Assessment of the Newport-Inglewood Fault Zone

AES Electrical Generation Facility, Poseidon Desalination Project

Newland Street and Pacific Coast Highway
Huntington Beach, California

Prepared for:

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May 13, 2020

Mr. Ray Hiemstra
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SUBJECT: **Assessment of the Newport-Inglewood Fault Zone**
AES Electrical Generation Facility, Poseidon Desalination Project
Newland Street and Pacific Coast Highway, Huntington Beach, California
LCI Project No. 1966.000

Dear Mr. Hiemstra:

Lettis Consultants International, Inc. (LCI) is pleased to present to you this revised report on our desktop assessment of the Newport-Inglewood fault zone (NIFZ). The report summarizes the geology and activity of the Newport-Inglewood Fault Zone (NIFZ), including the "South Branch" fault strand that has been mapped beneath the proposed AES Corporation electrical generation facility for the Poseidon Desalination Project. This version of the report (Revision 1) includes minor editorial changes, including recommendations by you to improve overall report clarity for the non-technical reader.

Please do not hesitate to contact us with any questions, comments, or concerns that you may have regarding this report. You may contact us directly at (661) 287-9900.

Respectfully,
Lettis Consultants International, Inc.

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EXECUTIVE SUMMARY

This report documents our "desktop" assessment of the Newport-Inglewood fault zone and fault strands proximal to the proposed Poseidon Water Huntington Beach desalination project site in Huntington Beach, California. Our study is based on published scientific literature, maps, and available consultant reports. We performed no field work for this study. The purpose of our study is to summarize existing information on the Newport-Inglewood fault zone and the geology, location, and activity of local faults that may impact the proposed Poseidon project, if such information is known.

A strand of the Newport-Inglewood fault zone, named the "South Branch" in some reports, has been mapped beneath the proposed AES Corporation electrical generation facility and is of particular interest. Little information, however, has been published on the recent history of this fault strand.

Based on our desktop assessment, we conclude the following:

- The South Branch fault at the site is not the principal active strand of the Newport-Inglewood fault zone. The principal active strand is located about 0.6 km east of the site and projects offshore near the mouth of the Santa Ana River. The largest surface displacements from future earthquake ruptures on the Newport-Inglewood fault zone are expected on the principal active fault strand, with relatively minor displacements expected on other secondary strands.

- Data do not exist to adequately assess whether the South Branch fault at the site has ruptured in the Holocene Epoch (past 11,700 yrs) and would be considered an active fault by the California Geological Survey (CGS). This fault strand has not met the criteria of "sufficiently active and well defined" to be included in an Alquist-Priolo Earthquake Fault Zone (APEFZ) by the CGS.

- Past studies at the Poseidon site by GeoLogic (2002), Ninyo & Moore (2011), and Geosyntec Consultants, Inc. (2013) have consistently concluded an "absence of evidence" for the presence of Holocene faulting on site. However, the subsurface exploration methods employed cannot definitively preclude the presence of minor secondary Holocene fault activity at the site.

- Although there is no information that directly implicates the "South Branch" as being active, there are no data that demonstrably preclude Holocene activity. Additional subsurface investigations could be performed to evaluate for the presence or absence of Holocene-active faults. However, thick Holocene deposits in the Santa Ana Gap could make such an evaluation difficult.

1.0 INTRODUCTION

Lettis Consultants International, Inc. (LCI) is pleased to submit this report documenting our desktop assessment of the Newport-Inglewood fault zone (NIFZ) and fault strands in close proximity to the proposed Poseidon Water Huntington Beach desalination project site (“the site”, Figure 1). The site is located near the intersection of Newland Street and Pacific Coast Highway in Huntington Beach, California.

The purpose of this investigation is to summarize existing information on the NIFZ and the geology, location, and activity of local faults that may impact the proposed Poseidon project, if such information is known. The scope of work for this project included: (1) literature research and data review, (2) synthesis and interpretation of the literature and data, and (3) preparation of this report. The literature review included both publicly available publications as well as reports for the Poseidon project site provided to us by Mr. Ray Hiemstra of Orange County Coastkeeper (OCCK). No new data were collected for this project, and there remain open questions as to the recency of activity for multiple fault strands of the NIFZ in the Huntington Beach area.

A strand of the NIFZ, named the “South Branch” in some reports, has been mapped beneath the proposed AES Corporation electrical generation facility and is of particular interest. Little information, however, has been published on the recent history of this fault strand. The Poseidon site lies in the Santa Ana Gap (also called the Talbert Gap), a low area traversed by the Santa Ana River which is underlain by a very thick sequence of young alluvium that records aggradation during post-glacial sea level rise. The consequence of the thick Holocene deposits and shallow groundwater is that there have been no trenching studies to definitively resolve recency of surface ruptures on the South Branch of the fault zone. Given the difficulty in assessing the recent age of faults in the Santa Ana Gap area and that they are not well-defined at the ground surface, the California Geological Survey (CGS) has not defined Alquist-Priolo Earthquake Fault Zones (APEFZs) for a major part of the NIFZ across the Gap, including in the vicinity of the Poseidon site.

The project team for this study included geologists Scott Lindvall and Chelsea Blanton from LCI. Dr. Thomas Rockwell of San Diego State University provided independent subject matter expertise and review. Jeffery Hemphill of LCI provided GIS and graphics support.

2.0 GEOLOGIC AND TECTONIC SETTING

The NIFZ is part of a broad system of faults, including the San Andreas fault (Figure 1), that comprises the plate boundary between the Pacific and North American lithospheric plates. Together, this system transfers approximately 50 mm/yr of dextral shear, of which the NIFZ accommodates a minor fraction. In the Los Angeles basin region (Figure 2), which is considered part of the Peninsular Ranges Province (Wright, 1991), the NIFZ and related strike-slip faults translate crustal blocks to the northwest and impinge on the Transverse Ranges, an east-west domain of crustal shortening.

The Los Angeles basin is a long-lived crustal feature in southern California that has sustained as much as 6 km of subsidence and consequent deposition of strata in the late Neogene (Wright, 1991), with 1.5 to 2 km of sediment accumulation in the Quaternary (Yeats and Rockwell, 1991). Beneath the sedimentary strata, the NIFZ juxtaposes Catalina Schist basement rocks on the west against granitic and metagranitic rocks on the east (Yerkes et al., 1965), indicating an earlier history of motion, with the modern motion on the fault propagating up through the very thick section of sedimentary rocks, resulting in its en echelon stepping pattern with localized uplifts (Wilcox et al., 1973). In this context, the term en echelon refers to closely spaced, parallel or subparallel, overlapping or step-like fault strands that lie oblique to the overall structural trend.

3.0 NEWPORT-INGLEWOOD FAULT ZONE

The Newport-Inglewood Fault Zone (NIFZ) is the northern part of a longer zone of coastal strike-slip faults that extends from south of San Diego to the northern Los Angeles basin, terminating against the Transverse Ranges (Figure 1). The entire fault zone includes the Rose Canyon fault (Figure 3) and is commonly referred to as the Newport-Inglewood/Rose Canyon (NIRC) fault zone or fault system (e.g., Fischer and Mills, 1991; Grant and Rockwell, 2002; USGS and CGS, 2018; Sahakian et al., 2017; Singleton et al., 2019). The three main portions of the NIRC fault system are the onshore Newport-Inglewood (length ~65 km), offshore Newport-Inglewood (length ~67 km), and Rose Canyon (length ~75 km) faults (Figure 1). Although this terminology is common in the literature, the three-part division does not necessarily reflect separate or isolated fault sections that rupture independently of each other. At a local scale, the NIRC includes many named and unnamed individual fault strands or fault segments. The naming conventions for individual fault strands and fault sections vary by both scale as well as between different publications.

The NIFZ is a major tectonic boundary that defines the western margin of the deep central trough of the Los Angeles basin (Hill, 1971; Wright, 1991) (Figure 2). At the surface, the NIFZ is expressed as a linear, approximately N45°W trending series of low hills and mesas associated with domal uplifts and oil fields. The fault zone consists of a series of discontinuous strike-slip faults and shorter secondary normal and reverse faults (Barrows, 1974; Bryant, 1988). The northern portion of the NIFZ consists of a series of left-stepping, en echelon faults. In contrast, the NIFZ appears to be a single main strand with local secondary fault “splays” from the Long Beach oil field and to the south (Wright, 1991) (Figure 2). In this report we use the term “splay” to refer to a relatively minor fault strand that branches off from or is otherwise separate from the principal main fault strand. Some have proposed that the pattern of en echelon faults and folds at the surface along the northern NIFZ is the result of an underlying deep-seated strike-slip fault (e.g., Moody and Hill, 1956; Harding 1973; Wilcox et al., 1973). Wright (1991), however, demonstrates that detailed mapping of oil fields along the NIFZ has revealed a variety of structural patterns and histories that cannot be simply explained by pure strike-slip faulting. Wright (1991) argues that classic wrench-fault deformation cannot produce most of the anticlinal structures, and other factors, such as local basement geometry, pervasive shear within the basement, and interaction with adjacent fault blocks, has contributed to the fold development along the NIFZ.

3.1 Seismicity

The largest historical earthquake produced by the NIFZ was the March 10, 1933 moment magnitude (Mw) 6.4 Long Beach earthquake (Richter, 1958; Hauksson and Gross, 1991). The moment magnitude (Mw) scale is the standard magnitude scale for ranking earthquakes by size, and largely replaces earlier scales such as the Richter scale, which is also known as the local magnitude (M_L) scale. The 1933 earthquake caused extensive damage in the southern Los Angeles basin area and resulted in 120 deaths and several hundred injuries (Wood, 1933). The 1933 Long Beach earthquake was so named because of the extensive damage to the City of Long Beach. The distribution of aftershocks defined the section of the fault that ruptured. The majority of the seismic moment released in 1933 was limited to a 13- to 16-km-long reach of the fault between Newport Beach and Long Beach (Hauksson and Gross, 1991). The mainshock hypocenter (-117.976°, 33.659°) is located in Huntington Beach (Figure 1) at a depth of 13 km, which suggests unilateral rupture from Huntington Beach northward toward Long Beach (Hauksson and Gross, 1991). Given a ~16-km rupture length, unilateral rupture, and the mainshock location from Hauksson and Gross (1991), the primary subsurface rupture of the 1933 earthquake is constrained to approximately the portion of the fault that extends from near the boundary between the cities of Huntington Beach and Newport Beach on the south to near the boundary between Orange and Los Angeles Counties (San Gabriel River) on the north (Figure 1). The estimated subsurface rupture is about half the length of the aftershock zone. Uplift produced by the 1933 earthquake (Barrows, 1974), as determined by precise leveling data, suggests that rupture may have extended a little farther to the northwest, which is more consistent with the extent of aftershocks.

