INTRODUCTION

Potentially active traces of the San Andreas and related faults in the Southeastern Mecca Hills-Bat Caves Buttes (SEMH-BCB) study area are evaluated in this Fault Evaluation Report (FER) (Figure 1). Traces of the San Andreas Fault, Hidden Spring Fault, Powerline Fault, Mecca Hills Fault Zone (Painted Canyon, NW Painted Canyon, Platform and Eagle Canyon faults), Skeleton Canyon Fault, and the postulated Witbaard Fault are located in the Mecca, Mortmar, Salton, Orocopia Canyon, and Durmid 7.5-minute quadrangles (CDMG, 1974a-1974e)(Figure 1, Plates 1a and 1b).

Traces of the San Andreas and related faults in the SEMH-BCB study area are evaluated as part of a statewide effort to evaluate faults for recency of activity. Initial maps issued by the State Geologist in 1974 as required by the Alquist-Priolo Earthquake Fault Zoning Act (then known as the Alquist-Priolo Special Studies Zones Act) encompassed faults in regulatory zones if they showed evidence of surface displacement during Quaternary time (last 1.6 million years). Thus, some faults in the SEMH-BCB study area may not meet current zoning criteria (Bryant and Hart, 2007). Those faults determined to be sufficiently active (Holocene) and well-defined are zoned by the State Geologist as directed by the Alquist-Priolo Earthquake Fault Zoning (AP) Act of 1972 (Bryant and Hart, 2007).

Most faults in the SEMH-BCB study area were included in Alquist-Priolo regulatory zones released on July 1, 1974 (CDMG, 1974a-1974e). At that time, these regulatory zones were known as Alquist-Priolo Special Studies Zones and the AP Act was called the Alquist-Priolo Special Studies Zones Act. In 1994, the name of the AP Act was changed to the Alquist-Priolo Earthquake Fault Zoning Act and the regulatory zones are now referred to as Alquist-Priolo Earthquake Fault Zones (APEFZ). For consistency in this FER, the regulatory zones will be called Earthquake Fault Zones.

SUMMARY OF AVAILABLE DATA

The SEMH-BCB study area lies partly in the Mecca Hills and partly in the Salton Trough. The Salton Trough is a complex structural and topographic depression dominated by active tectonism of the San Andreas Fault System. Topography here is of low relief characterized by landforms attributable to Holocene Lake Cahuilla. To the north, the Mecca Hills bound the northeastern margin of the Salton Trough and are underlain by pre-Cenozoic crystalline basement rocks that in turn are overlain by highly deformed Tertiary and Plio-Pleistocene age sedimentary rocks. Sylvester and Smith (1976) described the Mecca Hills as the surficial expression of a “palm tree structure” (or flower structure) formed as the result of convergent strike-slip faulting. Three structural domains within the Mecca Hills were described by Sylvester and Smith: a basin block located west of the San Andreas Fault, a highly deformed central block
bounded on the west by the San Andreas and Skeleton Canyon faults and on the east by the Painted Canyon Fault. East of the Painted Canyon Fault is the platform block.

Elevations in the study area range from 1781 feet above sea level (Shavers Peak) to about 230 feet below sea level. Development in the study area is very sparse and includes the towns of Mecca, North Shore, and Mortmar along the northern and northeastern shore of the Salton Sea.

Predominant rock types in the study area include pre-Cambrian metamorphic rocks of the Chuckwalla Complex, Mesozoic Orocopia Schist, Tertiary non-marine sedimentary rocks of the Mecca Formation, Plio-Pleistocene Palm Spring Group, Pleistocene Canebrake-Ocotillo Conglomerate, and latest Pleistocene and Holocene alluvium and Lake Cahuilla lacustrine deposits (Sylvester and Damte, 1999; Sheridan and others, 1994; Lutz and others, 2006). The 0.77 Ma Bishop Ash (Boley and others, 1994; Sarna-Wojcicki and others, 2000) is found in the upper Palm Spring Formation (Rymer, 1991).

LITERATURE REVIEW

San Andreas Fault

The San Andreas Fault is a major dextral transform fault that delineates the margin between the Pacific and North American plates. Traces of the San Andreas Fault were encompassed in Alquist-Priolo Earthquake Fault Zones (APEFZ) in 1974 on the Mecca, Mortmar, Orocopia Canyon, Salton, and Durmid 7.5-minute quadrangles using the mapping of Hope (1969), Dibblee (1954), CDWR (1964), Babcock (1969), and Ware (1958) (Plates 1a and 1b). Mapping by Dibblee (1954) was at a scale of 1:379,400 and the mapping by CDWR (1964) was at a scale of 1:146,215. Due to the small scale and generalized mapping of the San Andreas Fault, the maps by Dibblee and CDWR (1964) will not be considered further in this FER.

Although there have been no significant surface-rupturing historic earthquakes along this section of the San Andreas Fault, nearby historic earthquakes have triggered fault creep, or triggered slip, along specific traces of the San Andreas Fault. Notable triggered slip events along the San Andreas Fault are associated with the 1968 Mw 6.6 Borrego Mountain and 1979 Mw 6.5 Imperial Valley (El Centro) earthquakes (Allen and others, 1972; Hope, 1969; Clark, 1984). Other earthquakes that have triggered slip on this part of the San Andreas Fault include the 1992 Mw 7.3 Landers, 1999 Mw 7.1 Hector Mine, and Mw 7.2 El Mayor-Cucapah earthquakes (Rymer, 2000; Rymer and others, 2002; Treiman and others, 2010; Rymer and others, 2011; Wei and others, 2011). The general locations where triggered slip has been observed are shown by date of event on Plates 1a and 1b.

Hope (1969)

Mapping by Hope (1969) was focused on identifying recently active traces of the San Andreas Fault and in the study area was based primarily on aerial photographic interpretation (Plates 1a and 1b). Hope mapped discontinuous traces that are delineated by right-laterally deflected drainages, a southeast-facing scarp in Holocene alluvium, and linear vegetation contrasts. Mapping by Hope generally was verified by this writer (indicated by red check mark on Plates 1a and 1b).

Ware (1958)

Two short traces of the San Andreas Fault were mapped by Ware (1958), located just southeast of Painted Canyon, and were used in the 1974 APEFZ Map of the Mecca quadrangle.
(Plate 1a). Ware’s traces depicted on the APEFZ Map were somewhat generalized and locally mis-located, primarily due to the poor quality base map used by Ware. Faults mapped by Ware as depicted on the 1974 APEFZ Map of the Mecca quadrangle are shown in grey on Plate 1a. I’ve replotted his mapping using his original map at 1:27,150 scale and have depicted them in pink on Plate 1a. Recently active traces of the San Andreas Fault between Painted Canyon and Box Canyon generally are not well-defined and I was not able to verify mapping by Ware (1958). Refer to the discussion of mapping by Hays (1957) and Clark (1984) below for this area between Painted Canyon and Box Canyon.

Hays (1957)

Traces of the San Andreas Fault mapped by Hays (1957) are located southeast of Painted Canyon and extend about 2 km southeast of the Coachella Canal (Plate 1a). Faults mapped by Hays, at a scale of 1:14,000, were not used on the 1974 APEFZ Maps of the Mecca and Mortmar quadrangles. The San Andreas Fault between Painted Canyon and Box Canyon is poorly defined and is depicted by Hays as a polygon showing the boundaries of a zone of brecciated and altered rock, rather than specific traces (locality 1, Plate 1a). This zone varies in width from 10 meters to greater than 150 meters. The boundaries of the fault zone are irregular and dips along the margins vary from near vertical to angles between 35° to 60° NE.

