**Introduction.** The largest discontinuity along the 1100-km length of the San Andreas fault occurs in the San Gorgonio Pass region. The structural complexity presents a formidable challenge to forecasting the source characteristics of the fault system there. A primary objective of this field trip is to introduce student participants to some of the world-class geologic features on display and inspires questions and new directions for research. For those so inspired, a short overview article by Yule (2009) (and articles referenced therein) may be a good place to start learning more about the Pass region.

Mileages for this field trip begin at the intersection of Indian Canyon Drive and Tahquitz McCallum Way, a short distance to the west of the Hilton Palm Springs Resort, site of the 2009 SCEC Annual Meeting.

**Directions to Stop 1.** Drive 7.0 mi north on Indian Canyon Drive to Dillon Road and turn left (west). Drive 3.0 mi to Worsely Road and turn right (north). Drive 0.75 mi to Stop 1. Park vehicles on the right shoulder of Worsely Road.

**While driving to Stop 1.** Indian Canyon Drive intersects the Garnet Hill fault ~5 mi north of the starting point for this trip. The fault trace is mapped at the base of Hill, immediately to the northeast of this location. Located in the center of a broad alluvial plain, Garnet Hill’s occurrence can be explained by oblique slip (dextral-reverse slip) at a left stepover along the trace of the Garnet Hill fault (Figure 1). Other compressive steps in the fault trace occur to the northwest at Hugo Hill and East Whitewater Hill located to the east and west of the Hwy 62/Interstate 10 interchange, respectively. Indian Canyon Drive also crosses the Coachella Valley Banning fault ~6 mi north of the starting point. Buildings on both sides of the road are constructed directly on the fault trace here (pre Alquist-Priolo Act?). The Coachella Valley Banning fault also intersects Dillon Road ~0.75 mi to the west of Indian Canyon Drive. To the north of Dillon Road here, a south-facing scarp is evident where the fault has truncated an alluvial fan remnant. A similar-looking fan remnant occurs ~2 km along strike to the northwest, near Stop 1, and may represent the displacement across the Coachella Valley Banning fault since fan abandonment.

**Stop 1.** Coachella Valley Banning fault. Geomorphic expression of the fault here suggests pure, or nearly pure, strike slip motion. Shutter ridges occur to the east of the parking area. Here, a narrow, elongate gulley marks the fault and separates shutter ridges on either side of the fault. Walk east ~150 m to the top of these ridges for a view of the southern alluvial fan fragment that may match with the northern fragment along Dillon Road ~ 2 km to the east. On a clear day, Garnet Hill (and the trace of the Garnet Hill fault) is visible ~5 km to the southeast.

The epicenter of the 1986 Mw 5.9 North Palm Springs earthquake is located ~7.5 km to the north of Stop 1 (Figure 1). The rupture is interpreted to have occurred along a plane oriented ~N70°W, 45°NE, with a first-motion rake of 180°, indicating pure strike-slip faulting (Jones et al., 1986). First motion solutions for aftershocks indicate predominantly oblique motion (dextral reverse). Surface cracks were observed along the trace of the Coachella Valley Banning...
fault from Devers Hill to Whitewater Canyon; cracks were also observed in the fault scarp of the Garnet Hill fault at the mouth of Whitewater Canyon (Sharp et al., 1986). Displacements across cracks were determined to be legible.

Directions to Stop 2. Continue north on Worsely Road for 0.4 mi to the intersection with Painted Hills Rd. Make a hard left turn (now heading SW) and drive 0.25 mi to intersection with Old Morongo Rd. Bear left at intersection and drive 3.25 mi bearing generally SW to intersection with Whitewater Cutoff. Follow Whitewater Cutoff 0.65 mi across the Whitewater River to intersection with Whitewater Canyon Road. Turn right (north) and drive 1.45 mi to Stop 2. Park on shoulder of road and walk to where one has a good view of canyon exposures to the west.

While driving to Stop 2. The Coachella Valley Banning fault is follows the base of the hills to the north. About halfway to Whitewater Canyon, the road passes north of East Whitewater Hill, a hill located at a left stepover of the Garnet Hill fault (Figure 1). Descending into Whitewater Canyon, roadcut exposures show a well-developed, orange-weathering soil beneath the upland surface; also note the coarse alluvial gravel that comprises the outcrop beneath the soil. Note the south-facing scarp of the Garnet Hill fault to the north of the road and to the west of Whitewater River (Matti et al., 1985). Buildings are constructed at the base of this scarp.

Stop 2. Coachella Valley Banning fault at Whitewater Canyon (Figures 1 and 2). Vegetation in Whitewater Canyon marks the surface trace of the Coachella Valley Banning fault. The fault is also exposed in a large side canyon to the west of the parking area. Here the fault juxtaposes a Cretaceous-Precambrian granite and gneiss complex on the north against Pleistocene alluvial gravels on the south.