The best constrained nodal plane has a strike of N45°W and a dip of 80°NE with nearly pure right-lateral slip (Hauksson and Gross, 1991). The subsurface average slip estimate from the seismic moment is 85 to 120 centimeters (2.8 to 3.9 ft) (Hauksson and Gross, 1991). Surface rupture was not reported for this earthquake (Wood, 1933), although Guptill and Heath (1981) suggest that surface displacement may have occurred near the south end of rupture on the North Branch fault strand on west Newport Mesa.

Since 1920, at least five earthquakes of magnitude 4.9 or larger (including the 1933 Long Beach earthquake) have been attributed to the NIFZ (Barrows, 1974). The first of these events was the 1920 local magnitude (M_L) 4.9 Inglewood earthquake, which caused moderate damage in the town of Inglewood (Hauksson, 1987). A (M_L) 5.4 aftershock of the 1933 Long Beach earthquake occurred under Signal Hill on October 2, 1933. In 1941, two earthquakes of magnitude 5.0 and 5.4 caused damage in the Torrance Gardena area (Richter, 1958).

Hauksson (1987) analyzed small earthquakes from 1977 to 1985 along the NIFZ trend and determined that the maximum principal stress axis is oriented N10–25°E. Of the 39 focal mechanisms, most show strike-slip faulting with some reverse faulting for those located north of Dominquez Hills, and some normal faulting for those located south of Dominquez Hills to Newport Beach (Hauksson, 1987). Inversion of focal mechanism data indicates that minimum principal stress is vertical north of Dominguez Hills and the intermediate stress is vertical south of

Dominguez Hills. Hauksson (1987) suggested that the occurrence of both strike-slip and reverse faulting events observed along the northernmost NIFZ may be related to an increase in both north-south and east-west horizontal stresses adjacent to the Transverse Ranges.

3.2 Paleoseismic Information

The record of prehistoric activity on a fault from paleoseismic studies can provide useful information for evaluating seismic hazards, such as earthquake magnitude estimates, fault slip rates, and the repeat times of large surface-rupturing earthquakes. Very little paleoseismic information has been developed for the northern NIFZ. Slip rate estimates and paleo-earthquake records have been obtained at paleoseismic sites farther south along the NIRC fault system in Orange County and San Diego (Figure 3). In San Diego, Lindvall and Rockwell (1995) documented a minimum Holocene slip rate of 1.1 to 2.0 mm/yr for the Rose Canyon fault based on paleoseismic trenching. The Rose Creek site (Figure 3), located on a Holocene terrace to Rose Creek, also revealed evidence for three surface-rupturing earthquakes in the past 8.1 thousand years before present (ka), with the most recent event (MRE) occurring within the past ~500 years. Based on radiocarbon data from additional La Jolla and San Diego trench sites (Rockwell and Murbach, 1999), the Rose Canyon fault MRE was constrained to AD 1650 ± 125 (Grant and Rockwell, 2002). Based on this information, Rockwell (2010) further interpreted the Lindvall and Rockwell (1995) three-dimensional trench observations to: (1) estimate up to 3 m of right-lateral displacement in the MRE, and (2) a total of six earthquake ruptures in the past 9.3 ka. However, a new trenching study in Old Town (Figure 3) revealed that there have been several middle to late Holocene surface ruptures (Singleton et al., 2019), indicating that the Rose Creek site contained an incomplete record, likely due to non-deposition. At the Old Town site, large events are interpreted to have occurred with an average recurrence interval of about 700 years, with at least two smaller (magnitude ~6) events also having occurred. The most recent moderate event was the 1862 magnitude 6 earthquake described as the “Day of Terror in San Diego”, as reported in the Los Angeles Star (Singleton et al., 2019).

The Rose Canyon fault slip rate also appears to be higher than originally estimated, based on new assessments of campaign and continuous GPS data (Singleton et al., 2020 in review). Re-occupation of 20-year-old campaign stations combined with continuous GPS data suggests a modern strain rate across the Rose Canyon fault of 3-4 mm/yr, which is nearly half of the total strain measured across the Inner Borderland system of faults in the offshore between San Clemente Island and Monument Peak in eastern San Diego County.

In Huntington Beach (Figure 1), Grant et al. (1997) used cone penetrometer test (CPT) and borehole transects to identify paleo-earthquakes on the North Branch fault. The study identified three, and most likely five, Holocene surface rupturing earthquakes within a graben produced by a transtensional stepover of ~0.5 km width. The timing of the oldest three events is best constrained by radiocarbon dating as: between 11.7 and 10.5 ka, about 10.5 ka, and between 7.8 and 5.5 ka. The penultimate event is estimated to have occurred at about 4.3 ka and the MRE could postdate 4.3 ka by several millennia (Grant et al., 1997). These estimated ages of NIFZ earthquakes match closely with events identified on the Compton-Los Alamitos fault by Leon et al. (2009), which may suggest a structural connection between these structures as suggested by Wright (1991), but is in contrast to interpretations by Shaw and Suppe (1996) that interpret the Compton-Los Alamitos system as a low-angle blind thrust.

A minimum slip rate was estimated as 0.34 to 0.55 mm/yr, but Grant et al. (1997) stress that the actual rate could be significantly higher. The minimum estimated Holocene slip rate is similar to a long-term (post-Miocene) slip rate estimate of 0.5 mm/yr (Freeman et al., 1992), although the long-term rate is based solely on brittle offset of piercing points and does not consider folding and plastic deformation, which could exceed the amount of brittle offset. Critical from an earthquake generation point of view is the slip rate at basement depths where earthquakes nucleate, which is almost certainly higher than the rates measured in the near surface, which do not account for off-fault plasticity and folding.

In Seal Beach, located northwest of Huntington Beach and along the NIFZ (Figure 1), Leeper et al. (2017) cored, dated, and mapped salt marsh stratigraphy to recognize three abrupt changes in sedimentation during the past 2,000 years. These changes record burials of fine salt marsh strata with coarser terrestrial sediment and are presumed to represent rapid subsidence during surface rupturing earthquakes (Leeper et al., 2017). The most recent event at this Seal Beach salt marsh site is contemporaneous with the most recent Rose Canyon surface rupture that exhibited ~3 m of dextral slip in San Diego (Lindvall and Rockwell, 1995; Rockwell and Murbach, 1999; Singleton et al., 2019). Leeper et al. (2017) suggest that only one of the interpreted events at the Seal Beach salt marsh may correlate with the Huntington Beach site MRE (< 4.3 ka) (Grant et al., 1997), although it should be pointed out that the Huntington Beach record is based solely on CPT data and some events that exhibited purely strike-slip displacement could have been missed; therefore, it should be interpreted as a minimum record of Holocene earthquakes. Further, comparison of the Leeper et al. (2017) record on the NIFZ with that from San Diego (Singleton et al., 2019) suggests that these earthquakes occurred at similar times, although as Singleton et al. (2019) point out, they are not likely the same events as that would require very large ruptures on long faults with significantly more displacement than is supported by their recurrence intervals and slip rates.

The large uncertainties in the timing of past surface ruptures and large distances between the few paleoseismic sites along the NIRC (Figures 1 and 3) preclude the development of a correlation chart to estimate past ruptures and their lengths with any reasonable confidence. There is also a lack of data on the timing of surface ruptures for the ~65-km-long offshore section of the fault zone (Figure 1). Studies of the offshore reach of the fault zone by Sahakian et al. (2017) using marine seismic reflection data to refine the fault zone's continuity and geometry, however, have observed along-strike differences in the depth of the most recent deformation below the seafloor, which may have implications on the extent and timing of offshore ruptures. The Carlsbad strand (Figure 1) does not appear to reach shallow sediment near the seafloor as adjacent sections do. Sahakian et al. (2017) suggest that the absence of surface deformation on this reach of the fault may have persisted for over 100 ka or more and may not experience surface deformation, which would support independent rupture of the Newport-Inglewood and Rose Canyon faults.

3.3 POTENTIAL FOR MULTI-FAULT RUPTURES

Given that the ~65-km-long onshore NIFZ is part of a much longer fault system (NIRC) that extends south through San Diego for a length of over 200 km (Figure 1), it has the potential to rupture in large, multi-segment earthquakes. The timing of paleo-earthquakes on the Newport-Inglewood and Rose Canyon faults support this possibility. Seismic reflection studies have been used to map a relatively continuous zone of faulting offshore with only minor steps (≤ 2 km wide), suggesting that large multi-segment ruptures should be considered in seismic hazard analyses (e.g., Fischer and Mills, 1991; Sahakian et al., 2017). Empirical studies of historical ruptures worldwide demonstrate that earthquakes commonly rupture through steps of this dimension (e.g., Wesnousky, 2008), and Coulomb stress modeling of rupture scenarios illustrate that rupture of the entire NIRC fault zone is possible (Sahakian et al., 2017). The southernmost stepover between the La Jolla and Torrey Pines fault strands (Figure 1), however, may act as an inhibitor to through-going rupture due to width and geometry of the step (Sahakian et al., 2017).

Regional seismic source models have incorporated the possibility of linked, multi-fault ruptures along the NIRC. The UCERF2 model included both individual ruptures on the NIFZ, offshore NIFZ, and Rose Canyon fault, as well as a combined fault source that included all three sections (Field et al., 2008). The more recent UCERF3 model relaxes segmentation constraints and allows ruptures on faults to cascade from portions of one fault to many faults (Field et al., 2013). The more varied UCERF3 ruptures and the faults that participate in them are limited by a set of rules that include step-over width, distance between fault tips, and fault intersection angle. This model allows for numerous rupture combinations involving the NIRC.

4.0 FAULTS MAPPED IN THE SITE VICINITY

The Poseidon site is located within in the Santa Ana Gap, a topographic low area carved by the Santa Ana River between the elevated topography of the Huntington Beach and Newport Mesas (Figure 4). Mapping of the NIFZ strands within the Santa Ana Gap is primarily based on mismatches in the Miocene and Pliocene strata from oil field exploration, and from groundwater barriers in Pliocene and Pleistocene strata. The gap contains a thick late Pleistocene and Holocene fill associated with aggradation of the Santa Ana River during post-Marine Isotope Stage (MIS) 2 sea level rise (beginning about ~17–20 ka). Surficial deposits within the gap consist of young, Holocene deposits (Figure 5). Consequently, as the sediments are so young, it has been difficult to assess the recency of individual strands of the NIFZ in the Santa Ana Gap, as the base of the Holocene fill may be tens of feet in depth. Based on calibrated ages from radiocarbon dating at the site (GeoLogic Associates, 2002), the Holocene-Pleistocene boundary is located at a depth of approximately 80 ft.