Hays (1957) mapped two strands of the San Andreas Fault southeast of Box Canyon. These two strands offset Pleistocene older alluvium, but are shown as concealed by late (?) Holocene alluvium (Plate 1a). The short southwestern trace is delineated by a linear bench and offset channels that were also mapped by Clark (1984). I was able to verify these features on the southwestern trace (Plate 1a). The northeastern trace of Hays lacks geomorphic expression of Holocene right-lateral strike-slip faulting, based on mapping by Clark and air photo interpretation by this writer (locality 2, Plate 1a).

Hays (1957) reported that the San Andreas Fault dextrally offsets stream channels of probable late Pleistocene age. Skeleton Canyon, located just southeast of Painted Canyon, is offset about 4,000 feet (1,220 meters) along the San Andreas Fault (locality 3, Plate 1a).

Babcock (1969)

Traces of the San Andreas Fault in the Salton and Durmid 7.5-minute quadrangles mapped by Babcock were encompassed in an Earthquake Fault Zone in 1974 (Plate 1b). These traces locally were mis-located on the 1974 APEFZ map by as much as 220 feet (67 m), but are plotted accurately on Plate 1b. Traces mapped by Babcock locally agree with traces mapped by Hope (1969) and Clark (1984), although differences in detail exist, especially at the northern part of the Salton Quadrangle where Babcock’s trace is located 100-150 meters northeast of the fault mapped by Hope and Clark (locality 4, Plate 1b). Southeast of Salt Creek, Babcock depicts the San Andreas Fault as a zone of deformation up to 155 m wide (shown as a green hachured polygon on Plate 1b). The 1974 EFZ Map of the Durmid Quadrangle depicted mapping by Babcock as parallel and somewhat discontinuous traces southeast of Salt Creek (Inset A, Plate 1b).

Babcock noted that Salt Creek is right-laterally deflected about 2,800 feet (853 m), and inferred that the displacement is post Borrego Formation (Pleistocene) (locality 5, Plate 1b). Lutz and others (2006) reported that the Brawley/Ocotillo Formation that overlies the Borrego Formation ranges in age from 1.1 Ma at the base of the formation to 0.5 Ma at the top, based on paleomagnetic studies. This implies a minimum dextral slip rate of about 0.8 mm/yr. South of Bat Caves Buttes, Babcock reported that the stratigraphic separation between rocks of the Borrego Formation on either side of the fault zone is approximately 3,670 feet (1.1 km).
Recently active traces of the San Andreas Fault mapped by Clark (1984) are shown in blue on Plates 1a and 1b. Clark defined “recently active” as displacement during late Quaternary time, “roughly the past 100,000 years.” Traces of the San Andreas Fault mapped by Clark were based on aerial photographic interpretation and field inspection, and were shown on 1:24,000-scale strip maps with annotations showing geomorphic evidence of recent offset (Plates 1a and 1b). The San Andreas Fault mapped by Clark in the Mecca Quadrangle northwest of Painted Canyon is delineated by abundant geomorphic evidence of Holocene dextral displacement, including dextrally offset drainages, hillside valleys, and benches. Mapping by Clark locally corresponds to mapping by Hope (1969), although differences in detail exist (Plates 1a and 1b).

Clark noted the San Andreas Fault lacks geomorphic evidence of recent dextral displacement in the structurally complex badlands about 3 km southeast of Painted Canyon. This is the area where detailed mapping by Hays (1957) shows a broad, complex zone of faulting (locality 1, shown as a gray polygon on Plate 1a). My air photo interpretation confirms the lack of distinct, systematic geomorphic expression of recent dextral strike-slip offset along this stretch of the fault (Plate 1a). Significantly, Clark noted that triggered slip was not observed following the 1968 and 1979 earthquakes along this structurally complex reach of the fault. Clark suggested that displacement here is either distributed over a broad zone, or is partly to entirely absorbed by folding or other deformation of the Plio-Pleistocene sediments of the badlands.

Mapping by Clark (1984) differs somewhat from Hays (1957) just northwest and southeast of Box Canyon. Here Hays mapped faults about 250 meters to the northeast of Clark, although a short trace of Hays essentially coincides with the mapping of Clark (locality 2, Plate 1a). I did not verify the northeast trace mapped by Hays (1957) near locality 2.

From Box Canyon southeast to the vicinity of Mortmar, Clark reported that the San Andreas Fault is delineated by dextrally offset drainage channels, a scarp in older (late Pleistocene) alluvium, and aligned vegetation contrasts in Holocene alluvium (Plates 1a and 1b).

The southernmost San Andreas Fault along the eastern side of the Salton Sea lies entirely below the last Holocene Lake Cahuilla high stand (below the 40-foot contour). Therefore, the geomorphic expression of the fault generally has been modified by and/or developed since the latest withdrawal of the lake, about 200-400 years ago (Clark, 1984; Waters, 1983). Geomorphic features delineating recently active traces of the San Andreas Fault mapped by Clark (1984) include aligned vegetation contrasts, low scarps generally less than 1 m high (both northeast and southwest facing), and linear lithologic contrasts (Plate 1b). Clark reported that almost all of the geomorphic features associated with recency coincide with triggered slip associated with the 1968 Borrego Mountain and 1979 Imperial Valley earthquakes (Plate 1b). Triggered slip associated with these events is depicted in detail by Clark (shown as red hachured pattern on Plates 1a and 1b).

**Paleoseismic and Creep Monitoring Sites**

Behr and others (2010) reported a late Pleistocene dextral slip rate between 14 and 17 mm/yr for the Coachella section of the San Andreas Fault, based on a dextrally displaced 45-54 ka alluvial fan at the Biskra Palms site, located about 25 km north of the SMH-BCB study area. Shifflett and others (2002) reported a minimum late Pleistocene slip rate of 5-8 mm/yr at the Stone Rings paleoseismic site (locality 31, Plate 1a; Photo 1), based on dextrally offset lagoon...
deposits. They reported a Holocene slip rate of 12 ± 0.5 mm/yr, based on 28.4 m dextral offset of an eroded edge of a paleofan surface. Age control of the paleofan surface was inferred from a 2.3 ka radiocarbon age of pedogenic carbonate. Sieh and Williams (1990) calculated an average dextral creep rate of 3.4 ± 0.7 mm/yr for the past 300 years at the Indio site (about 18.5 km northwest of the SMH-BCB study area). At Salt Creek, a dextral creep rate of 1.9 ± 0.2 mm/yr was reported by Sieh and Williams (1990) for the period ~1906 to 1987. Bilham (2010) has established creep monitoring sites along the San Andreas Fault at the Ferrum, Salt Creek, and Durmid sites (Plate 1b). Creep rates for the period 2004 to 2009 ranged from less than 1 mm/yr at the Salt Creek site to about 1.77 mm/yr at the Ferrum site. Seitz and Williams (2007) identified 6 events in the past 1.2 ka at the Salt Creek paleoseismic site (Plate 2a). Measured creep associated with the 2010 El Mayor-Cucapah earthquake was 3.5 mm at the Salt Creek site and 3.2 mm at the Ferrum Site (Rymer and others, 2011).

