The Chariot Canyon Fault: *A Synthesis of Research 1974 to 2014*

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INTRODUCTION

CHARIOT CANYON, A 4.5 MILES LONG NORTH-SOUTH oriented drainage, is located south of Highway 78 near the foot of Banner Grade east of Julian, California (Figure 1). It may be accessed from Highway 78 by a rough unpaved road that parallels the canyon bottom for much of its length. Approximately 4.5 miles south of Highway 78 the road through Chariot Canyon joins the Mason Valley Truck Trail, a little travelled route extending from Highway S-2 in the desert to Highway 79 north of Cuyamaca Lake (Figure 2). The Chariot Canyon fault essentially parallels the road for most of its verified length of approximately 10 miles. The first good description of the Chariot Canyon fault was by Allison (1974) who named it for the prominent canyon in which the fault was first observed and mapped. Since that first publication the Chariot Canyon fault and its significance to the tectonic history of the Peninsular Ranges Batholith in eastern San Diego County has been the subject of much additional research. The following discussion is a summary of that research along with some postulations by the author regarding the length of the fault beyond its currently mapped extent and a discussion of possible late Tertiary reactivation and offset of "the old erosion surface" described by Gastil (1961) east of the fault whose counterpart exists north and east of Cuyamaca Reservoir.

According to Allison (1974) the existence of a fault through Chariot Canyon was first suggested by Ellis and Lee (1919) who show a fault along the west side of San Felipe Valley, crossing the Elsinore fault, extending through Chariot Canyon and following prominent drainages all the way to the U.S./Mexico border east of Otay Mountain. The fault as proposed by Allison (1974) extended southward from its intersection with the Elsinore fault at the north end of Chariot Canyon to the Sunrise

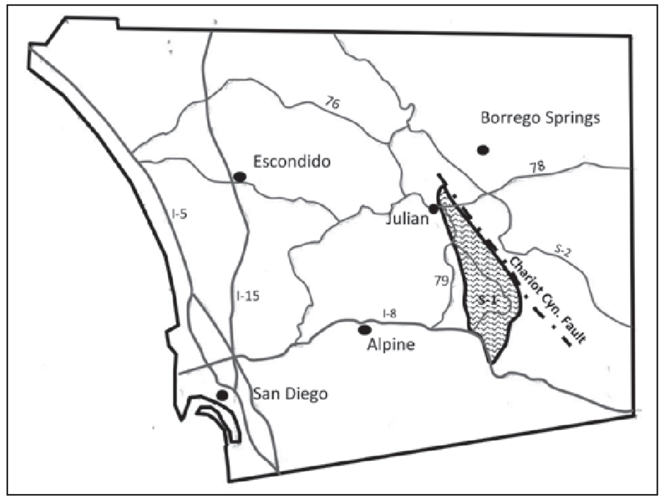

Figure 1. Location Map, patterned area; location of Cuyamaca Laguna Mountain Shear Zone (shear zone location after Wallawender, 2012)