There are several interpretations of faults at different structural levels in the Santa Ana Gap and naming of these faults varies with each interpretation. The North Branch and South Branch terminology has been used for faults in both the Huntington Beach and West Newport oil field areas, which can lead to confusion in describing the fault zone (Figure 6). The principal fault strand, highlighted yellow in Figure 6, represents the fault exhibiting the largest cumulative vertical separations of Miocene and Pliocene strata (see cross-sections in Figures 6 and 7). This principal fault consists of the North Branch in the Huntington Beach oil field and the zone of more southerly striking faults exiting the shoreline near the mouth of the Santa Ana River, which has also been called the South Branch (Figure 6). The North Branch in the West Newport oil field crosses the Santa Ana River and exhibits a similar strike as the North Branch in the Huntington Beach oil field, making it appear to be a continuous extension of the same fault in map view (Figure 6). However, in cross-section, this fault crossing the Santa Ana River exhibits significantly less vertical separation than the principal fault located southwest (Figure 7). Therefore, the North Branch in the West Newport oil field does not appear to be a continuation of the same large slip fault, the principal fault, which diverges to the south. The South Branch mapped through the Poseidon site is based on interpreted offsets in aquifers and represents a secondary fault of the NIFZ. Throughout this report, we refer to the fault mapped crossing the Poseidon site as the "South Branch" and the main fault of the NIFZ as the "principal fault" (Figure 6). To minimize confusion, we retain the North Branch and South Branch names in the Huntington Beach area, but try to avoid using these names for faults in the West Newport oil field in this report. Reproduction of some previously published figures do retain these names in the West Newport oil field (e.g., Figure 7).

Faults interpreted in the shallow subsurface and at greater depth were differentiated and named in subsequent studies conducted by the California Department of Water Resources (DWR) and others. The NIFZ in the Santa Ana Gap according to DWR (1966), from north to south, consists of the Bolsa-Fairview, Yorktown, Adams Avenue, Indianapolis, North Branch (the "principal fault"), and South Branch faults (Figure 4). The basis for mapping these faults is primarily groundwater and stratigraphic differences between wells. DWR (1966) describes that fault locations in the Santa Ana Gap were determined from "major lithologic and faunal discontinuities between exploratory wells, major stratigraphic discontinuities in deeper oil-bearing materials, marked changes in mineral character and quality of groundwater, abrupt piezometric level differences in aquifers, and anomalies in aquifer performance test data."

The Bolsa-Fairview fault was first mapped by Poland and Piper (1956), who inferred a fault in the northern Newport Mesa based on water well data. In this report, the term "inferred" is used in reference to the standard convention in geologic mapping that depicts faults that are not directly visible at the ground surface with a dashed, dotted, or queried line. Such faults are classified as concealed or inferred. DWR (1966) connected the inferred fault of Poland and Piper (1956) with a fault in the Santa Ana Gap mapped by Loken (1963). The Yorktown, Adams Avenue, and Indianapolis faults were inferred from hydrologic data and mapped by DWR (1966). Through-going faults were not mapped in the Santa Ana Gap between the Adams Avenue fault and the North Branch fault of Hunter and Allen (1956), which led Bryant (1985) to suggest that this zone of faults does not extend at depth. The South Branch fault was first inferred by Poland and Piper (1956) and was assumed to be a right-lateral strike-slip fault by DWR (1966, 1968). Poland and Piper (1956) inferred the location of the South Branch fault across Huntington Beach Mesa based on a gentle topographic slope and other deep structural features (Bryant, 1985). Then, DWR (1966) used groundwater data from exploratory wells to illustrate displaced or mismatched aquifers across all six faults mapped in the Santa Ana Gap (Figure 4).

4.1 Oil Field Data (Post-Miocene Faulting)

The main structural feature of the Huntington Beach and West Newport oil fields is the Newport-Inglewood fault zone (Figures 2 and 6). In the Huntington Beach oil field, the NIFZ is expressed as a single major fault (North Branch) with about five lesser faults to the southwest (Figure 6), which are depicted as terminating at the base of the Pliocene Lower Pico formation or within the Pliocene Repetto formation (DOGGR, 1992). The principal fault extends to the surface and separates a more steeply dipping section on the northeast from more gently dipping units on the southwest. The vertical separation on the contoured horizon (green contours in map and green horizon in cross-section A-B) is not significant, which implies a dominant horizontal component of slip on this principal strand (Figure 6).

Farther southeast in the West Newport oil field, the fault system appears to diverge southeastward into two major zones of faults (Figure 6). Both fault zones are interpreted with west-side-down normal separations and dip steeply to the southwest; however, the North Branch labeled in cross-section A-A' (Figure 7), has an order of magnitude less vertical separation than the other branching fault zone that strikes more southerly (Figures 6 and 7). The more southerly, large displacement fault is interpreted as the principal strand of the NIFZ at this location. The principal fault exhibits up to 2,000 ft of vertical separation across the Miocene top of "A" zone horizon (brown horizon in Figure 7). This fault represents the principal fault within the NIFZ, as it exhibits the greatest amount of cumulative displacement. The change in strike of the principal fault strand from the Huntington Beach oil field to the West Newport oil field likely explains the greater vertical separation observed in the West Newport oil field and is consistent with a releasing or transtensional bend in the right-lateral NIFZ.

Structure contour maps and faults interpreted at depth in the oil fields do not identify the South Branch fault as mapped through the Poseidon site. Figure 6 shows the faults mapped at depth in the oil fields in black and Quaternary faults mapped near the surface in red. Note how there is no through-going oil field fault that is interpreted along the length of the inferred Quaternary South Branch fault (Figure 6). The oil field data do not allow for the interpretation of stratigraphy younger than Pliocene age (Hunter and Allen, 1956; Allen and Joujon-Roche, 1958; Beyer, 1988; DOGGR, 1992) and therefore, do not depict faults in the younger Pleistocene and Holocene deposits near the surface. The differences observed between the deep oil field data and shallower fault interpretations suggest that either: (1) the South Branch fault is a small displacement fault that is difficult to recognize from the spacing of oil wells, or (2) the South Branch fault does not exist as a continuous, through-going fault as has been previously depicted in various maps.

4.2 Groundwater and Early Mapping Studies (Post-Plio-Pleistocene Faulting)

Various groundwater and early mapping efforts resulted in the delineation of faults within the Santa Ana Gap between the Huntington Beach Mesa to the northwest and the Newport Mesa to the southeast (Figure 4). In 1966, the Department of Water Resources Bulletin No. 147-1 concluded that direct displacement of recent sediments has not occurred along faults crossing the Santa Ana Gap and that, with the exception of the Talbert aquifer of recent (Holocene) age, other early to late Pleistocene age aquifers in the Santa Ana Gap have been faulted and folded across the Newport-Inglewood fault system. Geologic cross-sections directly east (B-B', Figure 8) and west (C-C', Figure 8) of the site depict all fault strands, including the South Branch of the NIFZ, terminating at the base of the Talbert aquifer (DWR, 1966). Poland and Piper (1956) assert that geologic, hydrologic, and geochemical evidence from water wells does not substantiate whether or not this South Branch transects deposits of Pleistocene age. Geologic cross-sections E-E' and C-C' in the vicinity of the site do not depict the South Branch of the NIFZ; however, the NIFZ is shown as terminating at the base of the Talbert water-bearing zone northeast of the site (Poland and Piper, 1956). To the northwest of the Huntington Beach Mesa in the Bolsa Gap (Figure 6), DWR (1968) does not map the South Branch fault as offsetting the early Holocene Bolsa aquifer. Hazenbush and Allen (1958) mapped faults in the Bolsa Gap sub-parallel to the South Branch fault, but they do not offset deposits younger than lower Pliocene (Bryant, 1985).

The NIFZ has a barrier effect in the lower Pleistocene aquifers along its entire length from Huntington Beach to Newport Mesa (DWR, 1966) (Figure 4). In the Santa Ana Gap, saline water intrusion has occurred in Pleistocene sediments across the North and South Branches of the NIFZ and continues inland. The North Branch fault forms a salinity barrier in late Pleistocene sediments, but groundwater moves freely within the Holocene age Talbert aquifer; therefore, this aquifer has a high salinity content on both sides of the North Branch fault (DWR, 1966). According to both DWR (1966) and Bryant (1985), the South Branch fault is not a saltwater barrier. At the Indianapolis fault, strata of silt and clay are faulted against the Main, lower Rho, and upper Rho aquifer zones, which form a nearly complete impediment to further inland saline intrusion in the lower Pleistocene aquifers. The Adams Avenue, Yorktown, and Bolsa-Fairview faults are partial barriers to groundwater flow (DWR, 1966) in Pleistocene deposits, but not in the Talbert aquifer.

The conceptual model describing aquifers in the Santa Ana River Basin is based on studies by the California Department of Water Resources in the 1960s (DWR, 1966) and the Orange County Water District (OCWD, 2004), which identified three major aquifer systems from middle Miocene through Holocene. Detailed knowledge of the stratigraphic character of the Santa Ana River Basin aquifers is mainly from descriptions of water wells drilled since the late 1930s. Currently, no modern sequence-stratigraphic analysis has been carried out in the Santa Ana River Basin (Edwards et al., 2009). Geologic cross-sections at the south-central (Santa Ana Gap) and western (Alamitos Gap) parts of the basin record a common stratigraphy (Zielbauer et al., 1961; Callison et al., 1991; Callison, 1992; Herndon, 1992). Generally, undeformed Holocene river channel sands and gravels (the Talbert and Recent aquifers) associated with the ancestral San Gabriel and Santa Ana Rivers unconformably overlie aquifers of Pleistocene age. Towards the coast, Pleistocene aquifers are deformed and faulted by the Newport-Inglewood Uplift, where they dip north, and extend to depth into the central Santa Ana River Basin (Edwards et al., 2009). Generalized cross-section B-B' from Edwards et al. (2009) shown in Figure 9 is located directly east of the site and shows the Newport-Inglewood fault system terminating at the base of the Talbert aquifer (Holocene age) in the south-central part of the Santa Ana Gap.

A recent generalized cross-section by OCWD (2016) to illustrate salinity concentrations through the Santa Ana Gap (Figure 10) is located approximately 4,000 ft east of the site and depicts the

South Branch of the NIFZ terminating at the base of the Talbert aquifer. This cross-section depicts all of the regional aquifers below the shallow Talbert aquifer as uplifted, folded, and offset to varying degrees by the NIFZ (OCWD, 2016).

Various recent cross-sections through the Santa Ana Gap (OCWD, 2016; EMA, 2015) are adapted from the California Department of Water Resources Bulletin No. 147-1 (DWR, 1966) and several others (Edwards et al., 2009; Geosyntec Consultants, Inc., 2013) are adapted from the Orange County Water District Groundwater Management Plan (OCWD, 2004). Interpretations from DWR (1966), including aquifer system names and fault interpretation, are still in use today to represent the subsurface geology of the Santa Ana Gap. It is important to note that while these interpretations are still in use, the water well data upon which these interpretations are based are not sufficiently dense to preclude Holocene fault displacement on any of the faults in the Santa Ana Gap.

