.5-1cm diameter. Large masses are exposed along western Glendora Ridge Road and upper Glendora Mountain Road. Intruded by TRqd-di and pegmatite units. Correlates with "Pea gneiss" body of Glendora Ridge dated at ca. 1.68 Ga ({Pb/Pb}; Ehlig, 1981)

pCpbgr Paleoproterozoic(?) strongly foliated to gneissic, medium grained porphyritic biotite granite, generally leucocratic.

pCgn Undifferentiated Paleoproterozoic fine-grained "San Gabriel" type gneiss recrystallized under upper amphibolite facies. Composes wall rocks to the Proterozoic augen gneisses and pCpbgd unit. Finely banded, millimeter scale foliation may appear mylonitic. Commonly displays recumbant isoclinal folds and preserves multiple generations of deformational fabric. Oldest basement lithology recognized in the western San Gabriel Mountains (Silver, 1971; Barth et al., 1995). Derived from texturally diverse igneous and/or immature sedimentary protoliths with felsic to mafic compositional ranges. Locally subdivided into:

pCqfgn quartzofeldspathic gneiss with variable proportions of biotite,

pCbgn biotite gneiss (in part derived from pCbagn or pCpbgd),

pCdign dioritic gneiss or amphibolite, and

pCgrgn leucocratic biotite granite gneiss.

METASEDIMENTARY STRATA OF ONTARIO RIDGE AND POTATO MOUNTAIN:

ms Undifferentiated Upper Proterozoic-Paleozoic(?) or Mesozoic(?) metasedimentary rocks, strongly foliated and isoclinally folded at middle-upper amphibolite facies. Intruded by Ktn, Kgd, Klgr, and Kgr units. Locally subdivided into:

bgn Biotite gneiss, garnet-biotite-quartzofeldspathic gneiss, biotite-quartzofeldspathic schist, and phyllite with well developed mm-cm scale chevron or isoclinal folds. Intruded by and deformed with

leucocratic biotite granite or pegmatite dikes and veins. Exposures west of Potato Mountain are interfolded with medium-grained pC(?)biotite granite augen gneiss.

m Marble or calcsilicate gneiss, complexly folded at amphibolite facies (May, 1986)

q Quartzite with generally orange-colored weathered surfaces. May contain significant component of feldspar and biotite**.**

cs Calcsilicate gneiss

cg Pre-Cretaceous Cucamonga granulite series (D. May, 1986; May and Walker, 1989). Protoliths include above metasedimentary rocks and Ktn unit of Ontario Ridge.

Map Symbols

lithologic contact, dashed when approximate, queried when uncertain

metamorphic foliation, showing mineral lineation

fault

Mid- Miocene basaltic or andesitic dike, showing dip

perennial spring

bedrock sample location

pebble sample location or boulder count site

geochronology sample location

Clast Analysis of Quaternary Gravels Along the East-Central San Gabriel Mountain Front: Implications for Evolution of the Sierra Madre-Evey Canyon Thrust System

Jeffrey D. Pepin, jdpepin@csupomona.edu; Audra M. Hanks, amhanks@csupomona.edu; Jonathan A. Nourse, janourse@csupomona.edu

Geological Sciences Department, California State Polytechnic University, Pomona

Abstract

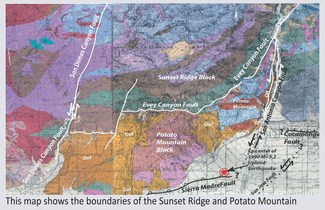
The Quaternary Sierra Madre-Evey Canyon thrusts are part of an active fault system that transects the east-central San Gabriel Mountains range front. Fault segments situated directly north of densely populated communities of Claremont and La Verne are poorly understood. Our efforts focused on the southward extending Upper Quaternary gravels associated with uplift and erosion of hanging walls of the thrusts. Our aim in studying this sedimentary system was to understand the regional geologic setting of an important seismic hazard and develop a model for fault block uplift.

We mapped and sampled portions of two basement block uplifts and collected pebble samples of associated gravels for clast analysis. The Sunset Ridge Block (SRB) forms the hanging wall of the north-dipping Evey thrust. This block is composed of a layered sequence of distinctive plutonic and metamorphic rock units, including Cretaceous tonalite, Precambrian quartzofeldspathic gneiss, Jurassic diorite and granite, and Triassic "dalmationite." Situated farther south in the footwall of the Evey fault and the hanging wall of the active Sierra Madre thrust, the Potato Mountain Block (PMB) is composed mainly of Precambrian quartzite, biotite gneiss / phyllite and Cretaceous leucogranite. Stratigraphic relationships constrain two generations of gravel deposits. Clast analyses of 8 gravel samples (60 to 200 pebbles / sample) and field inspection of boulders from 2 sites yielded systematic provenance ties to the two basement blocks and a consistent time progression: older gravels were derived from the SRB while younger gravels were shed from PMB bedrock sources. These data indicate the two fault blocks were uplifted sequentially such that early displacement on the Evey thrust (coincident with uplift of SRB) was succeeded by activation of the Sierra Madre thrust (and uplift of PMB). Thus the two gravel units record southward transfer of slip from Evey Canyon to the present-day mountain front.