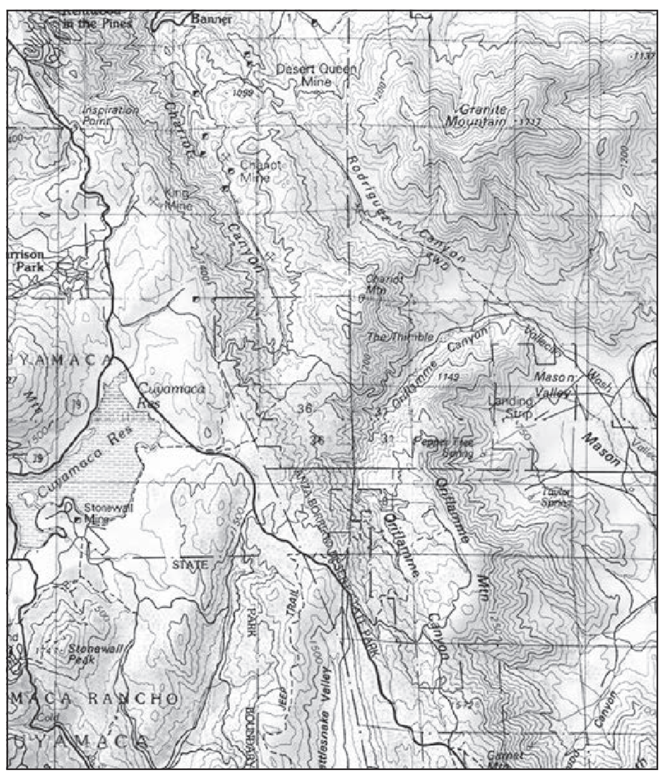

Figure 2. Location map showing areas discussed in text

Highway (highway S-1) where it is exposed in a roadcut near the Lucky 5 Ranch. Here the fault as mapped by Allison can be observed passing through Julian Schist and crushing and deforming rocks in an 8-ft-wide zone. Bethel-Thompson and others (in press) have since renamed the fault exposed in this roadcut and show that the Chariot Canyon fault actually lies further east.

Lampe (1988), Pinault (1984), and Todd (unpublished geologic map of the Julian Quadrangle, Figure 3) map a continuation of the Chariot fault on the north side of the Elsinore fault to the vicinity of the southwest margin of the San Felipe Valley north of Banner Grade. Lampe (1988) cites the following evidence for the existence of this northern extension of the Chariot Canyon fault:

> First, the presence of gold mines developed within sheared rock along the fault projection is similar to those found in Chariot Canyon. Second, both the Chariot Canyon fault and its proposed northern extension contain quartz rolls, lenses, and veins that sustain the gold mineralization. Third, lithified fault gouge and cataclasites have only been observed along the Chariot Canyon fault and along its northern extension. Finally, hydrothermal alteration that resulted in chloritization and albitization of the rock occurs in samples from localities along the northerly extension that is similar to the hydrothermal alteration that occurs along the southern portion of the fault.

The Chariot Canyon fault has played an important role in the mining history of the Julian area and in shaping the mountain and desert terrain of central and eastern San Diego County. A string of gold mines follows the trace of the fault in Chariot Canyon and along its extension north of the Elsinore fault. The richest of the mines, the Golden Chariot mine was worked as recently as the 1950s. The source of the gold is believed to be placer deposits in quartzite that were dissolved by superheated water rising through metamorphic country rocks above rising magma. As the water cooled the gold was precipitated in quartz veins (Walawender, 2000).

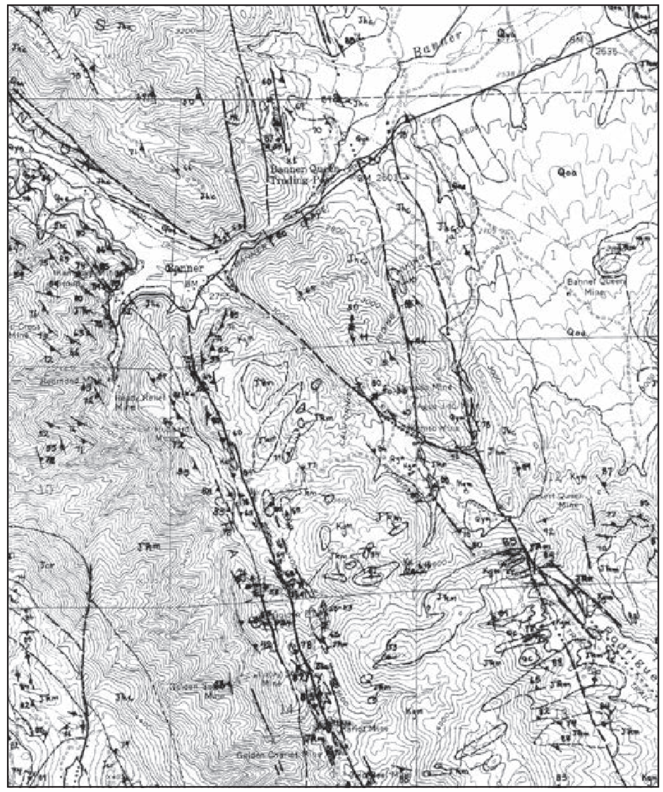

Figure 3. Portion of the unpublished Geologic map of the Julian Quadrangle by Victoria Todd. Kgm: Tonalite of Granite Mountain; Jhc: Harper Creek Gneiss; Kcr: granodiorite of Cuyamaca Reservoir; Jtrm; Julian Schist.