Witbaard Fault

The postulated Witbaard Fault, located between the San Andreas Fault and Mecca Hills Fault Zone, was proposed by Shifflett and others (2002), based on dextrally deflected drainages, a dextrally deflected ridge, aligned notches and vegetation lineaments in Pleistocene Ocotillo Formation (e.g. Witbaard Ridge, locality 22, Plate 1a). In addition, GPS surveys spanning the timeframe from 1992 to 1998 suggest that the Witbaard Fault may be creep active. Shifflett and others postulated that creep along the San Andreas Fault, common southeast of Mortmar, steps right to the Witbaard Fault. They reported a dextral creep rate of 2-4 mm/yr that they attributed to the Witbaard Fault. A seismic refraction survey also suggested the presence of a fault, although Shifflett and others did not provide data for the refraction line. The Witbaard Fault, as mapped by Shifflett and others, extends for about 11 km, connecting to the southeast with a sinuous, generally northwest-trending feature shown on Clark’s (1984) strip map (locality 6, Plate 1a). This feature mapped by Clark follows the 40-foot contour line and is coincident with a shoreline feature. Additionally, Clark provided no geomorphic annotations documenting that the feature is actually fault-related. I spoke with Clark in December 2010 and he stated that the feature shown on the map was in error: it is a shoreline and not a fault.

Skeleton Canyon Fault (Coachella Valley Fault)

The Skeleton Canyon Fault was first mapped and named by Hays (1957), based on an exposure of the fault in Skeleton Canyon. The fault has an overall strike of N52°W, trends generally parallel to the San Andreas Fault, and extends for more than 6 miles (9.6 km) as a southwest vergent thrust fault. Exposures of the fault show fault planes varying in width from a few inches to 2 feet (Hays, 1957). The fault dips 40° to 70° northeast. Hays wrote that although the Skeleton Canyon Fault is primarily a thrust fault in his study area, the fault has a complex history and northwest of Painted Canyon slip probably includes a strike-slip component. Hays estimated a maximum Plio-Pleistocene thrust displacement of about 3,000 feet (914 m) in the vicinity of Box Canyon, which would suggest a minimum reverse slip rate of 0.2 to 0.8 mm/yr (assuming that the age of the offset Palm Spring Formation ranged in age from 3.9 Ma to 1.1 Ma). Hays estimated significantly less dip-slip offset to the northwest.

There is some variation in the naming of this fault that strikes subparallel to the San Andreas Fault. Hays (1957) named the fault Skeleton Canyon Fault, based on an exposure of the fault in Skeleton Canyon. Ware (1958) mapped the fault northwest of Painted Canyon, but did not name the fault. Sylvester and Smith (1976) referred to this fault, extending from Box Canyon northwest to near its inferred intersection with the San Andreas Fault (beyond the study area – refer to Bryant, 2012), as the Skeleton Canyon Fault. Riverside County (2001) digitally compiled faults in their area of responsibility and assigned two names: the fault southeast of
Box Canyon is referred to as the Skeleton Canyon Fault and the Coachella Valley Fault was assigned to the trace to the northwest.

Traces of the Skeleton Canyon Fault in the FER study area were zoned in 1974 based on mapping by Ware (1958) and California Department of Water Resources (CDWR, 1964). Mapping by CDWR (1964), at a scale of 1:146,215, is somewhat generalized and will not be evaluated in this FER. Ware (1958) mapped traces of the Skeleton Canyon Fault that were used in the 1974 issue of the Mecca, Thermal Canyon, and Mortmar APEFZ maps (Plate 1a; see Bryant, 2012 for evaluation of traces on the Thermal Canyon Qd.). However, traces depicted on the APEFZ Maps were simplified and locally mis-located up to about 350 feet (Plate 1a). The fault zone is sub-parallel to the San Andreas Fault and essentially extends along the southwestern side of the Mecca Hills. Ware reported that the fault is characterized by right-reverse oblique displacement. The fault offsets Plio-Pleistocene rocks of the Palm Spring Formation and Pleistocene Brawley Formation. Very late Holocene alluvium is mapped as concealing the fault zone. Just northwest of Painted Canyon, a strand of the Skeleton Canyon Fault is characterized by north to west vergent thrust displacement.

Mapping by Sylvester and Smith (1976) and Sylvester and Damte (1999) is similar to Ware (1958), although differences in detail exist (see Figure 2 for small-scale map of the traces mapped by Sylvester and Smith and Sylvester and Damte – larger scale mapping was not available for this fault evaluation). Specifically, they mapped two closely spaced, essentially parallel traces where Ware had mapped one trace. They extended the northeastern trace farther south, beyond the thrust flap they and Ware had mapped, extending southeast of Painted Canyon. Sylvester and Damte do not directly address the issue of recency of the Skeleton Canyon Fault.

Clark (1984) did not observe geomorphic evidence of recent displacement along traces of the Skeleton Canyon Fault.

Hidden Spring Fault

The Hidden Spring Fault was zoned in 1974 in the Mortmar, Orocopia Canyon, and Durmid quadrangles, based on mapping by Crowell (1959) and Babcock (1969) (Plates 1a and 1b). Babcock’s traces of the Hidden Spring Fault locally were mis-located up to 160 feet (49m) on the 1974 APEFZ map, but are plotted accurately on Plate 1b. The fault was originally zoned because it offsets Plio-Pleistocene rocks of the Palm Spring Formation and locally offsets latest Pleistocene to Holocene lacustrine deposits of Lake Cahuilla (Babcock, 1969). The fault extends for about 20 km from the vicinity of Salt Creek northwest to near Shavers Well in the Box Canyon area of the Mecca Hills (Plates 1a and 1b). Babcock reported that the fault is expressed by a line of seeps, springs, and oases extending from the Eagle Mountain (Mining) Railroad northwest to the Coachella Canal (localities 7 and 8, Plate 1b). The fault acts as a groundwater barrier and has an apparent up on the southwest vertical component of displacement.

Hays (1957) also mapped strands of the Hidden Spring Fault in the Mortmar Quadrangle, but his mapping was not used in the corresponding 1974 EFZ map (CDMG, 1974c) (Plate 1a). In this area, Hays reported that the fault is steeply dipping to vertical and is expressed in outcrop as a gouge or breccia zone varying in width from a few inches to a foot (30 cm). Displacement is dextral-oblique and the most recent displacement is predominantly dextral strike-slip, based on generally horizontal slickensides observed in the fault plane. About 3/4 mile (1.2 km) of dextral strike-slip displacement was inferred by Hays in the Hidden Spring Canyon area, based on separation of the northeast limit of a distinctive basal breccia facies (locality 9, Plate 1a). On the west side of Box Canyon Hays mapped latest Pleistocene to
Holocene age terrace gravels offset by the Hidden Spring Fault (locality 10, Plate 1a; Photo 2). Hays reported about 15 feet (4.6 m) of east-side down normal offset at this location. If tectonic, it would indicate latest Pleistocene to Holocene offset, but Hays acknowledged that an alternative to tectonic offset was slumping of the gravel deposits into Box Canyon.

Clark (1984) mapped recently active traces of the Hidden Spring Fault in the Durmid Quadrangle (Plate 1b). Clark’s mapping does not extend but a few tens of meters north of the Durmid Quadrangle and does not extend as far to the southeast as mapping by Babcock (Plate 1b). Mapping by Clark and Babcock generally agree northwest of the small hill in the NE corner of section 16 (locality 11), but Clark mapped recently active traces stepping east south of the hill, toward what Babcock mapped as the Powerline Fault (Plate 1b). The fault mapped by Clark is expressed as a northwest-striking alignment of vegetation contrasts and boundaries, subtle southwest and northeast facing scarps in latest Pleistocene to Holocene Lake Cahuilla deposits (Plate 1b).