4.3 Shallow Geologic and Geophysical Investigations (Pleistocene and Holocene)

Recently, several geotechnical and seismic investigations gathered subsurface data in the vicinity of the site to assess fault activity of the NIFZ South Branch. GeoLogic Associates (2002) conducted 21 CPT soundings and six rotary boreholes to depths of 82 to 93 ft below the ground surface at the Orange County Desalination Project site (AES Generating Station) in Huntington Beach, California (Figure 11) as part of preliminary geotechnical and seismic investigations. They obtained radiocarbon dates for selected samples from the boreholes and conducted an evaluation of faulting based on stratigraphic correlations. The investigation did not find evidence of faulting at the site to the maximum depths explored and stated that, “Because the age of the stratigraphic section below the tank sites as determined by radiocarbon dating includes all of Holocene time, the absence of evidence of faulting suggests the risk of future surface faulting at the site is a relative minimum.” The GeoLogic (2002) report we were provided was a draft version dated August 2002 that was missing plates, cross-sections, and logs of CPTs and boreholes. Therefore, we were unable to make an independent review of their data and interpretations regarding the presence or absence of faulting in the Holocene strata at the site. The locations of GeoLogic boreholes shown in Figure 11 were obtained from a map in the Geosyntec Consultants Inc. (2013) report. At face value, the GeoLogic (2002) report stated that they found no evidence for the presence of faults in their explorations across the site, which span the inferred fault strand from the U.S. Geological Survey’s Quaternary fault and fold database (Figure 11). However, with CPT and borehole spacing ranging on the order of 50 to 100 ft, it may be difficult to preclude the presence of minor, secondary faults at the site.

Ninyo & Moore (2011) conducted a subsurface investigation at 21730 Newland Street in Huntington Beach, California (Figure 11) consisting of two hollow-stem auger boreholes to depths of approximately 51.5 ft and four CPTs to depths of approximately 75.5 ft. They concluded that, “Based on the distance of the mapped fault to the area of the proposed re-powering project, the potential for surface fault rupture impacting the project is relatively low.”

In 2013, a geotechnical hazards assessment of the Poseidon site was performed by Geosyntec Consultants, Inc. (2013). Geosyntec performed a review of available literature to assess the likelihood of a subsurface fault rupture at the site and found such fault rupture to be unlikely. Geosyntec also performed a limited field investigation consisting of five CPT soundings, ranging from depths of 50 to 98 ft. The version of the Geosyntec Consultants, Inc. (2013) report we were provided, and which we reviewed, did not include Appendix A containing the Geosyntec Consultants, Inc. (2013), Ninyo & Moore (2011), and GeoLogic (2002) CPT and boring logs. The report also does not include any geologic cross-section figures, and therefore, an independent assessment of the presence or absence of faulting at the site could not be made as part of our review. The locations of borings and CPTs by Geosyntec Consultants, Inc. (2013), Ninyo & Moore (2011), and GeoLogic (2002) are shown in Figure 11.

In order to evaluate the potential impact to proposed structures at the Poseidon site from rupture on the South Branch fault, Geosyntec Consultants, Inc. (2013) performed a finite element analysis and assumed: (1) a moment magnitude Mw 7.1 earthquake scenario, (2) the South Branch fault beneath the site is a secondary fault within the NIFZ, and (3) secondary faults are capable of producing only 25% of the main fault displacement. Displacements of 3.8 ft and 0.95 ft were estimated for the principal fault (located offsite) and the secondary South Branch fault (assumed to be located beneath the site), respectively. The finite element model included an approximately 200-ft-thick section of alluvial sediments through which 0.95 ft of fault displacement was propagated to the ground surface. The analysis demonstrated that, for the fault rupture scenario analyzed, the proposed structures may experience repairable aesthetic and temporary serviceability issues, but significant structural damage is considered to be unlikely (Geosyntec Consultants, Inc., 2013).

A network of shallow seismic reflection surveys was conducted offshore near the mouth of the Santa Ana River by EcoSystems Management Associates, Inc. (EMA, 2015) to provide more accurate information on the characteristics of the offshore subsurface where possible subseafloor intake systems may be constructed. The seismic line located nearest to the shoreline in this network of surveys, HBP-2101, is shown Figure 12 and its approximate location is shown in Figure 6. Many faults are interpreted along the length of HBP-2101 that have upward terminations in both late Pleistocene and Holocene sequences (Figure 12). The most prominent feature in this profile is a graben (South Graben) near the center of the line. Vertical separation on the strong reflection horizon appears to vary from a few to over 90 ft; however, EMA (2015) interpret that a 90-ft vertical separation appears too large for tectonic deformation and suggest that the steep boundary of the South Graben may be erosional rather than tectonic, such as a fault line scarp formed by channel erosion. The broad zone of young faults interpreted in HBP-2101 is consistent with a major strand of the NIFZ crossing the coastline near the mouth of the Santa Ana River (EMA, 2015). The strike of individual strands within this wide, complex, distributed zone of faulting imaged in the offshore seismic line is unknown (Figure 12), and therefore these faults cannot be confidently correlated to faults onshore and it is not known if any project toward the Poseidon site.

4.4 Principal Fault Strand

The principal fault strand, as portrayed in cross-sections by Hunter and Allen (1956), lies approximately 0.6 km east of the subject site. This deep, through-going fault is interpreted to accommodate the majority of slip, and exhibits up to 2,000 ft of vertical separation (Figure 7). The principal fault of the NIFZ, which does not intersect the Poseidon site, is highlighted in yellow in Figure 6. From cross-section A-A', this fault continues northwestward for about 1.5 km and makes a bend to a more westerly direction. South of cross-section A-A', the fault projects offshore near the mouth of the Santa Ana River.

Shallow offshore seismic reflection surveys near the mouth of Santa Ana River by EMA (2015), notably seismic profile HBP-2101, interpret a broad zone of faulting in late Pleistocene and Holocene deposits (Figure 12) that is consistent with the approximate offshore projection of the principal fault strand. The distributed zone of faulting, however, is much wider than the principal fault zone depicted at depth in the oil field (Figure 7), and as the EMA (2015) report points out, some of the interpreted offshore structures may be related to the presence of gas.

4.5 Observations Along the "South Branch" Fault

This section of the report describes additional observations that have been reported along the South Branch fault from Huntington Mesa to the Poseidon site.

Erickson (1976) trenched the inferred location of the South Branch fault on the southwest end of Huntington Beach Mesa based on subsurface oil-well data, located directly south of the Poland and Piper (1956) fault location, and did not find evidence of shallow faulting. Woodward-Clyde Consultants (WCC, 1984) inspected a gully for evidence of recent faulting along the inferred fault of Poland and Piper (1956) and excavated a trench across the trace. They observed no evidence of faulting in late Pleistocene deposits and WCC (1984) concluded that shallow surface faulting in Pleistocene and Holocene deposits has not occurred along the South Branch fault (Bryant, 1985).

A gully that coincides with the South Branch fault on the southwest side of the Huntington Beach Mesa was inspected for the presence of faulting. According to his personal correspondence with Bryant (1985), R. Miller did not observe evidence of significant faulting, but did observe a minor fault with a few centimeters of displacement in late Pleistocene deposits. Miller concluded that oil-well and near-surface hydrologic data do not support a significant fault, but that there may be a fault in the subsurface that could have caused warping in the mesa surface (Bryant, 1985).

Bryant observed a southwest-facing slope, a broad northwest-trending trough, and closed depressions at the mapped location of the South Branch fault on the Huntington Beach Mesa; however, he states that the closed depressions do not seem to be fault related (Bryant, 1985). He also concedes that the southwest-facing slope is gentle and may have formed from warping of the mesa surface or wave erosion. Bryant observed no other geomorphic evidence of recent faulting based on his air photo interpretation and he did not confirm the location of the South Branch fault in the Santa Ana Gap. As the fault is not well defined at the surface and there is insufficient evidence for activity, Bryant recommended that the South Branch fault not be included in an Alquist-Priolo Earthquake Fault Zone (APEFZ).

Evidence of surface landforms purported by Poland and Piper (1956) is weakly supported by Bryant (1985), but these features may not be indicative of tectonic activity. Therefore, the strongest evidence for the South Branch fault appears to be from groundwater data in exploratory wells that identified displaced units (aquifers) of Pleistocene age (DWR, 1966). The location of the South Branch fault in the Santa Ana Gap, which was interpreted as existing between two wells (Figure 8), has a considerable margin of uncertainty.

Although specific studies at the Poseidon site (GeoLogic, 2002; Ninyo & Moore, 2011; Geosyntec Consultants, Inc., 2013) have consistently found an "absence of evidence" for Holocene faulting, the methods employed do not preclude Holocene activity. These methods (CPT soundings and borehole transects) and spacing of explorations are insufficient to resolve minor vertical displacement and larger horizontal displacement in the subsurface. Considering the thick (~80 ft) Holocene section and shallow groundwater, trenching of the fault to the base of the Holocene section is impractical. Hence, the recency of activity on the South Branch of the NIFZ remains undetermined as there have been no studies that have explored the entire Holocene section across the "South Branch" of the fault zone. While it is permissible that the secondary South Branch fault could be active, there is currently no data or direct observations to support this.

5.0 CONCLUSIONS

Based on our review of available information, we can make the following conclusions regarding faults within the Santa Ana Gap and the South Branch fault, which has been mapped at the Poseidon site:

- The South Branch fault at the site is not the principal fault of the NIFZ. The principal active fault is located about 0.6 km east of the site and projects offshore near the mouth of the Santa Ana River. Future NIFZ earthquake ruptures will produce the largest displacements along the principal active main fault zone highlighted yellow in Figure 6.

- Various reports and studies have used the names "South Branch" and "North Branch" to refer to different faults along strike of the NIFZ. North and northwest of the site, the North Branch fault represents the active principal fault within the NIFZ, but this fault is likely not the same "North Branch" fault mapped in the Newport Mesa to the southeast. Likewise, the principal fault, which is located 0.6 km east of the site and crosses the shoreline near the mouth of the Santa Ana River, has been given the "South Branch" name in previous publications. This fault is not the same structure as the secondary South Branch fault mapped at the Poseidon site.

- The South Branch fault does not appear to correlate with any continuous faults mapped at depth from oil field data (Figure 6). This suggests this fault is mapped largely based on apparent offsets in the shallow aquifers and has not produced significant cumulative displacement that would be more readily recognized in deeper Miocene strata mapped within the Huntington Beach oil field.

- Local geotechnical data do not help constrain accurate locations or ages of faults within the Santa Ana Gap. This is largely because no large cumulative displacements will likely be observed within Holocene and latest Pleistocene deposits in boreholes (to the maximum depth of geotechnical exploration at the site of 98 ft). In addition, shallow groundwater depths prevent trenching, which is the best approach for obtaining continuous exposures for evaluating faults.

- Data do not exist to adequately assess whether or not the “South Branch” fault at the site has ruptured in the Holocene (past 11,700 yrs) and would be considered an active fault by the California Geological Survey (CGS). This fault strand, which continues northwest into the Pleistocene deposits of the Huntington Beach Mesa, has not met the criteria of “sufficiently active and well defined” to be included in an Alquist-Priolo Earthquake Fault Zone (APEFZ) by the CGS.