Figure 4. Jurassic gneiss in the Cuyamaca Laguna Mountain Shear Zone at Kwaaymii Point, Sunrise Highway.

SUMMARY OF RECENT WORK

Allison (1974) extended the fault all the way to the Mexican border based primarily on topographic evidence observed on satellite imagery and described what he termed the fault's most spectacular exposure in a borrow pit on the Sunrise Highway north of Interstate 8 discussed in Stop 2 of *Roadside Geology along Sunrise Highway* (Walawender, 2012). According to Allison (1974) at this locality construction workers removed easily excavated crushed rock on the east side of the fault all the way up to the fault surface where harder rock was encountered leaving the fault plane fully exposed for approximately 100 ft. However, according to Walawender (2012) there is no evidence of shearing at this locality and the existence of faulting here is questionable. From the exposure in the borrow pit Allison (1974) extended the fault to the U.S. Mexican border but by a more easterly route than that proposed by Ellis and Lee (1919).

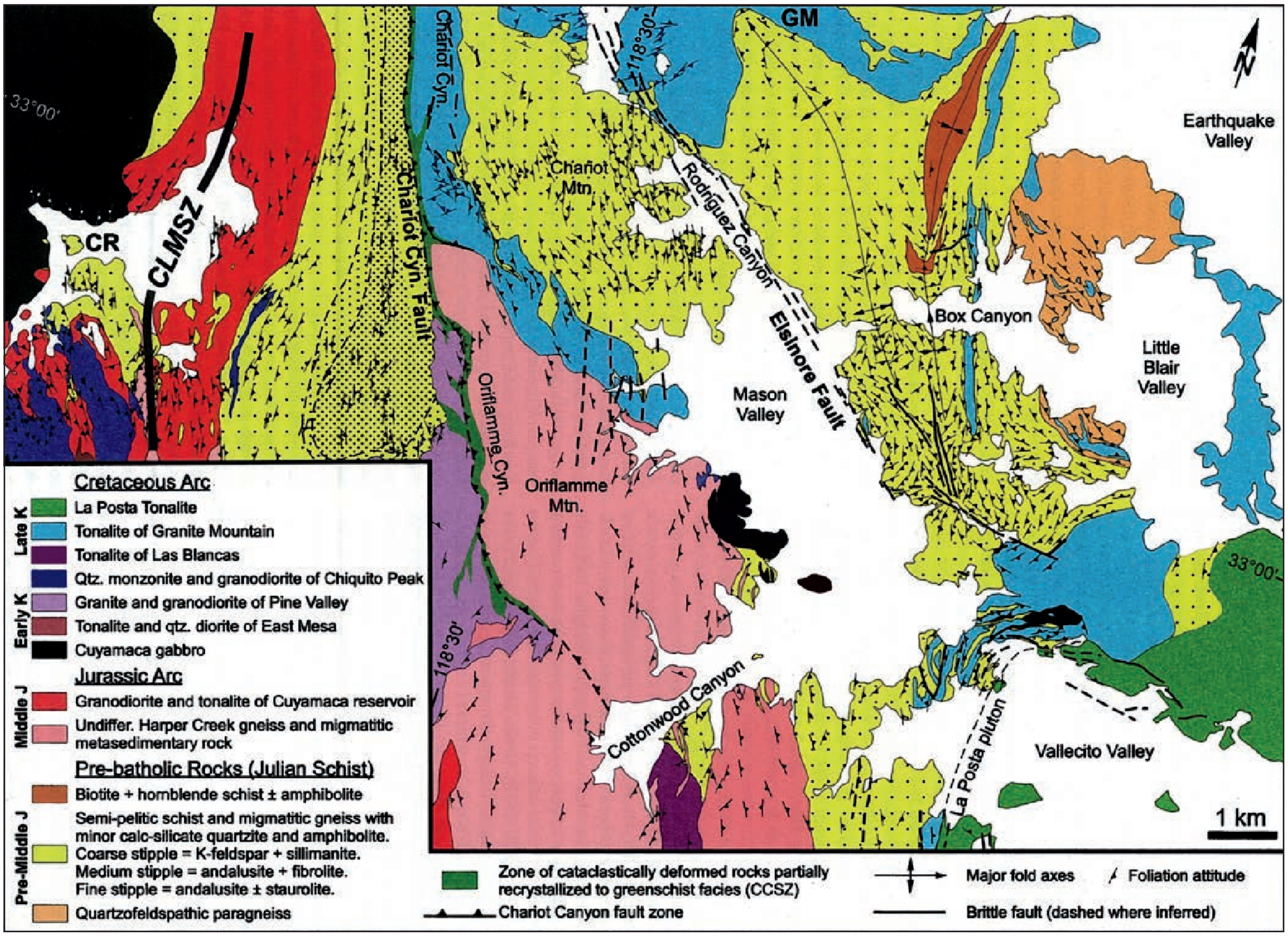

Figure 5. Geologic map of the Cuyamaca Reservoir area. From Grove and others (2003) reprinted with permission.

Later, Lampe (1988) Bethel-Thompson and others (in press) Grove, and others, (2003) and Bracci, (1993) remapped and reexamined the fault and describe its significance in the tectonic history of the eastern part of San Diego County. The results of their research indicate that throughout much of its length, the Chariot Canyon fault forms the eastern boundary of the Cuyamaca-Laguna Mountain Shear Zone (CLMSZ). Walawender (2012) describes the CLMSZ as a zone of intensely deformed and, in places, mylonitic rocks displaying a strong foliation (Figure 5) that consistently strikes northwestward and dips steeply to the northeast. The CLMSZ separates rocks older than 100 Ma on the west from rocks that are generally younger than 100 Ma on the east. The foliation was created during two distinct periods (Thornsen and Girty, 1994). The older compressional stage resulting in east-over-west faulting and ductile shearing occurred between 118 and 105 million years ago and the younger extensional phase occurred between 105 and 94 million years ago.

