QUATERNARY GEOLOGY OF LONG CANYON, WESTERN JOSHUA TREE NATIONAL PARK

An Undergraduate Thesis

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By

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ABSTRACT

Long Canyon is one of a series of north-south trending canyons located in the easternmost section of the Little San Bernardino Mountains in Southern California. This area is part of the Eastern California Shear Zone and is bordered to the south by the San Andreas Fault. Recent studies suggest that these two seismic areas impact each other inversely; as one zone goes through a period of fast slip rate the ability of the other zone to slip is suppressed. Long Canyon’s placement in this tectonically active area, coupled with a north-south trending fault that courses the western length of the canyon, indicates this area is likely being impacted by plate boundary deformation. Despite its location adjacent to the SAF, there has been very little research done in Long Canyon or the immediate surrounding area. Mapping of the Quaternary alluvial deposits and landforms in Long Canyon reveal several phenomena. First, a progressive change in the frequency of alluvium distribution moving northward up the canyon manifested by the substantial lessening of abundance of the oldest identified alluvial deposits towards the north. The older alluvial deposits also decrease in height above the thalweg northward in the canyon indicating northward tilt, which is consistent with long-term tilting indicated by low-temperature thermochronology studies. Second, there are noticeable degrees of vertical and horizontal offset between alluvial terraces of the same age that parallel each other on both sides of the canyon. Third, the atypical geomorphology of the Long Canyon streambed as a braided stream channel. I suggest that Long Canyon is currently undergoing both vertical and horizontal displacement caused by its proximity to the Eastern California Shear Zone and the Mission Creek strand of the San Andreas Fault.
INTRODUCTION

The Eastern California Shear Zone (ECSZ) is one of the major areas in Southern California involved in plate boundary related deformation along the San Andreas Fault. Many portions of the ECSZ have been extensively studied; however, very little geologic work has been done along southwestern flank of ECSZ particularly in the section of Joshua Tree National Park (JTNP) that overlaps with the Little San Bernardino Mountains. This study adds to the knowledge of this area by incorporating previous work with new fieldwork that includes mapping Quaternary alluvial deposits in Long Canyon of JTNP.

Long Canyon is located in western JTNP in the Eastern Little San Bernardino Mountains, near the town of Desert Hot Springs, CA (Figs. 1 and 2). Long Canyon is V-shaped valley that is characterized as a desert wash (Fig. 3). Hilltops surrounding the valley range in elevation from 2000 m to 3500 m with valley floor elevations of approximately 1600 m at the canyon mouth and 2600 m at its head. Rock units in Long Canyon and the surrounding area are comprised mainly of Precambrian and Mesozoic granitic and gneissic rocks (Powell, 1981). Tertiary and Quaternary alluvial deposits overlay the bedrock. Precambrian and Mesozoic rocks comprise the majority of the slopes with alluvial deposits forming the valley floor and terraced areas. Numerous faults trend east to west throughout the canyon (Plate 1).

The purpose of this study is to map and describe alluvial deposits of Long Canyon in JTNP in order to develop a sense of tectonic significance based on the genesis of Quaternary alluvial deposits and terraces. It is hoped that this study will further the efforts of others as this area is studied in greater detail.
GEOLeGIC SETTING

Long Canyon is one of series of canyons trending north-south in the eastern terminus of the Little San Bernardino Mountains (LSBM). The LSBM are within the Eastern California Shear Zone (ECSZ) and belong to a series of mountain ranges in Southern California known as the Eastern Transverse Ranges. The ECSZ is an area of mostly north-northwest striking, dextral slip faults (Dolan et al., 2007) located adjacent to the Basin and Range Province of the Western United States (Frankel et al., 2008). ECSZ is responsible for 20-25% of the relative motion between the N. American and Pacific Plates (Frankel et al., 2008). The ECSZ faults have been active for the past few million years (Savage et al., 1990).