Figure 1. (modified from Figure 1 of Yule, 2009). Field trip stops 1-5 located by “x’s”. Shaded-relief topographic map of San Gorgonio Pass (SGP) region. Traces of active faults shown in red, inactive faults shown in black. Mapping from Allen (1967), Matti et al. (1985), and Yule and Sieh (2003). Beach-balls show epicenters of moderate earthquakes to strike the region since 1948.
Where exposed, the fault dips 45° N in the south-facing slopes of the side canyon. Time permitting one may walk into the side canyon to view the fault and its geomorphic expression of small ridges cutting parallel to contour, across the south-facing slopes of the side canyon.

**Directions to Stop 3.** Return to intersection of Whitewater Canyon Road and Whitewater Cutoff. Turn right (west) and drive 0.15 mi to I-10 onramp. Enter Interstate 10 and drive 2.55 mi to exit for Haugen Lehman Way. Exit and follow off ramp for 0.2 mi (it passes beneath an overpass and then doubles back). Turn left (north) onto Haugen Lehman Way. Drive 0.7 mi to intersection with Cottonwood Dr. Turn right (NW) and drive 0.8 mi to end of pavement, continue uphill 0.5 mi on dirt road to parking area and Stop 3.

**While driving to Stop 3.** The large hill to the north, known as West Whitewater Hill, exposes fluvial deposits of the Cabezon Formation and is capped with a deep-red soil, indicative of ≥100,000 yrs of exposure. The surface has an anticinal shape. Moderate dips in underlying deposits define this anticlinal warp as well. The deposits appear more deformed than the surface, so the anticline was growing during, as well as after, deposition of the sediments (Yule and Sieh, 2003). Northwest-trending faults cut the deposits and the old surface.

The provenance of Cabezon gravels exposed at West Whitewater Hill indicates a source from the north of the Mission Creek fault, by way of an ancestral Whitewater River (Allen, 1957; Matti et al., 1985, 1992; Matti and Morton, 1993). Paleocurrent indicators in the gravels led Matti et al. (1985, 1992) and Matti and Morton (1993) to propose about 2-3 km of dextral slip across the Coachella Valley Banning fault since the gravels were deposited.

The Garnet Hill fault bounds the southern flank of West Whitewater Hill and has two traces, one along the flank of...
the steep southern slope of the anticline, and another in the young alluvium farther south (Matti et al., 1992; Matti and Morton, 1993; Morton et al., 1987). There is geomorphic evidence that slip on these faults is a combination of dextral and reverse slip, and by the rule of V’s, the trace geometry of the northern fault indicates a steep to moderate dip northward.

**Stop 3.** Cottonwood Canyon. A major change in the style of active faulting occurs at Cottonwood Canyon (Figures 1 and 2). To the east, shallow ridges in gravel as well as channels cut into bedrock show dextral offset along the Coachella Valley Banning fault. Active strike-slip motion on the Coachella Valley Banning fault diminishes toward the west where it appears to end as an active strike-slip fault at Cottonwood Canyon (Yule and Sieh, 2003).

To the west, thrust faults dominate the neotectonic landscape. The active and inactive thrusts include the San Gorgonio Pass thrust and Banning fault systems, respectively. We will explore the evidence for this style of faulting at this stop. Here, several old alluvial surfaces along the mountain front project well above neighboring active alluvial fans (see Figure 11 in Yule and Sieh, 2003). For example, a few hundred meters south of the mountain front a broad active channel separates an old alluvial surface into two remnant terraces. Young alluvium laps onto both remnants except for the western flank of the western remnant that has been eroded. The southeastern edges of both remnant terraces are also eroded, but that erosion occurred in response to uplift of the terraces along a NE-SW-striking, NW-dipping thrust.

Small thrust scarps also occur in young alluvium to the north of the remnant terraces, at the foot of the range. Exposed in the hill above these scarps, granite and gneiss overlie older alluvium along a low-angle, south-dipping contact. This contact in interpreted to be a thrust fault that is no longer active as slip has stepped southward to the thrusts described above.

A large rotational landslide obscures the geologic relationships of the slopes immediately west of Cottonwood Canyon (Morton et al., 1987; Yule and Sieh, 2003). The headscarp and lateral margins of this slide are readily apparent and leave no doubt that the feature is of non-\text{tectonic} origin. A small sector on the western flank of the slide failed in 1993.