- Past studies at the Poseidon site by GeoLogic (2002), Ninyo & Moore (2011), and Geosyntec Consultants, Inc. (2013) have consistently concluded an “absence of evidence” for the presence of Holocene faulting on site. However, the subsurface exploration methods and spacing of CPT and borehole explorations employed cannot preclude the presence of minor secondary Holocene activity.

- A wide zone of Holocene faulting was interpreted spanning nearly the entire length of a nearly 3-mi-long seismic reflection survey profile (EMA, 2015) located parallel to the shoreline (Figures 6 and 12). Given that the strike of faults interpreted in HBP-2101 are unknown, we cannot determine if any of these strands may project onshore near the Poseidon site.

- This desktop analysis of available scientific studies on the NIFZ indicates that although there is no information that directly implicates the “South Branch” as being active, there are no data that demonstrably preclude Holocene activity. Additional subsurface investigations could be performed to evaluate for the presence or absence of Holocene-active faults. However, thick Holocene deposits in the Santa Ana Gap could make such an evaluation difficult.

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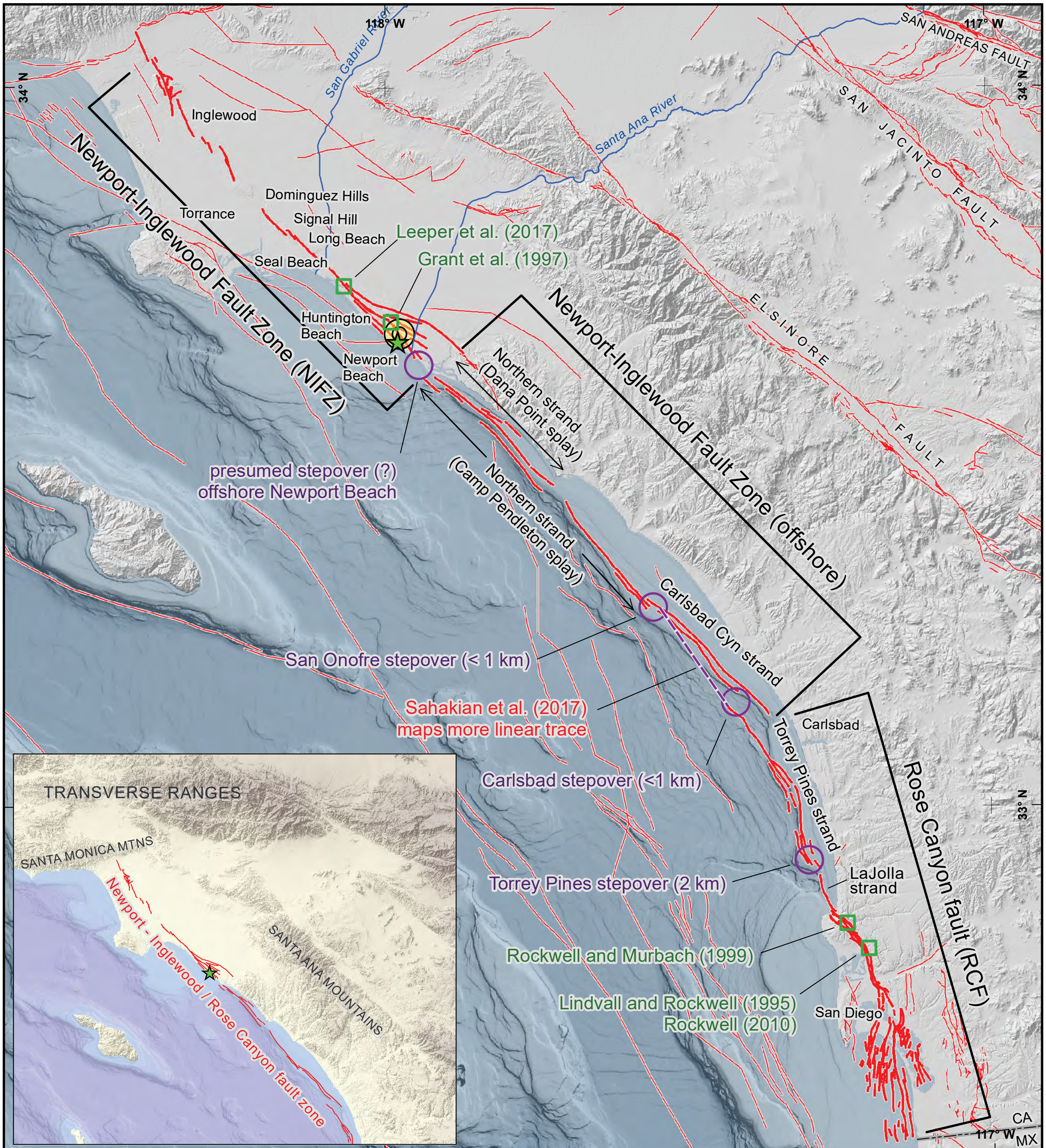


EXPLANATION

- ★ project site
- □ Paleoseismic study location
- ◎ 1933 Long Beach earthquake epicenter

Faults (USGS and CGS, 2018)

- Newport-Inglewood/Rose Canyon (NIRC) fault zone
- Quaternary Fault

0 15 30 mi
0 25 50 km

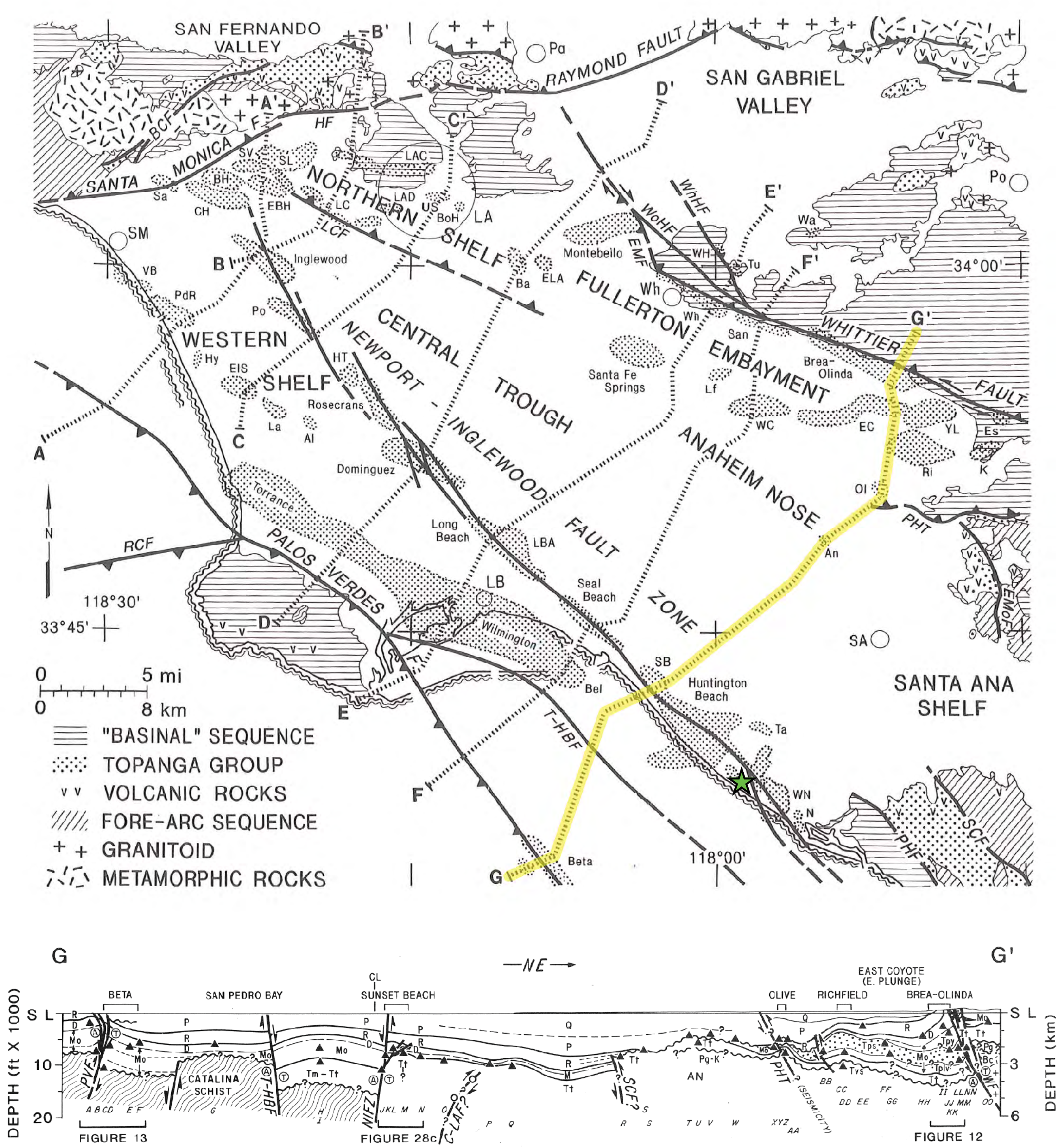
Map projection and scale: NAD83 StatePlane Zone 5 feet, 1:900,000

Map of Newport-Inglewood/Rose Canyon (NIRC) fault zone

OCCK ASSESS SOUTH BRANCH NIFZ

Lettis Consultants International, Inc. | Figure **1**

File path: I:\Projects\1966.000 OCCK Assess South Branch NIFZ\0700 GIS\1 - NIRC Fault Zone.mxd; Date: 04/28/2020; User: hemphill, LCI; Rev.1



EXPLANATION

★ project site

Key abbreviations of oil fields along NIFZ

BH	Beverly Hills	Po	Potrero
CH	Cheviot Hills	SB	Sunset Beach
EBH	East Beverly Hills	SL	Salt Lake
HT	Howard Townsite	SV	San Vicente
LBA	Long Beach Airport		

0 5 10 mi
0 5 10 km

Map projection and scale: NAD83 StatePlane Zone 5 feet, 1:472,000

Major Structural Features and Oil Fields in the greater LA Basin from Wright (1991)