Powerline Fault

The Powerline Fault is a northwest striking fault east of the San Andreas Fault and southeast of the Hidden Spring Fault (Plate 1b) that originally was mapped by Babcock (1969), based on a line of seeps expressed in Lake Cahuilla deposits. Babcock’s traces locally were mis-located by as much as 200 feet (60 m) on the 1974 APEFZ map, but are accurately plotted on Plate 1b. This surface expression coincided with a steep gravity gradient. The trace of the Powerline Fault was zoned in 1974 based on Babcock’s mapping. Clark (1984) mapped traces delineated by soil and vegetation contrasts near the northern end of the fault mapped by Babcock, but didn’t observe evidence of recent faulting south of locality 12 (Plate 1b).

Mecca Hills Fault Zone

For purposes of discussion in this FER, faults traversing the central part of the Mecca Hills collectively are referred to as the Mecca Hills Fault Zone. The Mecca Hills Fault Zone consists of the Eagle Canyon Fault, Painted Canyon Fault (also called the Mecca Hills Fault), NW Painted Canyon Fault, and Platform Fault (Plate 1a). The NW Painted Canyon Fault mostly lies to the north of this FER and is also discussed by Bryant (2012).

Painted Canyon Fault (Mecca Hills Fault) and NW Painted Canyon Fault

The Painted Canyon Fault traverses the central part of the Mecca Hills and extends to the southeast beyond the Mecca Hills (Riverside County, 2001) (Plate 1a). A portion of the Painted Canyon Fault was first mapped by Miller (1944), who called the fault the Mecca Hills Fault. Ware (1958) also referred to this fault as the Mecca Hills Fault, but Hays (1957), who mapped the fault just to the south of the area Ware had mapped, referred to the fault as the Painted Canyon Fault. The fault will be referred to as the Painted Canyon Fault in this FER.

The fault juxtaposes Tertiary sedimentary rocks of the Mecca Formation against Plio-Pleistocene Palm Spring Formation (Sylvester and Smith, 1976; Sylvester and Damte, 1999). Dips ranging from 25° SW to near vertical, averaging about 60° SW, characterize the fault (Ware, 1958). Northwest of Box Canyon Road the fault splays into several branches including the Painted Canyon, NW Painted Canyon, and an eastern branch variously known as the Eagle Canyon Fault (Hays, 1957) and the Platform Fault (Sylvester and Smith, 1976) (Plate 1a). Hays reported that the displacement history of the Painted Canyon Fault is complex. Structural and stratigraphic evidence indicates oblique-slip displacement since late Pliocene time. Dip-slip (reverse) displacement may be greater than 2,500 feet (761 m); the dextral strike-slip component may be less than 0.5 mile (800 m), although Hays reported that the strike-slip component is poorly constrained. Hays mapped remnants of late Pleistocene terrace deposits
(his unit Qto) that conceal traces of the Painted Canyon Fault. Specifically, a remnant terrace deposit conceals a strand of the Painted Canyon Fault just south of Box Canyon (locality 14, Plate 1a). I did not observe geomorphic evidence of recent displacement at this locality.

A southern strand of the Painted Canyon Fault mapped by Hope (1969) was encompassed in an Earthquake Fault Zone in 1974 (locality 13, Plate 1a). Hope observed geomorphic evidence of latest Pleistocene to Holocene displacement, such as notches, linear canyons, and right-laterally deflected drainages. Although Clark (1984) did not map this fault, I verified the location and expression of the strand mapped by Hope (Plates 1a and 2a).

A small section of the NW Painted Canyon Fault mapped by Ware (1958) extends southeast into the SEMH-BCB study area (Plate 1a).

Platform and Eagle Canyon Faults

The Platform Fault is considered an eastern branch of the Mecca Hills Fault Zone in this FER. The fault strikes slightly more to the north and splays off of the Painted Canyon Fault where there is a large right-lateral deflection of Box Canyon near locality 14 (Plate 1a). Although Hays (1957) named this splay the Eagle Canyon Fault, more recent researchers refer to this fault as the Platform Fault (Sylvester and Smith, 1976; Sylvester, 1991; Riverside County, 2001). The fault bifurcates near the northwestern boundary of the Mortmar Quadrangle. The eastern branch will be referred to as the Eagle Canyon Fault (Plate 1a).

Displacement is predominantly right-lateral strike-slip, with varying components of dip-slip (normal) displacement (Hays, 1957; Corona and Sabins, 1993). Hays observed that the largest amount of dextral offset occurred at the southern end of the fault; strike-slip offset diminished to the northwest. Hays estimated post early Pleistocene dextral offset to be no more than a few hundred feet, although he stated that the strike-slip component was poorly constrained. The dip-slip component is up-on-the-west normal, with maximum throw of early Pleistocene rocks as great as 500 feet (152 m).

About 3 km northwest of Box Canyon Hays depicted a solid line fault through Holocene alluvium (locality 15, Plate 1a). This may be a drafting error because in the text of Hays’ dissertation he did not mention that recent alluvium was offset by the fault (if a young unit was offset, Hays usually discussed the displacement). However, I verified that a northeast-facing scarp in latest Pleistocene to early Holocene alluvium is located where Hays mapped the offset alluvium. The fault is delineated by an approximately 1m-high northeast facing scarp in latest Pleistocene to early Holocene alluvium, based on air photo interpretation and field checking by this writer about 400 meters to the north (locality 30, Plates 1a and 2a).

Clark (1984) did not map either the Platform or Eagle Canyon faults.

Sheep hole Fault

Traces of the Sheep hole Fault were mapped by Riverside County (2001) and were not originally depicted on the 1974 AP EFZ Map of the Mortmar Quadrangle (CDMG, 1974c) (Plate 1a). The 4 ½ km long Sheep hole Fault strikes subparallel to and is located about 2 km west of the Hidden Spring Fault. Rocks of the Plio-Pleistocene Palm Spring Formation are offset, but latest Pleistocene to Holocene alluvium conceals the fault. Displacement data are lacking for this fault, but it is assumed that displacement is similar to the Hidden Spring Fault and is probably dextral-reverse oblique. The fault lacks geomorphic evidence of Holocene displacement, either strike-slip or vertical, based on air photo interpretation by this writer (Plate
For example, at locality 16 (Plate 1a), an early (?) Holocene terrace surface lacks geomorphic evidence of displacement.

AERIAL PHOTOGRAPHIC INTERPRETATION AND FIELD OBSERVATIONS

Aerial photographic interpretation by this writer of faults in the SEMH-BCB study area was accomplished using aerial photographic imagery accessed through Google Earth Pro ver. 5.0.1 software. Interpretations of geomorphic features using aerial photographs from the U.S. Department of Agriculture (USDA, 1953) augmented and essentially validated the use of the Google Earth images. Images from Google Earth Pro used for this evaluation included those taken in May 2009, January 2006, December 2005, April 2005, April 2003, and June 2002. The effective scale of the imagery is variable from greater than 1:24,000 for regional overviews to as large as 1:1,200 for detailed analysis. Principal active traces of the San Andreas Fault were also interpreted using LiDAR imaging (B4 kml data set, SAF segment 1 and segment 2, utilizing both 315° and 45° illumination angles, available at http://www.siovizcenter.ucsd.edu/topo/b4.php).