Our study has increased understanding of the local geologic history and will eventually serve as an important tool for city planners and emergency personnel in reducing seismic risk. Samples from both Quaternary units have been collected for cosmogenic dating; results are pending. This information will provide constraints on the uplift rate of the Quaternary gravels.

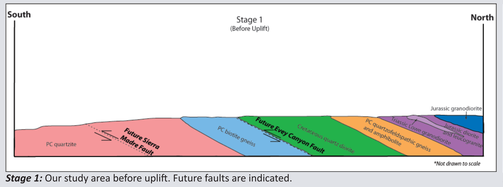
Location

This aerial view illustrates the study area's pertinent regional fault systems.

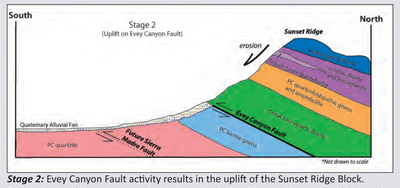


This map shows the boundaries of the Sunset Ridge and Potato Mountain blocks. The yellow shading represents gravels that have uplifted during recent movements on the Sierra Madre Fault.

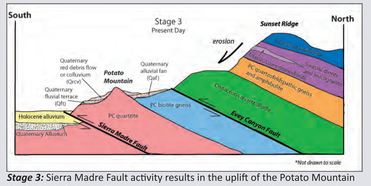
Cross Sections



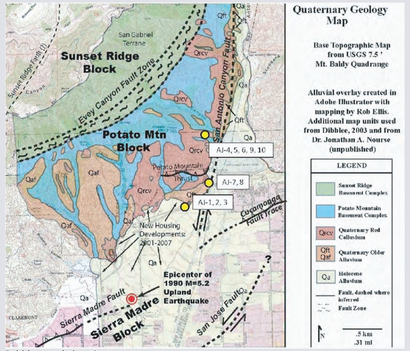
Stage 1: Our study area before uplift. Future faults are indicated.



Stage 2: Evey Canyon Fault activity results in the uplift of the Sunset Ridge Block. Eroded clasts of Jurassic granodiorite, Jurassic diorite, Precambrian quartzofeldspathic gneiss, and Cretaceous quartz diorite are deposited onto the Potato Mountain Block.



Stage 3: Sierra Madre Fault activity results in the uplift of the Potato Mountain Block. Eroded clasts of Precambrian quartzite and Precambrian biotite gneiss are deposited atop the Quaternary alluvium from the Potato Mountain Block. Note the compression of the section due to the thrust fault activity from Stage 1 to Stage 3.

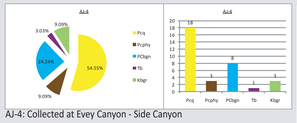


Pebble sample location map

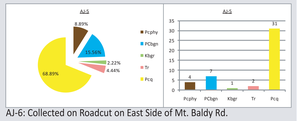
Rock Unit Legend		
SUNSET RIDGE BLOCK		
Rock Type	**Map Unit**	**Color**
Amphibolite	PCa	Tan
Coarse to Fine Grained Jurassic Diorite	Jdi	Red
Cretaceous Biotite Granite	Kbgr	Light Green
Fine Grained Jurassic Biotite Granite/Granodiorite	Jfbgr/gd	Dark Red
Hbld-Bio Tonalite or Qtz Diorite	Ktn-qd	Green
Hornblende Quartz Monzodiorite (Dalmatinite)	Trhqmzd	Purple
Jurassic Biotite Granite/Granodiorite	Jbgr/gd	Mahogany
Leucocratic Granite	Klgr	Aqua
Muscovite Schist (not pelona)	ms	Gray
Pelona Greenschist	Kgs	Seafoam
Pelona Muscovite Schist	Kms	Light Grey
Quartzofeldspathic Gneiss	PCqfgn	Blue
Triassic Monzogneiss	Trmzgn	Hot Pink
POTATO MOUNTAIN BLOCK		
Rock Type	**Map Unit**	**Color**
Evey Canyon Fault Rock	ecfr	Light Yellow
Marble	m	Light Red
Phyllite/Pscsa Schist	Pcphy	Brown
Precambrian Biotite Gneiss	PCbgn	Light Blue
Precambrian Quartzite	PCq	Yellow
MULTI-SOURCED / UNKNOWN SOURCE		
Rock Type	**Map Unit**	**Color**
Calcite	c	Peach
Epidote Bearing Clast	epi	Dark Orange
Pegmatite	peg	Orange
Tertiary Basalt	Tb	Dark Purple
Tertiary Rhyolite/Dacite	Tr	Light Pink
Unknown	Unknown	Black