The Eastern Transverse Ranges (ETR) are a series of east-west trending mountain ranges that include the LSBM, the Pinto and Cottonwood Mountains, and others. These mountain ranges underwent transtensional stress as they were rotated into their current position 18-12 million years ago as the boundary between the Pacific and North American Plates shifted from a subduction zone to a transverse boundary (Atwater, 1998). The boundary shift between the two plates has caused a transpressional area along the southern San Andreas Fault Zone (DeMets, 1995). Spotila et al. (1998) conducted a study in the nearby Wilson Creek and Yucaipa Ridge block that shows uplift in this area of the SAFZ to have been over 3-4 km in the last 5 million years. Recent work done in Long Canyon by Sabala (2010) also suggests that in the past 7 million years the Little San Bernardino Mountains, which include Long Canyon, have gone through rapid exhumation. Research done by Spotila and Anderson (2003) and Dolan et al. (2007) indicate that tectonic behavior in the Holocene between the Eastern Transverse Ranges and the ECSZ is one of slip/suppression. As one of these areas experiences high rates of slip it
causes suppression in the rate of slip in the other area. This relationship appears to have
alternated between the two zones over time.

METHODS

Field data collected in this study were combined with earlier research done by others (see
review below). Mapping was completed over a period of 9 days covering an area 0.4 km wide
east to west by 12 km in long north to south (Fig. 2). Mapping in the field was completed on
mylar paper overlaying Google Earth images and was focused on Quaternary alluvial deposits,
terraces, and fault traces. Quaternary units were identified and relatively dated based on field
observations including rubification, oxidation, consolidation, and clast sorting. Data collected in
the field was then put onto a digital topographic map using ArcMap (GIS). The final map was
formatted and drafted using Adobe Illustrator and is attached as Plate 1. In conjunction with the
field map a number of stations are identified in the field. These stations are marked on Plate 1
and are referenced in Table 1. Table 1 provides further information on each station as well as
any information on photographs taken at each respective station.

PREVIOUS WORK

Though Long Canyon itself has been studied very little, much work has been done in the
areas surrounding Long Canyon. Many of the fault zones that likely affect Long Canyon’s
seismicity have been mapped (Fig. 4). Bryant (1986) shows the Pinto Mountain Fault Zone to be
moving 1 to 5 mm/yr as a left lateral strike slip fault. The PMFZ trends east - west and is located
north of Long Canyon (Fig. 4). The Mission Creek strand of the San Andreas Fault System is a
north dipping strike-slip fault (Dair and Cooke, 2009) with a slip rate of 9 to 15 mm/y (Behr et
al., 2007). Work in Long Canyon has been done by Rymer (1993) who indicated a north-south trending fault in Long Canyon. This fault was also noted by Langenheim and Powell (2009). Geologic maps that include Long Canyon show it to be part of the Precambrian igneous and metamorphic rock complex unique to Southern California (Jennings et al., 1977) or as a single unit of Quaternary Alluvium surrounded by Precambrian gneissic rocks (Dibblee, 1967, Fig. 5).

**ROCK UNIT DESCRIPTIONS**

The geology of Long Canyon and the surrounding area has been mapped prior to this study (Dibblee, 1967; Jennings et al., 1977; and Powell, 1981). All known maps have an emphasis on rocks originating prior to the Cenozoic Era. This study’s focus was to map and differentiate between Quaternary alluvial deposits and associated landform features. For the purposes of this study, all rock units in Long Canyon not mapped are assumed to be bed rock units and are classified into two general groups: Precambrian gneiss or Mesozoic intrusive. The importance of the bed rock units to the study are to set Long Canyon in its geologic context and to indicate the provenance of the clasts that make up the different alluvium deposits.