Fault traces interpreted from standard aerial photographic coverage were plotted directly on the photograph using clear film overlays. The overlays were registered to geo-located digital orthophoto quadrangles, scanned using an Epson GT 10000 scanner, and digitized using MapInfo 9.0.2 GIS software. Faults interpreted using Google Earth Pro were digitized directly within the Google Earth Pro program. Digitized traces interpreted using Google Earth Pro were transferred to the MapInfo GIS platform either by capturing geo-referenced images from Google Earth Pro and registering and digitizing them in MapInfo Pro, or converting the interpretations to the Google Earth kml file format, converting to ESRI shape file format using Zonum Solutions (freeware for kml to GIS conversion, located at http://www.zonums.com/online/kml2shp.php). Location accuracy using the Google Earth interpretation procedure is estimated to be less than 10 m, often less than 5 m. This location accuracy estimate is based on plotting fault traces as described above and digitally overlaying the traces on ADS40/NAIP (Aerial Digital Sensor/National Agriculture Imagery Program) imagery collected in 2009, assuming that the NAIP imagery provides the best location accuracy. In the study area, fault-produced geomorphic features can be very well-defined and allow a measurable benchmark for assessing location accuracy.

Approximately 4 ½ days (May 16-21, 2011) were spent in the field area checking faults in the SEMH-BCB study area and the adjacent Indio-Thermal Canyon study area (Bryant, 2012). Selected fault strands were field checked and subtle features not observable on the aerial images were mapped in the field. Results of aerial photographic interpretation and field observations by this writer are summarized on Plates 2a and 2b.

San Andreas Fault

Traces of the San Andreas Fault in the study area are characterized by moderately defined to locally well-defined geomorphic features indicative of Holocene dextral strike-slip displacement, based on aerial photographic interpretation and limited field mapping by this writer (Plates 2a and 2b). Northwest of Painted Canyon traces of the active San Andreas Fault are delineated by well-defined geomorphic features including right-laterally deflected drainages and ridges, linear sidehill benches, linear troughs, NE and SW facing scarps, linear ridges, and linear vegetation contrasts (e.g. locality 17, Plate 2a).

Between Painted Canyon and Box Canyon, recently active traces of the San Andreas Fault are difficult to locate in detail, although the overall structural trend can be inferred (see
discussion above for Hays (1957) and Clark (1984). I attempted to map recently active traces between Painted Canyon and Box Canyon, but this reach of the fault lacks the systematic dextral deflection of drainages and ridges seen to the northwest. The fault zone is quite broad, but there seems to be a continuity of broad linear drainages, saddles, and a small linear ridge in late Pleistocene alluvium (Plate 2a). Southeast of locality 18 the fault is better defined and I mostly verified the traces mapped by Clark (1984) (Plates 1a and 2a). Here the fault is delineated by linear sidehill troughs, a back-facing scarp, dextrally deflected drainage, linear trough, truncated older alluvium, and a broad linear valley (Plate 2a). The fault between Box Canyon Road and the Coachella Canal is delineated by well-defined geomorphic evidence of Holocene to late Holocene offset, including right-laterally deflected drainages, a sidehill bench, linear ridges in late Pleistocene and Holocene alluvium, and well-defined vegetation lineaments and low scarps (~0.2 to 1 m high) in late Holocene alluvium (Plate 2a; Photos 1 and 3).

Traces of the San Andreas Fault in the area southeast of the Coachella Canal and northwest of section 21 are mostly concealed by late Holocene alluvium. An alignment of subtle linear vegetation contrasts projects toward a well-defined linear vegetation contrast and southwest and northeast facing scarps near locality 19 (Plate 2a). This section of the San Andreas Fault exhibited triggered slip associated with the 1968 and 1979 earthquakes (Clark, 1984; Plate 1a). Between locality 19 and the fault’s intersection with Highway 111, the San Andreas Fault is well-defined and exhibits geomorphic evidence of Holocene displacement, including low northeast and southwest-facing scarps in late Holocene alluvium, including a 5.4 m-high southwest-facing scarp that crosses 72nd Avenue (Plate 2a). I did not observe evidence of fault creep across 72nd Avenue. About 370 m southeast of 72nd Avenue Clark (1984) noted open cracks up to 5 mm wide following the 1979 Imperial Valley earthquake. Mapping by Clark and this writer coincides very well along this reach of the fault (Plates 1a and 2a).

The San Andreas Fault in the Salton and Durmid quadrangles is generally well-defined by aligned vegetation contrasts, dextral displacement of minor drainages, and low scarps on late Holocene Lake Cahuilla surfaces (Plate 2b). My mapping and that of Clark (1984) agree well through much of this section (Plates 1b and 2b), with a possible exception a few hundred meters northwest of locality 21. Although the mapped location of the San Andreas Fault differs by about 40 meters, it is probable that Clark and I both identified an approximately 0.5m-high northeast-facing scarp and prominent lithologic contrast (Photo 4). Topographic control is very limited in this area and it is conceivable that Clark slightly mis-located the fault trace.

Mapping by Babcock (1969) is more generalized than Clark’s mapping and may be mis-located by as much as 60-75 meters in some locations. Because ground surfaces have been modified by the most recent Lake Cahuilla high stand 200-300 years ago, only the most recent geomorphic features (mostly scarps less than 1 meter high) have been preserved. Southeast of locality 20 (Plate 2b), the fault lacks geomorphic expression of Holocene faulting. Babcock’s mapping here identifies a zone up to 170 meters wide of highly deformed and faulted late Quaternary rocks (Plate 1b).

Hope mapped two minor north-northwest striking faults branching off of the San Andreas Fault at Salt Creek and near Hill -55 (locality 21, Figures 2b and 3b). I did not verify the northern fault, but the southerly trace of Hope is delineated by truncated Plio-Pleistocene lithology (Babcock’s Plio-Pleistocene Shavers Well Formation against latest Pleistocene to Holocene Lake Cahuilla Sands).
Witbaard Fault

Traces of the postulated Witbaard Fault mapped by Shifflett and others (2002) were not verified by this writer (Plate 1a). The dextrally deflected ridge at locality 22 (Plate 1a) exists, but additional ridges developed in Pleistocene Ocotillo Formation are unaffected, strongly indicating a cause other than active faulting. None of the additional geomorphic evidence of recent right-lateral strike-slip displacement mapped by Shifflett and others was verified by this writer (Plate 1a). Additionally, several late Pleistocene surfaces that cross the proposed surface trace of the fault are not offset, based on my air photo interpretation (e.g. locality 23, Plate 1a). Evidence for fault creep on the Witbaard Fault, instead of the San Andreas Fault, is not compelling, based on the data presented in Shifflett and others. The fact that a 6 mm creep event clearly occurred on the San Andreas Fault in 1997 (Shifflett and others, 2002) weakens their argument that active creep by-passes this reach of the San Andreas Fault and instead occurs along the postulated Witbaard Fault.

Skeleton Canyon (Coachella Valley) Fault

Traces of the Skeleton Canyon Fault in the study area are delineated by strong lithologic contrasts, a linear drainage, and a vague vegetation contrast in Holocene (?) alluvium at location 24 (Plate 2a). Traces mapped by Ware (1958) generally were verified with respect to location, but geomorphic evidence of systematic latest Pleistocene to Holocene dextral to dextral reverse oblique offset was not observed in the study area except for the noted vegetation contrast in Holocene alluvium. Farther northwest, Bryant (2012) reported that the fault trace is delineated by aligned linear ridges and drainages, faceted spurs and notches, and locally by dextrally deflected drainages. The trace of the Skeleton Canyon Fault southeast of Painted Canyon is delineated by a well-defined lithologic contrast, but geomorphic evidence of latest Pleistocene to Holocene strike-slip or vertical displacement was not observed by this writer (Plate 1a).