**Directions to Stop 4.** Return to I-10. From the onramp, enter I-10 freeway and drive 4.9 mi to Cabezon exit. Drive 0.15 mi to stop sign at end of off ramp and turn left (west) onto frontage road. Drive 1.9 mi to a roundabout intersection and continue west on frontage road for 1.3 mi to Fields Rd. Turn right and proceed to entrance gate to Morongo Band of Mission Indians Reservation. Note: permission to access tribal lands can be obtained beforehand from the Tribe’s Environmental Office. Once inside the gate make an immediate right turn onto Martin Road. Drive 1.0 mi to end of pavement and bear left (NE) onto dirt road heading into Millard Canyon. Drive 0.65 mi to intersection with small dirt road and park (Stop 4a). If time permits, continue north 0.75 mi to a four-way, dirt intersection and park (Stop 4b).

**While driving to Stop 4.** As one approaches the 27-story Casino Morongo and Hotel, look to the north and notice a scarp that cuts at a high angle across the mouth of Millard Canyon. This base of this scarp marks the surface trace of the San Gorgonio Pass thrust. We will visit this feature at Stop 4a. The scarp at Millard Canyon continues southwest where it almost intersects Interstate 10 (Figures 1 and 2). Here, cutting through the parking lots behind a large factory-outlet shopping mall, the fault trace bends northwest toward the mountain front along a series of strike-slip tear faults (Yule and Sieh, 2003). After entering the Morongo Reservation, look to the south while driving east on Martin Road and notice that the alluvial surface projects above the outlet mall. This surface has been uplifted in the hanging wall of the San Gorgonio Pass thrust.

**Stop 4a.** Millard Canyon, San Gorgonio Pass thrust scarp. A fluvial terrace riser is evident ~150 m east of the parking area. Climb the riser and walk southeast to the highest point on the scarp, a height of 12.5 m above the base of the scarp. Walk down the scarp and notice that the slope gradually gets steeper and reaches its maximum steepness at the base of the scarp. This steeping down the slope defines an asymmetric fold and suggests that little, if any, diffusion has occurred across the scarp. Shortening at the surface may be accommodated entirely by folding above a blind thrust. If the thrust has reached the surface here it must have a slip vector of ~S40°E parallel to a small fluvial terrace riser that can be followed from the hanging wall block to the footwall block with no lateral offset (see Fig. 6 in Yule and Sieh, 2003).

Walk east from the high scarp and climb down another fluvial terrace riser onto a much younger alluvial surface. Look for a 1.5 m scarp on this lower surface to the east of a dirt road. The west wall of the modern arroyo exposes gravel and sand layers cut by a 24° north-dipping thrust. Ages of the high and low scarps are poorly constrained. Detrital charcoal from gravel layers beneath the lower surface yield an age of 2850-3600 radiocarbon years (J.C. Tinsley and J.C. Matti in Matti et al., 1992a, p. 26). The poor degree of soil development on the upper surface suggests that it is no older than latest Pleistocene in age. The preliminary age data from these surfaces constrain uplift
and north-south shortening each to be >1-2 mm/yr over the past 10,000 yrs or so.

**Stop 4b.** Millard Canyon, Banning fault scarp. Much of the Banning fault in San Gorgonio Pass is inactive. However, a 3-km-long segment of the northern strand is active. About 100 m to the north of the parking area, a 5-m-high scarp and a 2.5-m-high scarp occur in older and younger alluvial surfaces. The fluvial terrace riser between these two surfaces appears to be offset right-laterally ~4.5 m (Figure 8, Yule and Sieh, 2003). Thus the dextral offset across the fault appears to be ~80% greater than the vertical component.

To the east, this active portion of the Banning fault also offsets the late Pleistocene Heights fanglomerate several hundred meters. On the eastern wall of the canyon, the fault trace rises from the canyon floor at a dip of ~45° N and juxtaposes crystalline rocks over the fanglomerate. Farther up the canyon wall the fault flattens to a nearly horizontal dip and overrides the surface of the Heights fanglomerate. Exposures in the canyon wall reveal a buttress unconformity between the fanglomerate and an older eastern wall of the canyon. The base of the buttress unconformity is offset obliquely across the Banning fault with a strike-slip: dip-slip ratio of ~2.5:1, greater than that derived from the younger scar on the valley floor (Yule and Sieh, 2003). Nonetheless, both observations show that strike-slip offset exceeds dip-slip offset on this active section of the Banning fault.

**Directions to Stop 5.** Return to the Reservation’s entrance gate at the intersection of Fields and Martin Roads. Proceed (north) on Fields Road 1.0 mi to Morongo Road and turn left (west). Drive 0.35 mi west to Potrero Road and turn right (north). Drive 0.65 mi to Foothill Road; continue north through the intersection and a metal gate. Drive 2.75 mi uphill along a graded dirt road to a fork in the road at the foot of a small hill. Park and walk to the top of the hill (Stop 5a). If time permits drive on the right fork and continue uphill 0.35 mi to a ‘T’ intersection. Turn left (west) and drive 1.25 mi to fork in road and park (Stop 5b, a walking tour along a 500 m segment of the fault).