**Precambrian and Mesozoic Bed Rock Units**

The Precambrian bedrock units in Long Canyon are classified by Powell (1981) as crystalline granite overlain by orthoquartzite and series of metamorphic rocks of sedimentary protoliths. The whole series has been metamorphosed to granitic gneiss, quartzite, and schist. The Mesozoic rocks can be divided into two plutonic batholithic suites. The older are Jurassic gabbro-diorites and monzogranites. The younger suite is made up of Cretaceous granodiorite and monzongranites (Powell, 1981). Figure 6 is a photograph of typical basement rock found in Long Canyon.
Quaternary Alluvial Units

$Q_{a1}$ is the oldest alluvium identified in study. The color tends to be orange-brown from a distance and a medium gray brown when observed up close (Fig. 7). The unit is clast supported with a silty sand matrix moderately sorted. Clasts are angular to sub angular and are comprised of quartz, biotite-hornblende schist and grantitic gneiss. Clast sizes range from coarse sand to cobble 0.2 cm – 15 cm. Occasional boulders sized clasts are found in the unit from 0.5 m to 1 m in diameter. Exposed clasts have developed relatively flat surfaces and high degree of desert varnish. The undersides of overturned rocks show a high degree of rubification (Fig. 8). Interiors of terrace remnants are becoming desert pavement with minor compaction. Overall topography of the unit is fairly flat with vestigial bars and swales. Vegetation tends to be very sparse.

$Q_{a2}$ is the second oldest alluvium unit in Long Canyon. From a distance the color varies from orange-brown to dark gray up close the unit is light gray to light brown. Clasts are very angular to sub angular. The unit is clast supported with a silty sand matrix, moderately to poorly sorted. Clasts range in size from coarse sand to cobble 0.2 cm – 20 cm. Occasional boulders are found in the unit. Clasts are comprised of granitic gneiss, quartz and feldspar lithics and, biotite schist. Slight to moderate rubification has developed on the underside of clasts (Fig. 9). Minor desert varnish has developed on exposed surfaces. The overall topography of the unit is flat with occasional shallow bar and swale topography. $Q_{a2}$ tends to be mostly unconsolidated. Vegetation is sparse.

$Q_{a3}$ is the second youngest alluvium unit in the study area. The overall color is light to medium gray. Clasts are angular to sub rounded. The unit is matrix supported with a sandy gravel composition. Clasts range from pebble to cobble size, 0.5 cm – 15 cm with sporadic boulders.
Boulders tend to be sub rounded and can be as large as 1.5 m. Clasts tend to be granitiods rich in quartz and feldspar; some gneissic and schistose rocks are present. Little to no rubification on the undersides of rocks (Fig. 10). Vegetation is moderately thick on this unit.

\textbf{Qa}_4 is the youngest alluvium in mapping area and is divided into two subunits \textbf{Qa}_{4a} and \textbf{Qa}_{4b}. \textbf{Qa}_{4a} is the youngest unit in the field and is differentiated from \textbf{Qa}_{4b} by the being at a lower elevation in the stream channel than \textbf{Qa}_{4b} and less abundant vegetation growing on it than on \textbf{Qa}_{4b}. \textbf{Qa}_{4a} tends to be between 0.1 and 0.5 m below the surface of \textbf{Qa}_{4b}

\textbf{Qa}_{4b} has a light gray color (Fig. 11). Clasts are sub rounded to round. The unit is moderately sorted matrix supported with medium sand to cobble sized clasts 0.2 cm – 15 cm. The unit is unconsolidated with little to no compaction. No rubification or desert varnish is present on clasts. The unit has pronounced bar and swale topography from 0.25 - 0.5 m deep and 0.1 – 2.0 m wide. Vegetation is large and frequent.

\textbf{Qa}_{4a} has a color of light gray to off white. Clasts are sub round to round. The unit is unconsolidated with no compaction and poorly sorted. Matrix is made up of silt to coarse sand sized clasts with large amounts pebble and cobble size clasts as well. No rubification or desert varnish on clasts. Bar and swale topography typifies this unit ranging from 0.25 - 0.5 m deep and 0.1 – 2.0 m wide. Vegetation is sparse but plants tend to be large for the area (Fig. 12).