Recent work of Bethel-Thompson and others (in press) indicates the presence of several other faults within the CLMSZ that approximately parallel the Chariot Canyon fault in the vicinity of the Sunrise Highway near the Lucky 5 Ranch. In this area, the Chariot Canyon fault forms the eastern boundary of the CLMSZ. South of the Lucky 5 Ranch, Grove and others (2003) map the Chariot Canyon fault as diverging from the CLMSZ on the eastern slopes of the range and extend the fault as far as Cottonwood Canyon a prominent drainage descending the eastern escarpment of the Laguna mountains (Figure 5). Although most workers indicate that the Chariot Canyon fault dies out just south of Oriflamme Mountain, Grove and others (2003) show that the southern end of the Chariot Canyon fault is coincident with the 85 Ma isochron separating comparatively shallow rocks on the west from deeper rocks in the northeast. They note that although the 85 Ma isochron coincides with a steep age gradient between the eastern and western rocks, only localized faulting has been detected along it.

Inspection of aerial photos and satellite imagery of the region south of Cottonwood Canyon indicates the presence of strong lineaments and other geomorphic evidence that suggest the series of discontinuous faults mapped by Todd (1979) may represent a continuation of the Chariot Canyon fault that extends to the south at least as far as Canebrake Wash. In fact, Todd (1979) shows a generalized Chariot Canyon fault extending a short distance past Canebrake Wash. This dies out before reaching the In-Ko-Pa Mountains to the south. The best geomorphic evidence of major normal faulting south of the previously mapped termination of the fault by Grove and others (2003) is located on a prominent spur that descends from the crest of the Laguna Mountains on the north side of Canebrake Wash (Figure 6). The faceted spur at this location appears to be an easterly dipping fault plane separating tonalite of Las Bancas (Todd, 1979) from much lighter colored tonalite of the La Posta pluton to the east. The presence of faulting here is further suggested by the presence of a dense growth of riparian vegetation indicative of a spring in an area that is otherwise sparsely vegetated. From this location northward, Todd (1979) maps a series of short *en echelon* fault segments near the base of the Laguna Mountains escarpment all the way to Cottonwood Canyon. South of the spur where the fault would pass through the La Posta pluton, there is little evidence of down-to-the-east faulting; only numerous very strong northerly striking topographic lineaments are evident.