**While driving to Stop 5.** Note several ‘bumps’ in Fields Road that step up on the north. A large house is constructed adjacent to the third and largest of these steps. Each step represents a fault trace of the San Gorgonio Pass thrust system. These structures are interpreted as tear faults that connect thrust faults west of Potrero Canyon with those of Millard Canyon (Matti et al., 1985, 1992a; Matti and Morton, 1993; Yule and Sieh, 2003).

A fluvial terrace riser occurs immediately west of the intersection with Morongo Road. The higher, oldest surface is an isolated erosional remnant that shows an east-west striking scarp, parallel to and north of Morongo Road. Potrero Road crosses this structure providing a profile view of the broad asymmetric fold exposed in the west wall of the modern arroyo. This structure is slightly larger, but similar in style, to the scarp observed at Stop 4a.

The subtle expression of a scarp along the Gandy Ranch fault (Allen, 1957) occurs ~1 km north of the mouth of Potrero Canyon. The scarp is defined by a slight steepening of the alluvial fan surface from north to south immediately north of the modern arroyo.

**Stop 5a – Burro Flats overview.** Stop 5a is located on top of a low east-west ridge. This ridge is underlain by granite and gneiss and capped by a veneer of coarse alluvium. A marshy area occurs at the base of the hill to the north where groundwater ponds against the bedrock contact. A small up-on-the-south scarp cuts obliquely across the alluvial fan to the north of the marsh. East-trending, down-on-the-south faults occur at the base of the mountains to the north. These east-trending faults comprise the Cox Ranch fault zone, a discontinuous set of inferred normal slip faults in the hanging wall of the San Gorgonio Pass thrust (Yule and Sieh, 2003). The Cox Ranch fault zone can be traced east to the Cottonwood and Whitewater Canyon areas where it appears to merge with the Coachella Valley Banning fault. To the west, the San Bernardino San Andreas fault occurs as a series of right-stepping fault segments. The road to stop 5b runs parallel to the fault. Burro Flats is therefore a fault-bounded, intermontane basin.

On a clear day, this vantage point provides a spectacular view of San Jacinto Peak (elev. 3,270 m). Also to the south, the mouth of Potrero Canyon frames the 27-story Casino Morongo Hotel located in the foothall of the San Gorgonio Pass thrust system.

**Stop 5b – Burro Flats trench site.** The parking area is located at right-stepover along the San Bernardino San Andreas fault. Walk northwest along the fault trace ~250 m to where the fault branches into two strands at the southeastern edge of another right stepover. Here, in an middle Holocene alluvial fan cut by the fault, a three-dimensional trench excavation was undertaken to explore for buried channels and other features to try and constrain the slip across the fault (Orozco, 2004). A wedge of sand and silt was discovered on both sides of the fault. The wedge tip provided a crude piercing line that indicates 30 ± 15 m of dextral offset has occurred across the fault since deposition of the sand and silt. Detrital charcoal grains constrain the age of the sand/gravel at ~3,800 yrs BP. The slip rate for the San Bernardino San Andreas fault here is 4-12 mm/yr (Orozco, 2004). Further excavation here may help to better constrain the dextral offset and provide a more precise slip rate.
Farther to the northwest, the fault zone broadens to form a 100-m-wide stepover basin. Here the fault enters a marsh that is partially buried by a very young alluvial fan. Interlayered peat and alluvium, in combination with active deformation of the stepover basin, make this an ideal paleoseismic site. A series of 10 trenches excavated at this site expose evidence for at least nine paleoearthquakes that span the last 2,000 yrs. The most recent rupture deformed peat layers that contain European-introduced pollen and therefore must post-date ~1750 A.D. This most recent event probably represents the 1812 earthquake known from sites 50 to 150 km to the northwest. The penultimate event is constrained to have occurred between 1670 and 1730 A.D. and may correlate with a large earthquake ~300 yrs ago that is known from the paleoseismic record in regions both to the northwest and southeast. In fact, the timing of five paleoearthquakes at this site overlap with the timing of ruptures at sites in both the Mojave and Coachella Valley regions. However, the overlap in age data of 50-100 years cannot rule out competing scenarios. On the one hand, one very large (M 7.9) quake may have ruptured a >300 km length of the fault from the Salton Sea to the Mojave Desert. On the other hand, two or more large (M 7.4) quakes may have ruptured the same length of the fault over a span of 50 to 100 yrs, perhaps with the structural complexity of San Gorgonio Pass acting as a barrier to thoroughgoing rupture. The former scenario has been adopted over the latter for use in preparing the ShakeOut Exercise.

End of Trip.

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References Cited

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