\textbf{Co} is a colluvium unit with a white to pink color (Fig. 13). Clasts are very angular to angular. Clasts are coarse sand to cobble size 0.5 cm – 15 cm. Composition of the unit is a plagioclase rich granitic rock. Minimal desert varnish and medium rubification is present on some of the rocks. The unit is relatively flat with no bar and swale topography. Vegetation is sparse to moderate.
STRUCTURAL AND GEOMORPHOLOGIC OBSERVATIONS

Faults are common throughout Long Canyon; the majority of these faults trend east – west and cut across Long Canyon. The abundance of these faults creates a series of east-west trending canyons and depressions that intersect Long Canyon. These faults can readily be seen to cut across bedrock units (Figs. 6, 21, 22). The immediate areas around the faults tend to have noticeable amounts of chlorite, fault gouge and fault breccia (Fig. 6).

One fault trends north - south along the western side of the canyon and likely affects the geomorphology of the valley floor as well as other aspects of the topography surrounding the canyon. This fault was mapped previously by Proctor (1968) and Rymer (1993) and will be referred to as the Long Canyon Fault (LCF). The LCF can be identified most of the extent of the canyon. Horizontal displacement can be seen offsetting by a few meters many of the east-west trending side canyons that intersect the western flank of Long Canyon (Fig. 17). Vertical displacement caused by the LCF can be seen in unconformities along the sides of the main stream channel. Alluvial deposits that form terraces are found on both sides of the canyon and tend to have a greater height on western side of the canyon. These unconformities are composed of either Qa₂ or Qa₃ except near the mouth of the canyon where Qa₁ also makes up some of the overlying layers. The overlain rock units in the canyon are the Mesozoic and Precambrian rocks.

Throughout Long Canyon terraces trend along both sides of the canyon. These terraces are more frequent and prominent towards the southern end of the canyon. Terraces range from approximately 1 - 20 m above the canyon floor (Fig. 14). The gradation of the canyon walls shift gradually from north to south. The canyon walls along the southern portion of Long Canyon tend to have noticeable terraces, as previously stated, which creates a ‘step’ topography. The walls along the northern section of the canyon gradually become more slopped and steeped (Fig.
The slope of the canyon floor north to south varies little maintaining an average slope of 1 meter vertical for every 24 meters horizontal.

**CHANGES IN ALLUVIAL DEPOSIT AND TERRACE DISTRIBUTIONS AND ELEVATIONS**

Using data gathered in the field, the final map (Plate 1) and satellite imagery, I have divided Long Canyon into four zones based on geomorphology. These zones include from south to north: the mouth, the south-central, the north-central, and the north.

The mouth of the canyon has a wide channel 50 - 100 m across. In this portion of the canyon all of the mapped units are visible and in sequence as seen in figure 3. Slopes tend to be gentler than the rest of canyon and abandoned terraces are easily recognized.

The south end of the south-central zone is located where the valley floor narrows to a width approximately 15 – 60 m. In this section terraces are made up mostly of Qa₁ and Qa₂ and are still easily observed. This section of the canyon has the highest visible unconformity at approximately 15 m high on the west side of the canyon (Fig. 16). Parallel unconformities in this zone vary more in height between the east and west sides of the canyon than in any other zone. Terrace surfaces on the west side of the canyon can be up to 10 m above the surfaces of those on the east side. Qa₁ becomes less frequent towards the northern portion of the south-central zone. This zone contains numerous streambeds on the western side of the canyon that have been off set by the Long Canyon Fault that appears to strike the length of the study area (Fig. 17). The north end of this zone is at base of the hill mapped as colluvium in the center portion of the mapping area, where station 16 is located.
The north-central zone of the map starts at the previously mentioned colluvial hill. On the west size of this hill the large north-south trending fault mapped by Rymer (1993) is more clearly seen than in any other location in the study area. This marks the transition between narrow valley floors and terraced hill slopes farther south to a wider canyon floor approximately 50 – 120 m wide and slopes that become more graded farther north. Some terraces are still easily visible in this portion of the canyon. However, Qa₁ is no longer found on the hill slopes in this zone or farther north. Terraces become both less elevated from the floor (approximately 1 – 5 m) and become more level with each other on both sides of the canyon. In this section of the canyon terraces are mostly made up of Qa₂ with some Qa₃.