Hidden Spring Fault

Traces of the Hidden Spring Fault locally are well-defined and exhibit geomorphic features indicating Holocene strike-slip displacement (Plates 2a and 2b). The best-defined section of the fault is found between the Coachella Canal and the Mining Railroad (localities 7 and 8, Plates 1b and 2b). My interpretations agree well with mapping by Clark (1984) in this area. Here the fault is delineated by a linear alignment of well-defined vegetation contrasts and subtle northeast and southwest-facing scarps in late Holocene Lake Cahuilla deposits/surfaces (Plates 1b and 2b). Neither Clark nor I verified Babcock’s trace southeast of locality 11 (Plate 1b). Both Clark and I also mapped what is either a step-over to the Powerline Fault of Babcock, or a slight change in strike at the southeastern end of the Hidden Spring Fault. The location of a small hill where the Mining Railroad crosses these faults supports the interpretation that the Powerline Fault is part of a left restraining step along the Hidden Spring Fault (Plate 2b). My mapping extended the southern end of the Hidden Spring Fault across the stepover about 4 ½ km farther than Clark’s mapping, generally based on moderately defined vegetation lineaments (locality 25, Plate 2b).

The Hidden Spring Fault northwest of the Coachella Canal is somewhat discontinuous but locally is delineated by geomorphic features suggestive of latest Pleistocene to Holocene strike-slip displacement (Plates 2a and 2b). Mapping by Babcock (1969) and Crowell (1959) was locally verified by this writer, based on aerial photographic interpretation (Plates 2a and 2b). Crowell mapped western, central, and eastern branches of the Hidden Spring Fault, but generally I was only able to verify the central branch. Geomorphic evidence of latest Pleistocene to Holocene dextral strike-slip displacement observed by this writer, based on air photo interpretation, includes right-laterally deflected drainage channels, linear sidehill bench,
linear troughs and ridges, a beheaded drainage, and scarp in late Pleistocene alluvium (localities 26, 27, and 32 Plates 2a and 2b). A dextrally deflected drainage marks Crowell’s eastern trace near locality 27 (Plate 2a). However, the deflected drainage lacks associated geomorphic evidence of Holocene displacement along strike to the northwest and southeast. I mapped a subtle 20 cm-high northeast-facing scarp in a latest Pleistocene to early Holocene terrace surface that is associated with a linear swale and vegetation lineament to the northwest and southwest-facing scarp just to the southeast, (locality 32, Plate 2b; Photo 5). The terrace surface has moderately developed rock varnish, moderately developed desert pavement, and stage I CaCO3 soil development, suggesting latest Pleistocene age of the surface.

The vertically displaced Pleistocene terrace deposit mapped by Hays (1957) at locality 10 (Plate 1a) is not associated with geomorphic evidence of youthful strike-slip or vertical displacement, nor is the region along the fault’s strike for at least 3 to 4 km, based on my air photo interpretation. However, I did verify that the deposit is vertically displaced, probably due to slumping, based on field inspection (locality 10, Plate 1a; Photo 2).

**Powerline Fault**

See discussion above for the Hidden Spring Fault.

**Mecca Hills Fault Zone**

The Mecca Hills Fault Zone is located in the central Mecca Hills and in this FER includes the Painted Canyon, Platform, and Eagle Canyon faults. A short strand of the NW Painted Canyon Fault also extends into the northern part of the study area.

**Painted Canyon Fault (Mecca Hills Fault) and NW Painted Canyon Fault**

I did not verify Holocene active traces of the Painted Canyon Fault other than the well-defined traces mapped by Hope (1969) at locality 13 and a trace mapped by Ware (1958) just northwest of Painted Canyon (Plates 1a and 2a). Traces near locality 13 are delineated by well-defined sidehill benches, linear drainages and troughs, beheaded drainages, aligned notches, and right-laterally offset drainages. To the northwest, the fault mostly lacks geomorphic evidence for systematic Holocene strike-slip displacement in the SEMH-BCB area and is typically expressed as notches, linear drainages, and contrasts in bedrock lithology (Plate 1a). The youngest lithologic unit offset along the Painted Canyon Fault is the Pleistocene Ocotillo Conglomerate mapped by Ware (1958) in the Thermal Canyon Quadrangle, just north of this FER study area (see Bryant, 2012). I observed well-defined left-stepping en echelon east-facing scarps at locality 28 (Plate 2a). These scarps are located close to traces mapped by Ware (1958), but only extend for about 250 meters. Most of these features are adjacent to steep free-faces along both east and west facing slopes. It is probable that they are not tectonic, but could be ridgetop spreading features. They are anomalously fresh and are inconsistent with any other geomorphic expression observed along the Mecca Hills Fault Zone, based on air photo interpretation by this writer.

The NW Painted Canyon Fault extends northwest of the study area and is evaluated in the Indio-Thermal Canyon study area where the fault offsets latest Pleistocene to Holocene alluvium (Bryant, 2012). In the SEMH-BCB study area the NW Painted Canyon Fault is delineated by a right-laterally deflected drainage, linear drainage, and possible east-facing scarp in bedrock (Plate 2a). A trace mapped by Ware (1958) generally corresponds with my mapping, although differences in detail exist.
Platform and Eagle Canyon Faults

Traces of the Platform Fault locally are well-defined and offset latest Pleistocene to Holocene alluvium, based on air photo interpretation and field mapping by this writer (localities 29 and 30, Plate 2a). Specifically, a short section of the fault at the northern end of the study area is delineated by geomorphic features indicating strike-slip displacement such as a right-laterally deflected drainage, sidehill bench, and east-facing scarps in Plio-Pleistocene Palm Spring Formation (Plate 2a). Although the offset Holocene deposit at locality 15 (Plate 1a) was not discussed in detail by Hays, I was able to verify a subtle northeast-facing scarp in latest Pleistocene to early Holocene alluvium just to the north (locality 30, Plate 2a). Southeast of this location traces of the Platform Fault lack geomorphic evidence of latest Pleistocene to Holocene offset. The Eagle Canyon Fault, a north-northwest striking branch of the Painted Canyon Fault, lacks geomorphic evidence of latest Pleistocene to Holocene strike-slip displacement, based on air photo interpretation by this writer.

SEISMICITY

A and B quality epicenters for the period 1970 through 2009 are plotted on Figure 3 (Data from Southern California Seismic Network, available at http://www.data.scec.org/ftp/catalogs/SCEC_DC/). Seismicity adjacent to the study area is dominated by activity along the Brawley Seismic Zone just south of the study area, and several clusters of epicenters north of the study area. Although the San Andreas Fault exhibits fault creep and has displaced the ground surface due to triggered slip (Hope, 1969; Clark, 1984; Rymer and others, 2002; Sieh and Williams, 1990; Bilham, 2002; Rymer and others, 2011), it is notably lacking seismic activity for this time period.