OCCK ASSESS SOUTH BRANCH NIFZ

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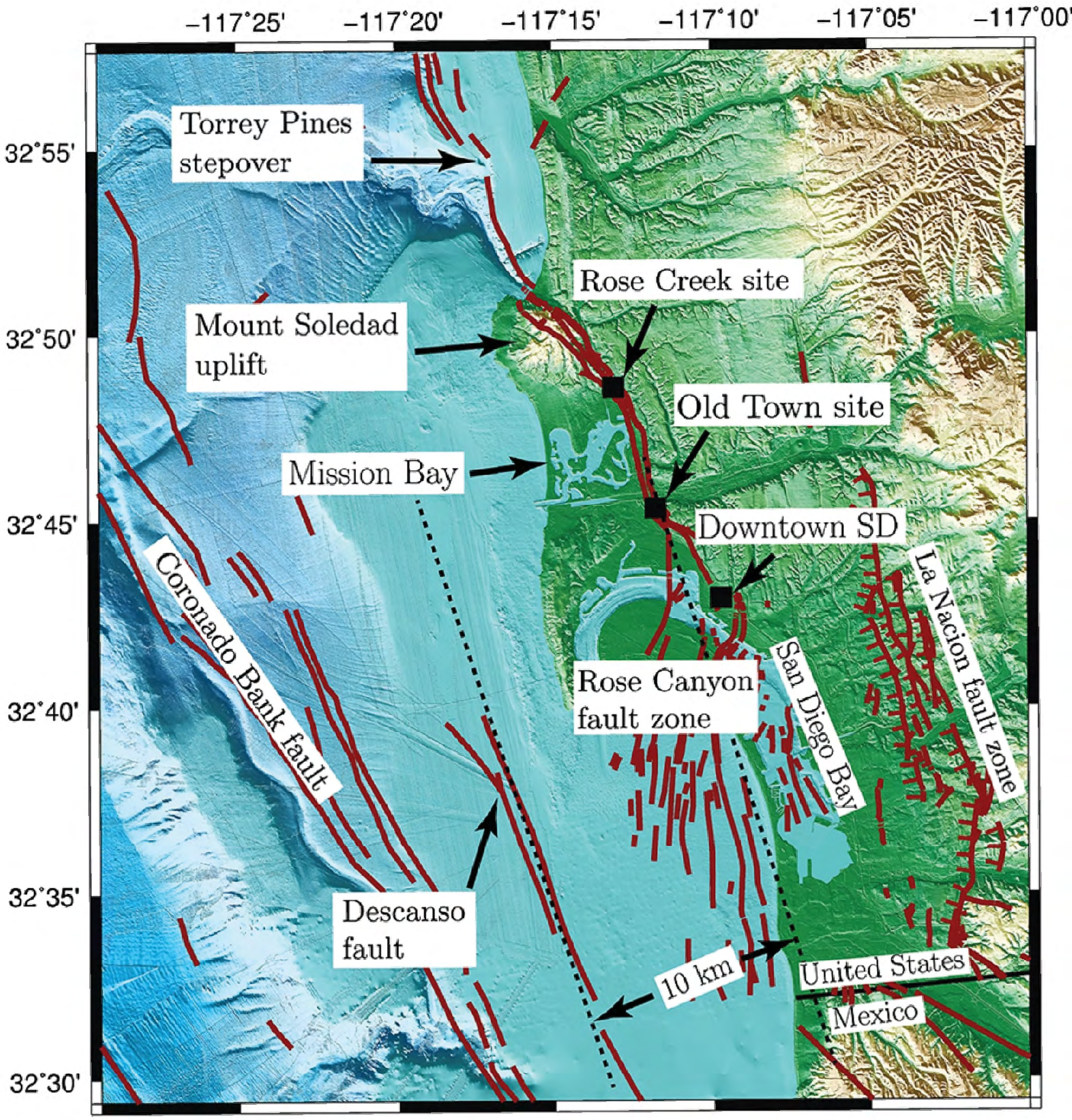
Figure **2**



source: Singleton et al. (2019)

EXPLANATION

■ Paleoseismic study location

0 5 10 mi

0 5 10 km

Map projection and scale: NAD83 StatePlane Zone 5 feet, 1:315,000

Rose Canyon Fault Zone (RCFZ) through San Diego

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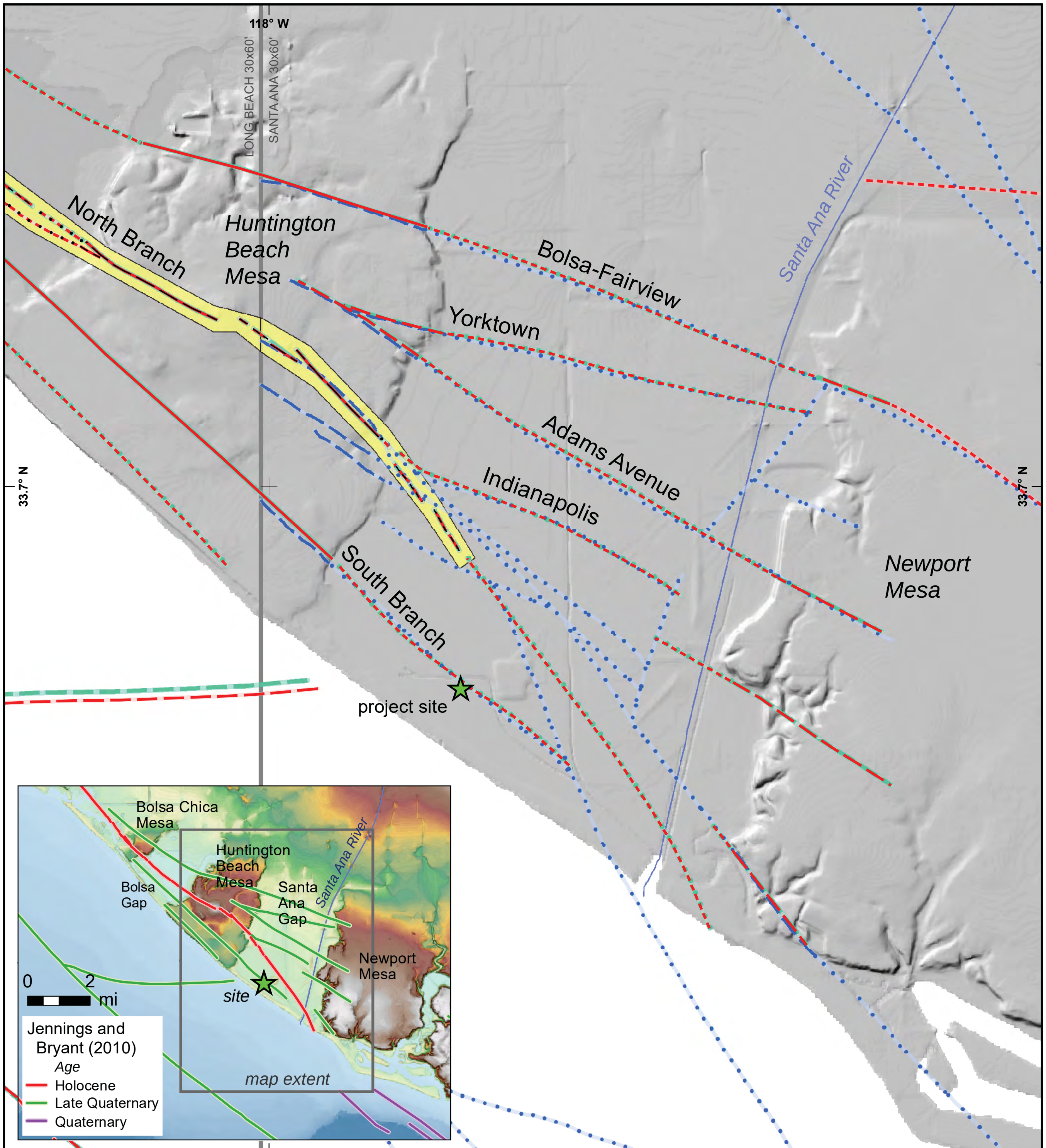

EXPLANATION

Alquist-Priolo Fault Trace and Zone (CGS, 1986a, 1986b)
long dash where approximately located, short dash where location inferred, dotted where concealed

Morton (2004), Santa Ana 30x60'
dashed where approximately located, dotted where concealed

Jennings and Bryant (2010)
solid where certain, dashed where approximately located, dotted where concealed

Quaternary Fault and Fold Database (USGS and CGS, 2018)
solid where certain, long dash where approximately located, short dash where inferred or concealed

N S W E

0 1 2 mi
0 1.5 3 km

Map projection and scale: NAD83 StatePlane Zone 5 feet, 1:60,000

Santa Ana Gap Faults

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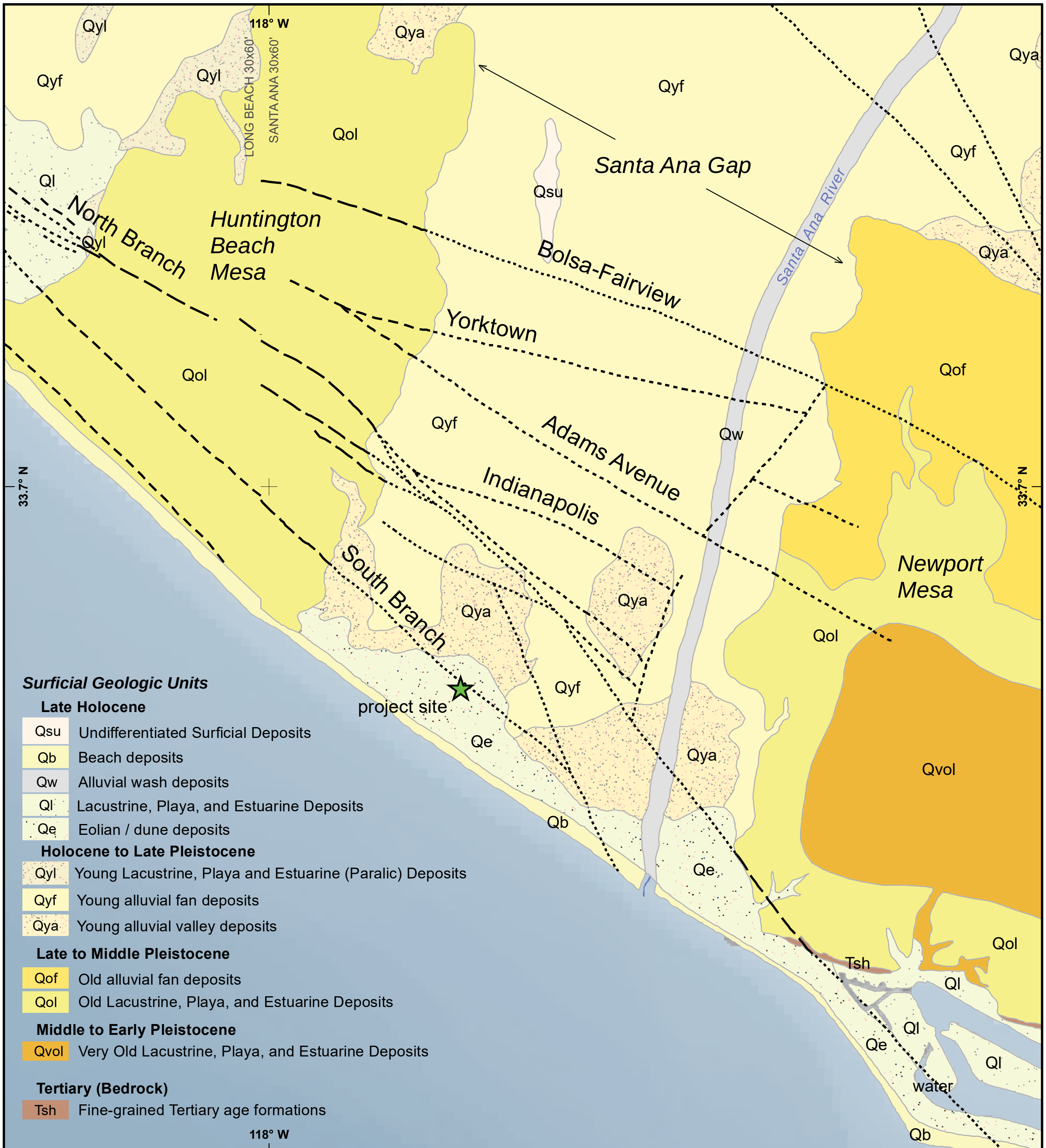
File path: I:\Projects\1966.000 OCCK Assess South Branch NIFZ\0700 GIS\4 - Santa Ana Gap faults.mxd; Date: 05/04/2020; User: hemphill, LCI; Rev.1