The north zone is the northernmost portion of the study area and begins just north of streambed with the Chuckawalla Bill Spring. In this zone the canyon forks into multiple branches. The valley floor begins to narrow to approximately 20 – 60 m wide. Qa₂ begins to become more infrequent on the canyon slopes. Using work done by Dibblee (1967) it can be assumed that the alluvial terrace deposits gradually give way to solid bedrock moving northward up the canyon.

**INTERPRETATION AND DISCUSSION**

Long Canyon’s valley floor is an ephemeral streambed shaped by fluvial processes in an arid environment. Ideally, it should take on specific characteristics that form under such conditions. Most notably a streambed in this environment would be expected to have a concave-up shaped stream profile with steeper gradients towards the headwaters and a flatter more subdued topography towards the mouth. Long Canyon appears to have a relatively flat profile for most of its course, except at the northernmost sections of the stream where the gradient must
increase in gradient. Additionally, the distance between the thalweg and the oldest alluvial terraces tends to decrease towards the northern section of the canyon in the direction of the headwaters. Also, the oldest alluvial deposits, Q$_{a1}$, diminish to the north until they are no longer detectable. This study indicates that this is due to a northward tilt of Long Canyon away from the SAF.

Research done by Luke Sabala (2010) in and around Long Canyon looked at low-temperature thermochronology using apatite fission-track and (U-Th)/He dating. The fission-track data shows increasing ages in the rock samples moving northward away from the SAF. Ages near the SAF are 7 Ma and increase northwards as distance from the SAF increases, to 20 Ma. Beyond 12 km the average age increases dramatically to 53 Ma. The (U-Th)/He data shows relatively same ages from samples dating 3-5 Ma. North from the SAF (U-Th)/He ages are relatively constant at 3-5 Ma until approximately 12 km. North of 12 km ages increase to 20 Ma and then to 40 Ma approximately 16 km north of the SAF. Sabala’s findings conclude that exhumation was produced by northward tilting of the LSBM as a consequence of transpressional forces along the SAF about 5 Ma (Fig.18).

The younger time scale findings of this study correspond with the older time scale findings in the Sabala study. The decreasing size and elevation of the Q$_{a1}$ terraces above the thalweg towards the northern section of Long Canyon and the decreasing vertical distance between older terraces and the streambed thalweg indicate a north tilt of the area. The north striking LC fault mapped in this study likely creates additional offset in Long Canyon while northward tilt occurs(d). This puts the movement of the LC fault in the correct context with other ECSZ faults that parallel the LC fault.
CONCLUSIONS

Comparing research done in this area by others and data gathered during the study suggests that Long Canyon has experienced northward tilt away from the SAF in the last 5 million years and that the Long Canyon Fault has created additional offset of the canyon. This is evidenced by:

- The uncharacteristic unevenness of height between parallel unconformities between the Precambrian-Mesozoic bedrock and the Quaternary alluvial deposits on the east and west sides of the canyon.
- The constant streambed gradient. This goes against normal stream behavior where the gradient tends to become less steep towards the mouth of the stream. This suggests vertical and/or oblique displacement somewhere along the streambed.
- Streambeds that have been horizontally offset on the west side of the canyon and horizontal offset between alluvial layers along the main stream channel.
- The widening in the north central and then narrowing of the thalweg in the south central zone in the study area. This may suggest displacement by indicating an interruption in the natural geomorphology of typical braided stream channel geometry.
- The decrease in height from the thalweg to the oldest alluvial terraces and the eventual disappearance of the oldest terraces towards the north section of the canyon. This indicates vertical tilting of the study area, which is consistent with the longer-term rock uplift determined from low-temperature thermochronology.
References


Jennings, C.W., 1994, Fault activity map of California and adjacent areas: Department of Conservation: Division of Mines and Geology, scale 1:750,000, 1 sheet, 92 p.