Seismicity in the Durmid, Orocopia Canyon, and Mortmar quadrangles generally forms a northwest-southeast linear alignment subparallel to the Hidden Spring and Painted Canyon faults (Figure 3). Near the southern end of the Orocopia Canyon quadrangle, the epicenter pattern tends to splay into two diffuse alignments: one near the Hidden Spring Fault and a slightly more easterly trend just east of Babcock’s Powerline Fault. There appears to be a left-step in the epicenter alignment from the central to northern area of the Mortmar quadrangle, perhaps stepping from the Hidden Spring to the Painted Canyon fault. However, the epicenter alignments in this region both are offset from the surface traces of the Hidden Spring and Painted Canyon faults from 1.2 km to 1.4 km. Hypocenters shown in cross-sections B-B’ and C-C’ allow interpretation of a steeply-dipping fault or faults possibly associated with the Hidden Spring Fault (Figure 4). The northern cross-section A-A’ shows a less distinct alignment of hypocenters and may indicate a broad step-over in seismicity from the Hidden Spring to the Painted Canyon faults (Figures 3 and 4).

CONCLUSIONS

San Andreas Fault

The San Andreas Fault is a major active dextral strike-slip fault. Most traces of the San Andreas Fault in the SEMH-BCB study area are historically active. Triggered slip associated with the 1968 Borrego Mountain, 1979 Imperial Valley, 1992 Landers, 1999 Hector Mine, and 2010 El Mayor-Cucapah earthquakes has been documented along this reach of the San Andreas Fault (Allen and others, 1972; Hope, 1969; Clark, 1984; Rymer, 2000; Rymer and others, 2002; Treiman and others, 2010; Rymer and others, 2011; Wei and others, 2011).

Traces of the San Andreas Fault in the Mecca Quadrangle northwest of Painted Canyon are mostly well-defined and are delineated by geomorphic evidence of Holocene strike-slip
offset such as right-laterally deflected stream channels, beheaded drainages, linear ridges and troughs (including a linear ridge in alluvium), and scarps in late Pleistocene alluvium (Plates 1a and 2a). Mapping by Hope (1969) and Clark (1984) here is mostly verified by this writer, although slight differences in location exist, no doubt due to the different mapping techniques employed by Clark and Hope, compared to digital mapping techniques available to this writer.

As noted by Clark (1984), and confirmed by this writer, an approximately 3 km section of the fault southeast of Painted Canyon lacks systematic geomorphic evidence of Holocene strike-slip displacement (locality 1, Plates 1a and 2a). Hays (1957) mapped the San Andreas Fault in this 3 km section as a broad area ranging in width from 10 meters to greater than 150 meters (Plate 1a). A broad fault zone up to 150 meters can be inferred here based on broad linear drainages, saddles, and a small linear ridge in late Pleistocene alluvium (Plate 2a).

Southeast of the Coachella Canal my mapping agrees well with Clark's mapping (Plates 1a, 1b, 2a, and 2b). Holocene active traces of the San Andreas Fault here are expressed by geomorphic features such as well-defined linear vegetation contrasts in Holocene alluvium, right-laterally deflected drainages, low northeast and southwest-facing scarps in Holocene alluvium and late Holocene surfaces of Lake Cahuilla (Plates 1a, 1b, 2a, and 2b). Mapping by Babcock (1969) is somewhat generalized and differs from locations shown by Clark (1984) and this writer by up to 75 meters. Southeast of locality 20 (Plate 2b) the fault lacks geomorphic features of Holocene displacement. Here Babcock (1969) mapped a zone up to 170 meters wide of highly deformed and faulted late Quaternary rocks (Plate 1b).

Witbaard Fault

The postulated Witbaard Fault is not well-defined and geomorphic evidence of recent right-lateral strike-slip offset reported by Shifflett and others (2002) was not verified by this writer (e.g. locality 22, Plate 1a). Evidence for fault creep on the postulated Witbaard Fault, instead of the San Andreas Fault, is not compelling, based on the data presented in Shifflett and others. The fact that a creep event occurred on the San Andreas Fault in 1997 (Shifflett and others, 2002) weakens their argument that active creep by-passes this reach of the San Andreas Fault and instead occurs along the postulated Witbaard Fault.

The short, sinuous fault trace near the southern end of the postulated Witbaard Fault shown on Clark (1984) is in fact a drafting error. A personal communication (December 2010) with Malcolm Clark confirmed a non-fault/drafting error explanation of the sinuous feature near the southeast end of the postulated Witbaard Fault (locality 6, Plate 1a). This postulated trace coincides with a Lake Cahuilla beach ridge and does not appear fault-related.

Skeleton Canyon Fault (Coachella Valley Fault)

First mapped and named by Hays (1957), the Skeleton Canyon Fault extends northwest sub-parallel to the San Andreas Fault for about 9 ½ km (Plate 1a). This fault also has been referred to as the Coachella Valley Fault by Riverside County (2001). The fault offsets Plio- Pleistocene Palm Spring Formation (Hays, 1957), and locally may offset Holocene alluvium at locality 24, based on air photo interpretation by this writer (Plate 2a). In the study area traces of the Skeleton Canyon Fault are delineated by strong lithologic contrasts, a linear drainage, and a poorly defined vegetation contrast in Holocene (?) alluvium, based on air photo interpretation by this writer (locality 24, Plates 1a and 2a). The fault is better defined to the northwest in the Indio-Thermal Canyon study area (Bryant, 2012).
**Hidden Spring Fault**

The Hidden Spring Fault mapped by Crowell (1959) and Babcock (1969) locally offsets latest Pleistocene to Holocene alluvium and lacustrine deposits of Lake Cahuilla (Babcock, 1969) (Plates 1a and 1b). Clark (1984) reported that the fault is well-defined by a northwest-striking alignment of vegetation contrasts and subtle southwest and northeast facing scarps in latest Pleistocene to Holocene Lake Cahuilla deposits (Plate 1b). I generally verified the mapping of Clark (1984) between the Coachella Canal and the Mining Railroad (localities 7 and 8, Plate 2b). Neither Clark nor I verified Babcock’s trace southeast of locality 11 (Plates 1b and 2b). The Hidden Spring Fault probably continues to the southeast across a left restraining step-over to Babcock’s Powerline Fault. In this FER the Powerline Fault of Babcock is considered to be the southeastern end of the Hidden Spring Fault.

Northwest of the Coachella Canal the Hidden Spring Fault is discontinuous, but is locally well-defined by geomorphic features suggestive of latest Pleistocene to Holocene dextral strike-slip displacement including dextrally deflected drainage channels, a linear sidehill bench, linear troughs and ridges, a beheaded drainage, and scarps in late Pleistocene alluvium (localities 26, 27, 32, Plates 2a and 2b). Crowell (1959) mapped western, central, and eastern branches of the Hidden Spring Fault, but I was only able to verify the central branch. A dextrally deflected drainage is probably structurally controlled by Crowell’s eastern trace near locality 27 (Plate 2a), but the eastern branch lacks associated geomorphic evidence of Holocene displacement along strike to the northwest and southeast. I did not verify the offset late Pleistocene terrace deposit mapped by Hays (1957) (locality 10, Plate 1a).

**Powerline Fault**

See discussion above for the Hidden Spring Fault. For this FER it is assumed that the Powerline Fault of Babcock (1969) is actually a southeastern continuation of the Hidden Spring Fault along a left restraining step-over.

**Mecca Hills Fault Zone**

**Painted Canyon Fault (Mecca Hills Fault) and NW Painted Canyon Faults**

Traces of the Painted Canyon Fault in the SEMH-BCB study area mapped by Hays (1957) and Ware (1958) offset Plio-Pleistocene rocks of the Mecca and Palm Spring Formation, but latest Pleistocene and Holocene deposits are not offset. Hays mapped a strand of the fault in the Box Canyon area that is concealed by late Pleistocene terrace deposits (locality 14, Plate 1a). I did not observe geomorphic evidence of recent faulting along traces of the Painted Canyon Fault, including the terrace surface mapped by Hays at this locality.