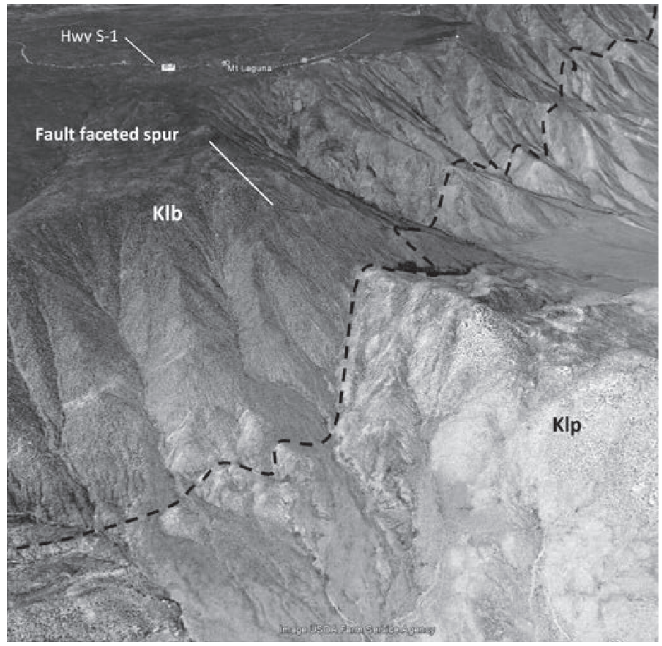

Figure 6. Google Earth view of fault-faceted spur east of Laguna Mountain at lat. 32° 52.275′, Long. 116° 22.676′) Klp: La Posta Tonalite; Klb: Tonalite of Las Bancas.

TECTONIC HISTORY

Following Allison's work, the next detailed description of the fault was by Lampe (1988) who mapped the Elsinore and Chariot Canyon faults in the vicinity of