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<th>STATION</th>
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<th>FIGURE</th>
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<td>N3759258 E0551455</td>
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<td>Qa₂ surface across canyon 20 m above drainage, near mouth of canyon.</td>
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<td>At Site</td>
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<td>Qa₂ an example of rubification on overturned granitic clast.</td>
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<td>Qa₁ surface across canyon on same side of canyon, surface dips 10º east.</td>
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<td>At Site</td>
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<td></td>
<td></td>
<td>Qa₁, an example of rubification on underside of cobble.</td>
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<td>Photo of fault on east side of canyon, fault dips 70º north.</td>
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<td>N3759300 E0551531</td>
<td>012º</td>
<td>12/26/09 13:30</td>
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<td>Photo of Qa₄, subdued bar and swale 3-4 cm cobbles, very few boulders up to 1.5m sub rounded.</td>
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<td>N3759242 E0551573</td>
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<td>Photo of alluvium layers looking North West Qa₄, Qa₅, and Qa₆.</td>
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<td>N3759233 E0551632</td>
<td>140º</td>
<td>12/16/09 14:00</td>
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<td>Fault looking up canyon northward on eastern side of canyon. Attitude: 140º, 60ºN. Extensive fault gouge. Fault does not cut across Quaternary deposits.</td>
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<td>N3759685 E0551423</td>
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<td>Photo looking northward of north to south trending fault.</td>
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<td>N3760043 E0551483</td>
<td>190º</td>
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<td>Photo looking down canyon to the southeast of north to south trending fault. Offset approx. 2 m. Author is pointing at fault.</td>
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<td>Photo looking north of stream bed off set by fault.</td>
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<td>Photo of fault offsetting stream bed shown in fig. 16, fault strike and dip: 114º, 34º SW.</td>
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<td>Photo of fault strike and dip of: 192º, 86ºE.</td>
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<td>Photo of unconformity between Qa₁ and bedrock, looking East, Unconformity trends north-south.</td>
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<td>320º</td>
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<td>Photo of scarp separating Qa₅ on top and Qa₄ on valley floor, looking west, scarp trends north-south.</td>
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<td>Photo looking northward up the canyon at north-south trending fault on west side of canyon, separating canyon walls from large hill on East.</td>
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<td>Photo looking south towards mouth of the canyon at small ridge trending east-west. Station 16 is on top of irregular hill noticeable from both ariel photos, topographic map, and while traversing the canyon on foot.</td>
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<td>N3763857 E0551297</td>
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<td>Photo looking southwards uplifted Qa₂ on west side of canyon, Qa₂ is no longer visible on canyon walls.</td>
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<td>Photo of fault trending east-west on east side of canyon attitude: 65º, 90ºE.</td>
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<td>N3764706 E0550926</td>
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<td>Photo looking south from station 19 showing incline of valley floor.</td>
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<td>N3765427 E0551034</td>
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<td>Photo looking east toward unconformity bedrock ends at valley floor goes strait up to hill top.</td>
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<td>Photo looking east at a fault striking east to west.</td>
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Figure 1. Digital relief map of California and satellite image of Long Canyon and the immediate surrounding area. Long Canyon is surrounded by the yellow box. (Relief map generated using nationalatlas.gov, satellite image generated using Google Earth.)
Figure 2 – Sections of Topographic maps showing the approximate study area outlined in red. Northern section (left map) modified from 'Yucca Valley South' 7.5 minute quadrangle (USGS, 1994). Southern section (right map) modified from ‘Seven Palms Valley’ 7.5 minute quadrangle (USGS, 1978).
Figure 3 – Photo looking southward down Long Canyon taken from station 19. This photo shows the overall V-shape of the canyon and the desert wash forming the valley floor, here, covered with dense vegetation.
Figure 4 – Shaded relief topographic map of mapped faults in and around Long Canyon. Active faults are shown in red inactive faults are shown in black. Long Canyon is highlighted in the yellow box. Image taken and modified from Yule (2009).
Figure 5 – Image of Geologic map done by Dibble (1967) of the Joshua Tree Quadrangle. Long Canyon is highlighted in the red box. Long Canyon is mapped as one unit of Quaternary Alluvium. The surrounding rock (green) is mapped as a Precambrian Gneissic Unit. A digitally archived copy of this map can be found in the USGS database online at.
Figure 6 – Photograph of the metamorphosed basement rock in Long Canyon. Photo was taken at Station 11, which can be located on Plate 1 and referenced on Table 1. Note the fault dipping almost 90° in the center of the photograph.
Figure 7 – Photograph of the author standing on top of Qa‘. Notice the orange-brown color, development of desert pavement, and sparse vegetation.
Figure 8 – Photograph of underside of Qa₁ clast illustrating the degree of rubification. Pen is for scale.
Figure 9 – Photograph of overturned Qa$_2$ clast showing the color of rubification
Figure 10 – Photo showing the development of rubification on underside of Qa$_3$ clast.
Figure 11 – Photograph of the author standing on top of Qa4b. Notice the thick vegetation on this unit compared with that on the surrounding slopes.
Figure 12 – Photo looking northward up Long Canyon from station 5. Qa4a is distinguished from Qa4b by its location in the stream bed and the sparse vegetation growing on it.
Figure 13 – Photograph of Colluvium clasts. Pen is for scale.
Figure 14 – Photograph looking southeast across the main drainage at the mouth of Long Canyon from station 1. Qa₂ terrace can be seen across valley floor.
Figure 15 – Photo Looking south from station 16. Canyon walls are becoming more evenly graded and terraces comprised of older alluvium are becoming less prominent.
Figure 16 – Photograph of Phil Armstrong standing next to unconformity between basement rock and Qa$_2$. Alluvium deposit is approximately 15 m high.
Figure 17 – Photograph looking northward from station 7 showing offset in stream bed along the Long Canyon Fault (indicated by black line) trending north to south on west side of Long Canyon.
Figure 18 – Model illustrating the northward tilt of the LSBM away from the SAF over a period of 20 Ma by estimating paleodepths of samples taken in the area around Long Canyon using (U-Th)/He and apatite fission track dating. Image taken from Sabala (2010).
Accompanying this written work is a CD containing additional photographs that coincide with stations denoted on Plate 1 and described on Table 1. Also, digital copies of files and data used to compile this study as well as digital copies of this text and Plate 1 can be found on the CD.