Map projection and scale: NAD83 StatePlane Zone 5 feet, 1:60,000

Note: geologic mapping from Bedrossian et al. (2012)

Surficial Geologic Map

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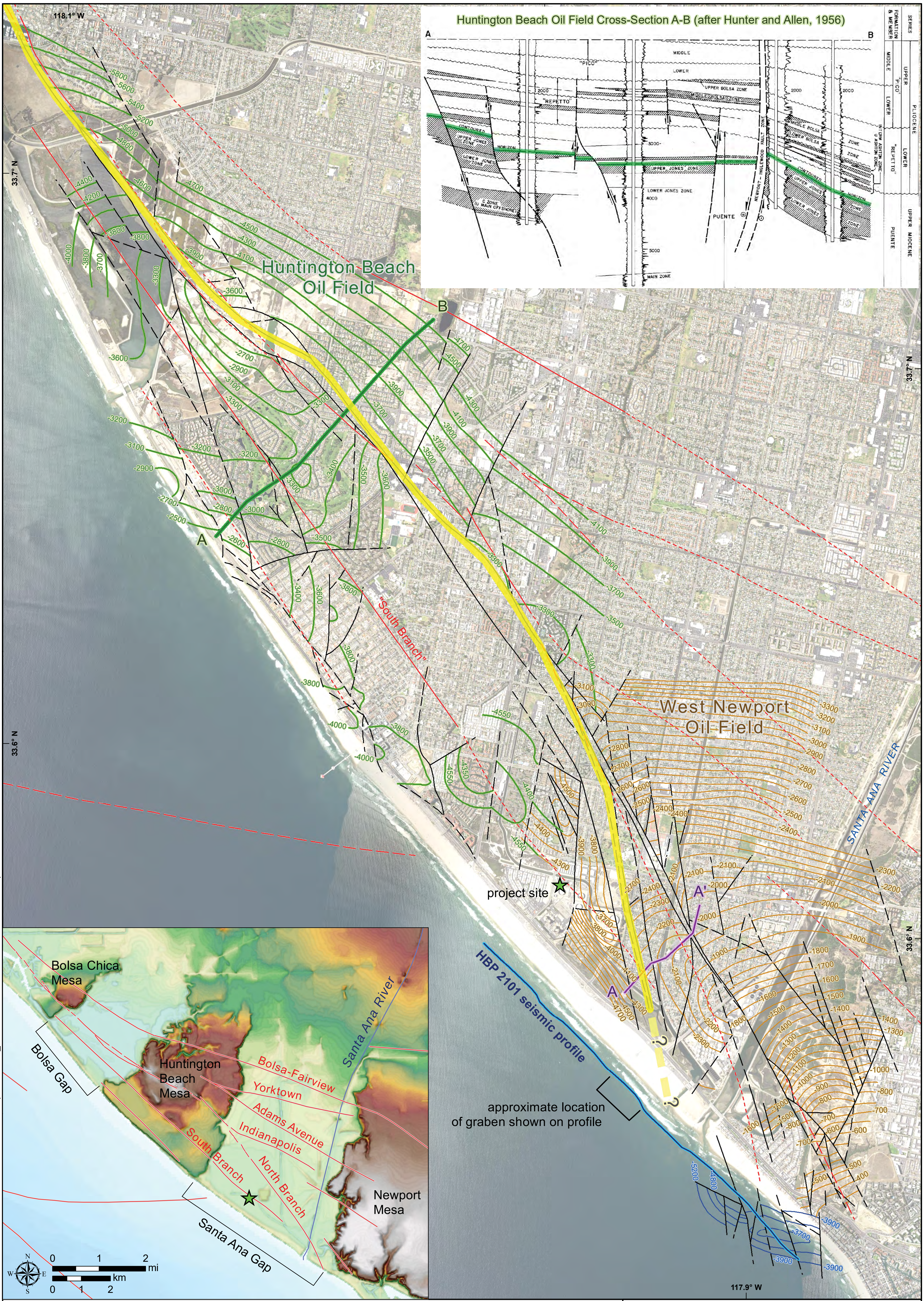

deep structure fault (Huntington Beach and West Newport Oil Field)
surface fault trace (USGS Quaternary Fault and Fold Database, 2018)
main fault trace shown at depth of contoured horizons

West Newport Oil Field
- cross-section A - A'
- structure contour
- structure contour (Offshore)

Huntington Beach Oil Field
- cross-section A-B
- structure contour

Map projection and scale:
NAD 1983 StatePlane California V FIPS 0405 Feet, 1:125,000

note: profile A-A' shown on Figure 7
base image: NAIP 2016

Deep Structures of the Huntington Beach and West Newport Oil Fields

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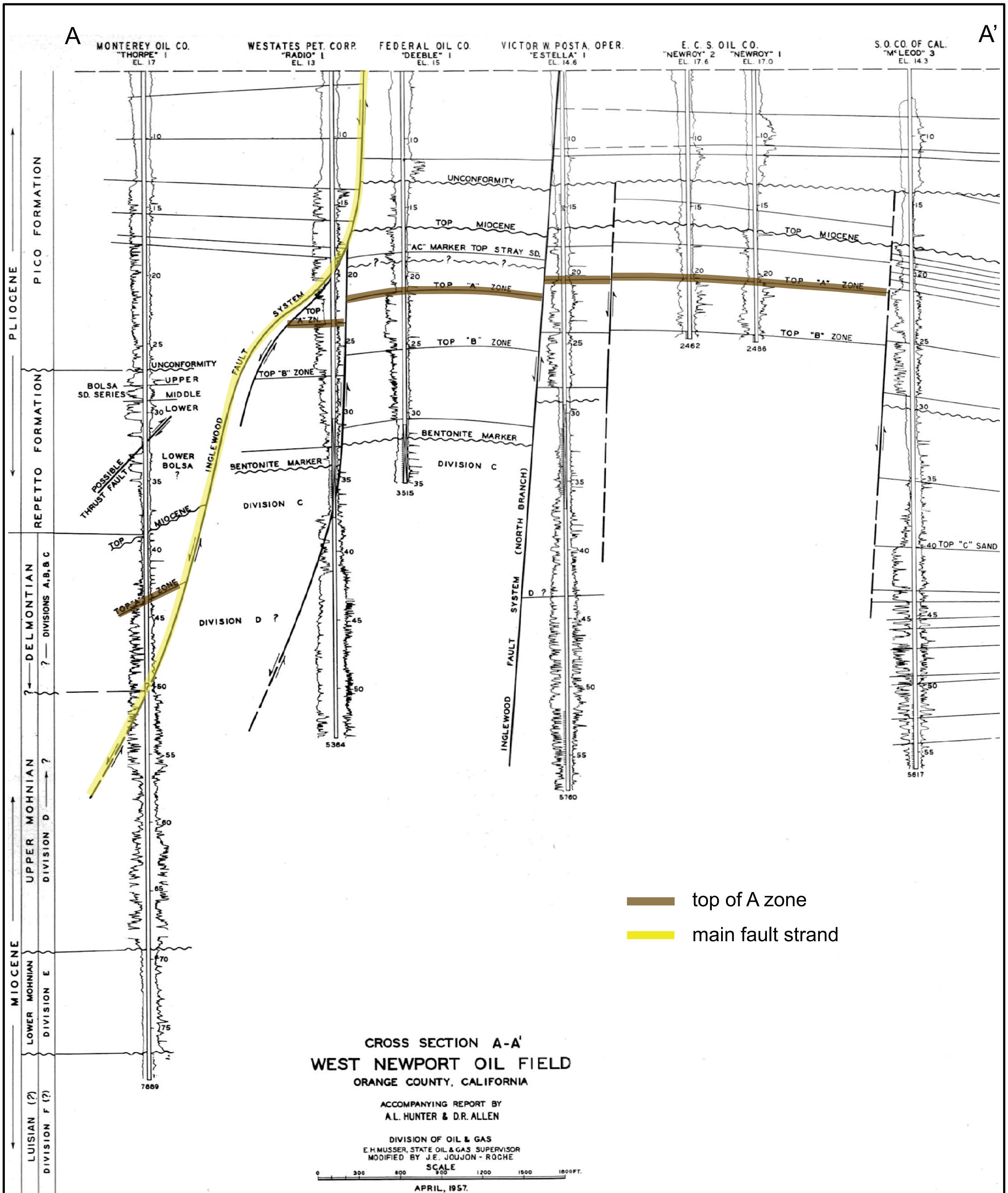
Figure **6**

File path: I:\Projects\1966.000 OCCK Assess South Branch NIFZ\0700 GIS\6 - Deep Structures_11x17P.mxd; Date: 05/04/2020; User: hemphill, LCI; Rev.1



Notes:
1. location shown on Figure 6
2. modified from cross-section A-A' of Hunter and Allen (1956)

West Newport Oil Field
Cross-Section A-A'