Pebble/Boulder Count Data

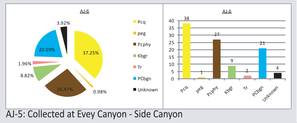
Assemblages Dominated by Potato Mountain Clasts (younger)



AJ-4: Collected at Evey Canyon - Side Canyon

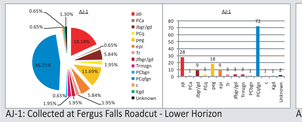


AJ-6: Collected on Roadcut on East Side of Mt. Baldy Rd.

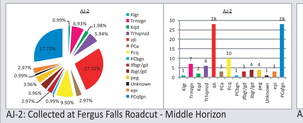


AJ-5: Collected at Evey Canyon - Side Canyon

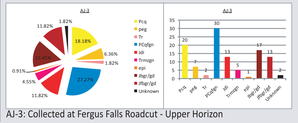
Assemblages Dominated by Sunset Ridge Clasts (older)



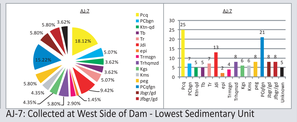
AJ-1: Collected at Fergus Falls Roadcut - Lower Horizon



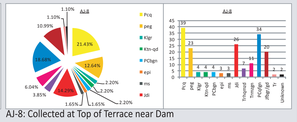
AJ-2: Collected at Fergus Falls Roadcut - Middle Horizon



AJ-3: Collected at Fergus Falls Roadcut - Upper Horizon

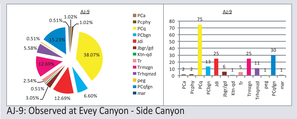


AJ-7: Collected at West Side of Dam - Lowest Sedimentary Unit

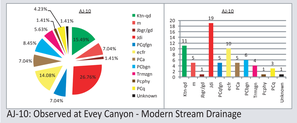


AJ-8: Collected at Top of Terrace near Dam

Observed Boulder Counts



AJ-9: Observed at Evey Canyon - Side Canyon



AJ-10: Observed at Evey Canyon - Modern Stream Drainage

Bedrock Units

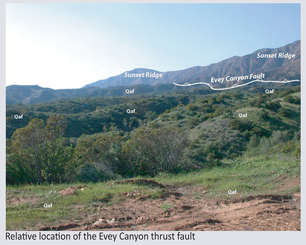
Some units from Sunset Ridge Block: Jurassic diorite and Triassic monzogneiss

Examples of Potato Mountain Precambrian quartzite

Setup of all bedrock samples

Field Methods

Aerial photograph depicting pertinent field relationships



Relative location of the Evey Canyon thrust fault

Interpreting field stratigraphy on Sunset Ridge Fire Road

Analyzing pebble sample data in Microsoft Excel

Collecting and recording samples on Sunset Ridge Fire Road

Taking a foliation measurement on the quartzofeldspathic gneiss

Overlooking San Antonio Dam

Collecting sample for OSL dating. Samples must be collected at least 10 meters below the surface in order to obtain accurate results.

Dr. Lewis Owen collecting sample for OSL dating.

Conclusions

Two blocks are involved in the fault system along the East-Central San Gabriel Mountains. The older gravels come from Sunset Ridge Block and the younger gravels from the Potato Mountain Block. This demonstrates the sequential uplift of the two blocks, as hypothesised in the cross sections above.

Future Work

Optically stimulated luminescence (OSL) geochronology dates are pending. With the help of Dr. Lewis Owen and Kate Hedrick from the University of Cincinnati, we collected samples that will be dated. The geochronology data will assist us in dating the gravel deposits we focused on and will aid in deriving an uplift rate for these blocks.

Acknowledgments

We thank Mike Oxford of the United States Forest Service for providing access to the necessary restricted access zones of our study. Hardware, computer facilities and field site transportation were provided by the Geological Sciences Department of California State Polytechnic University of Pomona.