Appendix A - Contains digital copies of all photographs used as figures in this study as well as photographs not used in the main body of text. Photographs are labeled in continuation from the figures numbered in the main body of the text. Some of the figures cited on Table 1 have been used in the main body of this work and therefore figures are not listed sequentially on Table 1, rather data is assigned to a station and organized numerically by station number. Not all figures used in this paper are listed on Table 1 as some of the figures used in the main body of text are not attached to a station.

Appendix B – Contains a digital copy of this text saved as a .pdf file.

Appendix C - Contains copies of Plate 1 saved as a .pdf file and as an .ai file with all the layers used to draft the final copy of Plate 1.

Appendix D – Contains copies of all the files used to draft Plate 1 in ArcMap before the final edits were made using Adobe Illustrator.

Appendix E – Contains copies of the original files generated using Google Earth that were used in the field mapping portion of this study.

Appendix F – Contains digital photocopies of the 7.5 minute quadrangle USGS topographic maps used in the study saved as .tiff files.

Author’s note: Likely the reader, after looking over Table 1 and Plate 1, will soon notice the absence of station 9. This was done intentionally. After going through the data I decided that data taken at station 9 was not relevant to the current study. However, I felt that in order to maintain integrity with records taken in the field it would be better to exclude station 9 from the final work without changing the original numbers assigned to each station.