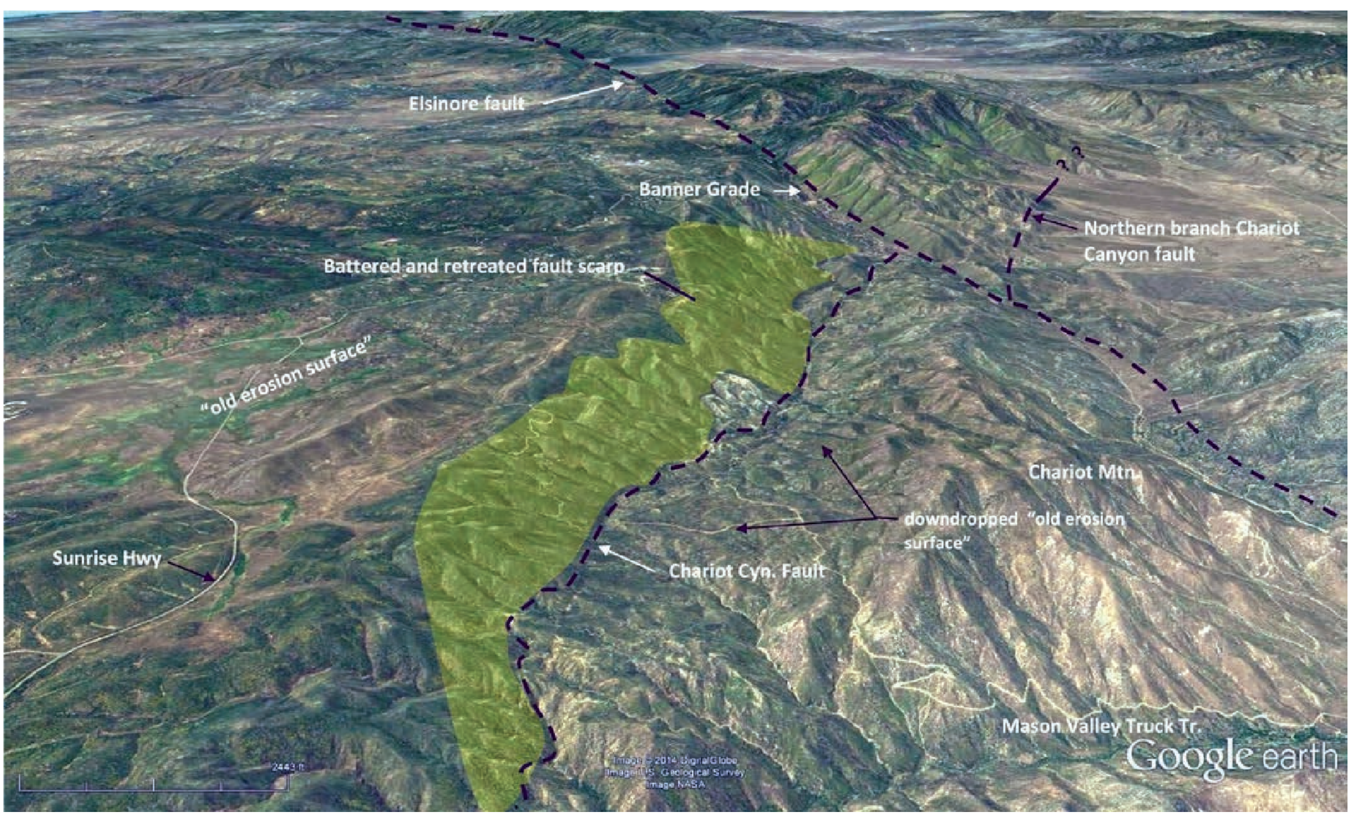

Figure 7. Google Earth image showing the postulated highly eroded and retreated Chariot Canyon fault scarp ahd offset "old erosion surface".

Granite Mountain south of Banner Grade for her Master's Thesis. Lampe (1988) describes the Chariot Canyon fault as juxtaposing Triassic-Jurassic Julian Schist on the west and metamorphic and plutonic rocks of Chariot Mountain on the east. An interesting result of her work is the conclusion that the fault is truncated by the Elsinore fault at its junction with Banner Canyon (Figure 3). In her report she describes the fault zone as consisting of fractured and gneissic rocks up to 70 m in width. Lampe (1988) was apparently the first to describe the fault zone as being characterized by both brittle and brittle-ductile deformation. Bracci (1993) also described the fault as having a two-fold tectonic history. First, Early Cretaceous (124 Ma) westward thrusting along low angle NE dipping reverse shear zones that occurred as a result of arc collision to the west followed by localized extension at 100–95 Ma. Grove and others (2003) indicated that brittle emplacement of deep seated rocks east of the fault over shallower level rock began approximately 95 Ma and that faulting was complete by 80 Ma. They noted also that the thermal history of the rocks indicates a 150°C temperature difference across the fault prior to 78 Ma that corresponds to a 5 km vertical separation.

Grove and others (2003) conclude that the northeast dipping fault was reactivated much later as an east-side-down normal fault during Late Cenozoic time with the result that early Tertiary erosion surfaces preserved in the topographically lower desert terrain northeast of the Elsinore fault generally occur at lower elevations than counterparts west of the fault. The result is a net down drop of desert ranges of approximately 500 m (depending on the elevation of the point at which the Eocene river system crossed the mountains). This is exemplified by remnants of the Eocene Ballena Gravels in the Vallecito Mountains of eastern San Diego County whose counterparts are found near Ramona (Abbott and others, 1984). This down-to-the-east displacement is compatible with late Tertiary extension and formation of the Salton Trough. In addition, a low-angle oblique view along the fault zone (Figure 7) suggests that the east facing escarpment extending from just south of Banner Grade to the vicinity of Oriflamme Canyon is a highly eroded and somewhat retreated fault scarp responsible for the down-to-the-east displacement of a portion of the "old erosion surface" that extends east and north of the Cuyamaca Reservoir. First described by Gastil (1961) the old erosion surface is cut in the crystalline rocks and generally stands well above modern stream valley and canyon gorges. It is believed to be related to a pre-Pleistocene erosion base (likely Late Cretaceous) of considerable duration. Its contours showed a distinct respect for more resistant rocks leaving small knobs and some considerable monadnocks above the more general elevation. El Cajon Mountain , Viejas, and Cuyamaca Peaks must have been prominent landmarks then as they are today" (Gastil, 1961).