The southern extent of the Painted Canyon Fault mapped by Hope (1969) is delineated by well-defined geomorphic features indicating latest Pleistocene to Holocene strike-slip displacement such as linear drainage channels, right-laterally deflected drainages, beheaded drainages, sidehill benches, and aligned notches (locality 13, Plate 1a). Although Clark (1984) did not map this strand, I verified the location and expression of this well-defined trace (locality 13, Plates 1a and 2a).

In the vicinity of Painted Canyon the NW Painted Canyon Fault splays off of the Painted Canyon Fault along a more northwesterly strike. Here the fault is delineated by a right-laterally deflected drainage, linear drainage, truncated lithology, and a possible east-facing scarp (Plate 2a). The NW Painted Canyon continues northwest in the Indio-Thermal Canyon study area and offsets latest Pleistocene to Holocene alluvium (Bryant, 2012).
Platform and Eagle Canyon Faults
The Platform Fault is an eastern branch of the Mecca Hills Fault Zone. The Eagle Canyon Fault is the eastern bifurcation of the Platform Fault (Plate 1a). Hays mapped possible offset of Holocene alluvium at locality 15 (Plate 1a). There is an east-facing scarp on latest Pleistocene to Holocene alluvium just north of where Hays mapped offset Holocene alluvium (locality 30, Plate 2a). Just to the northwest I mapped geomorphic features indicative of dextral strike-slip offset including a dextrally deflected drainage, sidehill bench, and east-facing scarps in Plio-Pleistocene Palm Spring Formation (localities 29 and 30, Plate 2a). To the southeast traces of the Platform Fault and Eagle Canyon fault lack geomorphic evidence of latest Pleistocene to Holocene offset.

Sheephole Fault
The 4 ¼ km long Sheephole Fault trends parallel to and is located about 2 km west of the Hidden Spring Fault (Riverside County, 2001; Plate 1a). Amount and sense of displacement are not well-constrained, but the location and strike of the fault are consistent with dextral reverse-oblique offset. The fault is not well-defined and lacks geomorphic evidence of latest Pleistocene to Holocene offset. An early (?) Holocene terrace surface is not offset along the Sheephole Fault (locality 16, Plate 1a).

RECOMMENDATIONS
Recommendations for encompassing faults in Alquist-Priolo Earthquake Fault Zones are based on the criteria of “sufficiently active” and “well-defined” (Bryant and Hart, 2007).

San Andreas Fault
Revise the Earthquake Fault Zones on the Mecca, Mortmar, Durmid, Orocopia Canyon, and Salton quadrangles based on the mapping of Clark (1984) and Bryant (this report) as shown on Plates 3a and 3b.

Witbaard Fault
The postulated Witbaard Fault is not recommended for inclusion in an Earthquake Fault Zone. The fault postulated by Shifflett and others (2002) is neither sufficiently active nor well-defined.

Skeleton Canyon Fault
Modify traces of the Skeleton Canyon Fault encompassed by Earthquake Fault Zones to incorporate selected mapping Ware (1958) and Bryant (this report) as shown on Plate 3a.

Hidden Spring Fault
Modify traces of the Hidden Spring Fault encompassed by Earthquake Fault Zones to incorporate mapping by Clark (1984), Crowell (1959), and Bryant (this report) as shown on Plates 3a and 3b.

Powerline Fault
Refer to the recommendations for the Hidden Spring Fault.
Mecca Hills Fault Zone

Painted Canyon Fault (Mecca Hills Fault) and NW Painted Canyon Fault

Modify traces of the southern Painted Canyon Fault encompassed by an Earthquake Fault Zone to incorporate mapping by Hope (1969) and Bryant (this report) as shown on Plate 3a. Other traces of the Painted Canyon Fault are neither sufficiently active nor well-defined and are not recommended for inclusion within an Earthquake Fault Zone.

Encompass the trace of the NW Painted Canyon Fault mapped by Bryant (this report) in an Earthquake Fault Zone as shown on Plate 3a.

Platform and Eagle Canyon Faults

Encompass traces of the Platform Fault mapped by Hays (1957) and Bryant (this report) as shown on Plate 3a. Traces of the Eagle Canyon fault are neither sufficiently active nor well-defined.

Sheephole Fault

The Sheephole Fault as shown by Riverside County (2001) is not recommended for inclusion within an Earthquake Fault Zone. The fault is neither sufficiently active nor well-defined.

William A. Bryant
CEG 1554
March 2, 2012

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Figure 1 (to FER-252). Location of the Southeastern Mecca Hills-Bat Caves Buttes study area. Blue boxes are Alquist-Priolo Earthquake Fault Zones issued in 1974.
Figure 2 (to FER-252). Geology of the central Southeastern Mecca Hills-Bat Cave Buttes study area mapped by Sylvester and Damte (1999), showing depiction of the Skeleton Canyon Fault northwest of Painted Canyon.
Figure 3 (to FER-252). A and B quality seismicity for the period 1970 to 2009 in the Southeastern Mecca Hills-Bat Caves Buttes study area. Faults shown: SAF - San Andreas; HS - Hidden Spring; MCFZ - Mecca Hills Fault Zone; PC - Painted Canyon; PF - Platform; PL - Powerline; SC – Skeleton Canyon; SH - Sheephole. Cross-sections A-A', B-B', and C-C' are shown in Figure 4.
Figure 4 (to FER-252). Cross sections of hypocenters in the Southeastern Mecca Hills-Bat Caves Buttes study area, showing A and B quality hypocenter locations of earthquakes ranging in magnitude from 1 to 3.9. Refer to Figure 3 for cross-section locations. Data is from the Southern California Seismic Network, available at [http://www.data.scec.org/ftp/catalogs/SCEC_DC/](http://www.data.scec.org/ftp/catalogs/SCEC_DC/).
Photo 1 (to FER-252). Principal active trace of the San Andreas Fault is expressed by a northeast-facing scarp (20-30cm high) and sharp vegetation lineament, view to the northwest. Stone Rings paleoseismic site (Shifflett and others, 2002) in background.
Vertically offset Pleistocene terrace deposits mapped by Hays (1957); view to the southwest. Hays suggested this displacement in Box Canyon could be due to slumping of terrace deposits, rather than offset along northern Hidden Springs Fault. Lack of geomorphic expression along this reach of the Hidden Springs Fault lends support to a slump interpretation.
Photo 3 (to FER-252). Well defined trace of the San Andreas Fault delineated by a linear northeast-facing scarp in alluvium and a right-laterally deflected drainage, view to the southeast. Scarp is about 1m high and drainage is deflected about 3 meters.
Photo 4 (to FER-252). San Andreas Fault is expressed by a low (~0.5m) northeast-facing scarp, prominent lithologic contrast (Pleistocene Borrego Formation against latest Pleistocene to Holocene Lake Cahuilla Sands of Babcock (1969), and gouge zone at least 3 meters wide developed in Borrego Fm.; view to the northwest.
Photo 5 (to FER-252). Subtle, 20cm-high northeast-facing scarp developed in latest Pleistocene to early Holocene terrace surface delineates a trace of the Hidden Springs Fault north of the Coachella Canal; view to the northwest. A linear swale and vegetation lineament delineate the fault just northwest of this subtle scarp. A southwest-facing scarp is located about 50m in back of the photographer.