The Chariot Canyon fault also provides a piercing point along the Elsinore fault that enables a determination of the amount of total slip along the southern portion of the Elsinore fault. There is approximately 19 miles of right slip of the fault at the northern end of the batholith, however, a much lesser amount is indicated by Todd (unpublished geologic map of the Julian 7.5 min. quadrangle) and Lampe (1988) who both show the Elsinore fault displaces the Chariot Canyon fault in a dextral sense approximately 1.6 miles near the foot of Banner Grade. This amount of slip is confirmed by a similar amount of offset of the Granite Mountain Tonalite at the same locality.

CONCLUSION

The research of graduate students and faculty in the Department of Geological Science at San Diego State University has solved much of the mystery of the timing and geometry of major tectonic events in the San Diego County portion of the Peninsular Range Batholith. In particular, the role the Chariot Canyon fault played in the structural history of the batholith and its significance in shaping the present day landscape has been well-documented. The nature of the fault's northern and southern terminus and how the rocks in those areas accommodated an apparent gradual die-out remains to be worked out and could be the subject of additional research.

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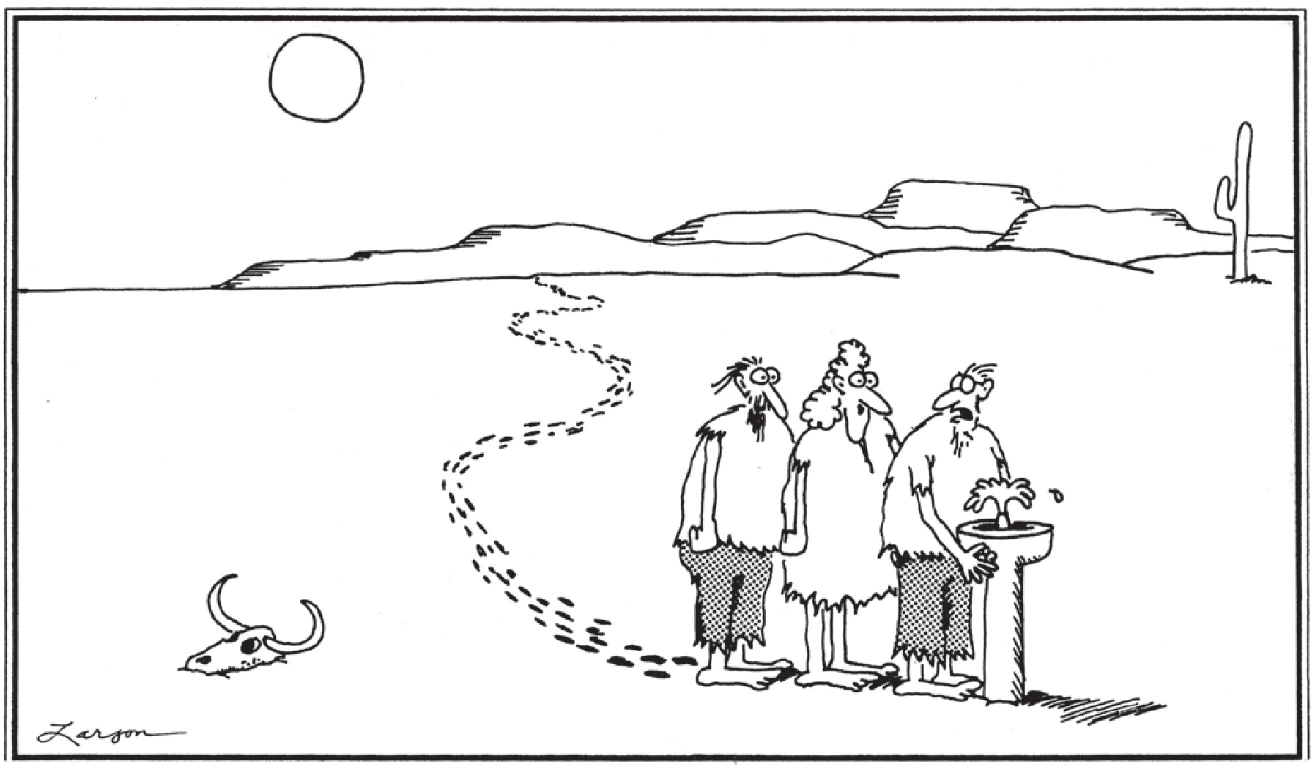

"Now just hold your horses, everyone. … Let's let it run for a minute or so and see if it gets any colder."