OCCK ASSESS SOUTH BRANCH NIFZ

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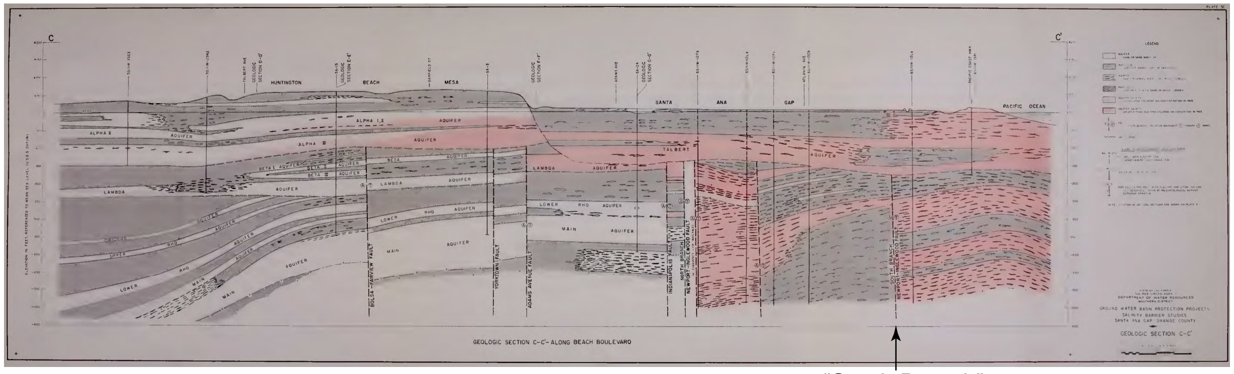
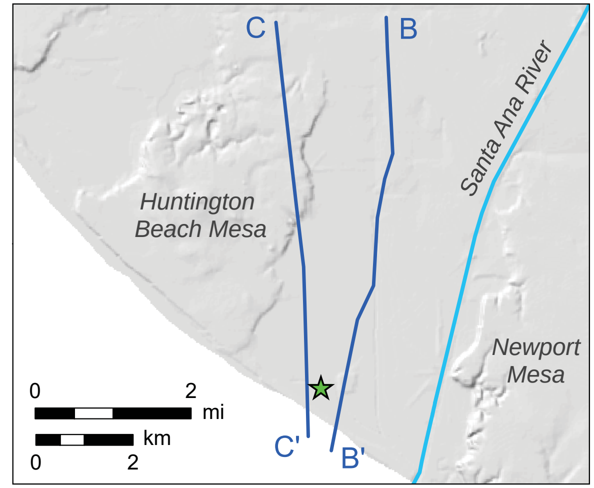
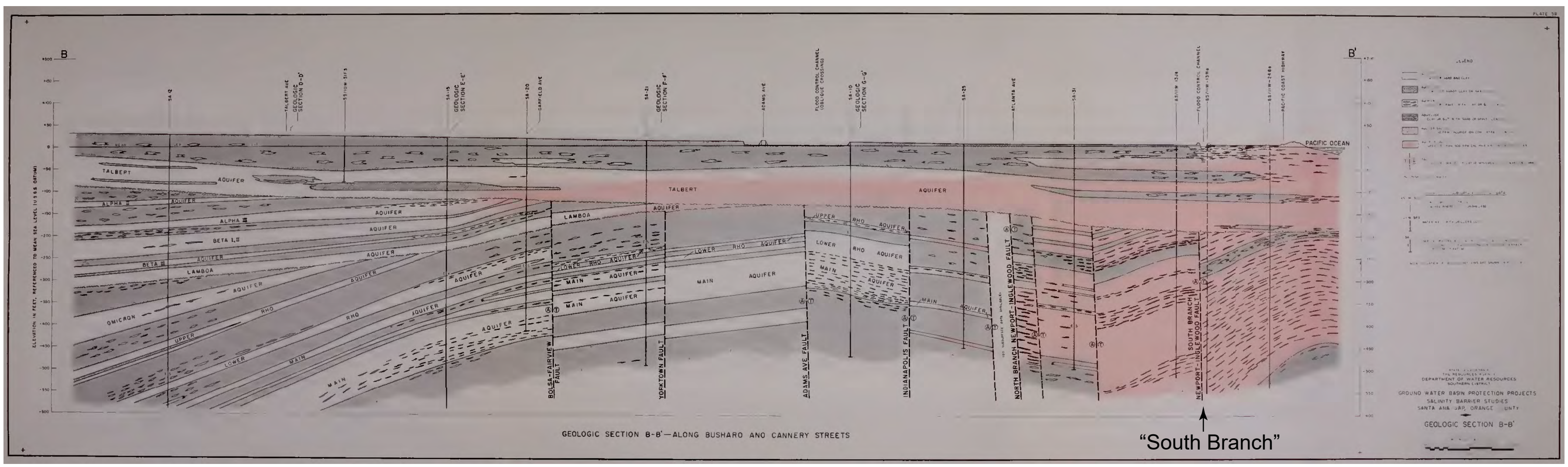
File path: I:\Projects\1966.000 OCCK Assess South Branch NIFZ\0700 GIS\7 - West Newport Cross-Section.ai.pdf; Date: 04/28/2020; User: hemphill, LCI; Rev.1



"South Branch"



DWR (1966)



"South Branch"

DWR (1966) Geologic Cross-Sections

OCCK ASSESS SOUTH BRANCH NIFZ

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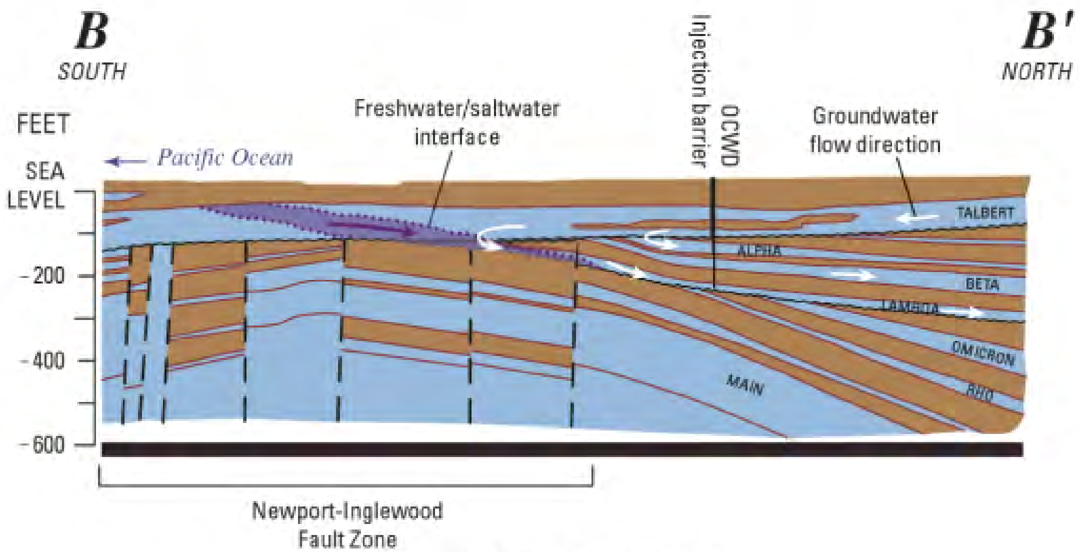
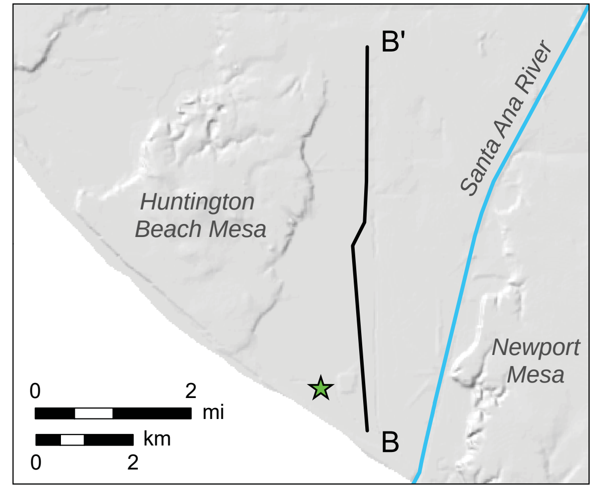
File path: I:\Projects\1966.000 OCCK Assess South Branch NIFZ\0700 GIS\8 - DWR (1966).ai.pdf Date: 4/28/2020; User: Blanton, LCI; Rev. 0



Talbert Barrier (*B-B'*)

Geologic age	Aquifer system
Holocene	Talbert
Pleistocene	"Alpha"
	"Beta"
	"Lambda"
	"Omicron"
	"Rho"
	"Main"



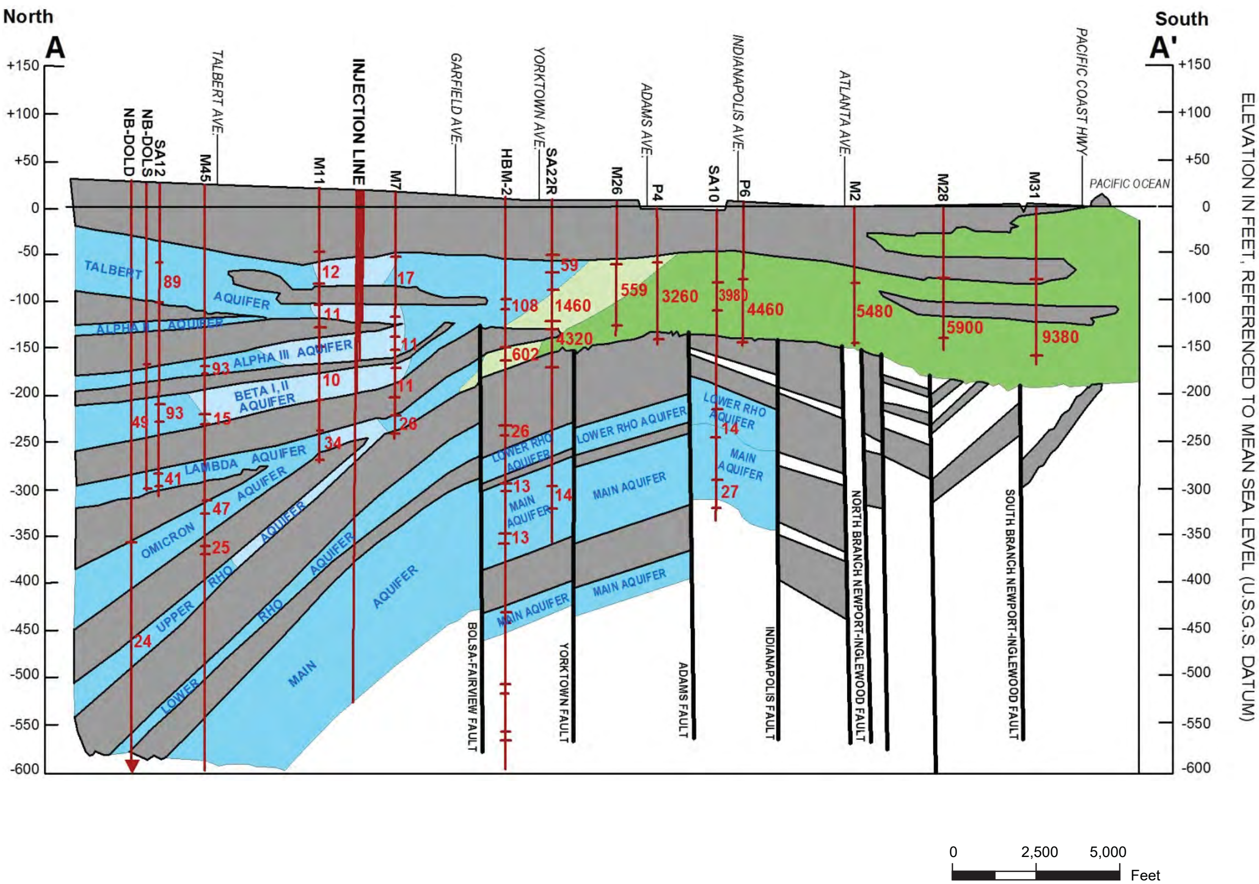
—— Edwards et al. (2009)

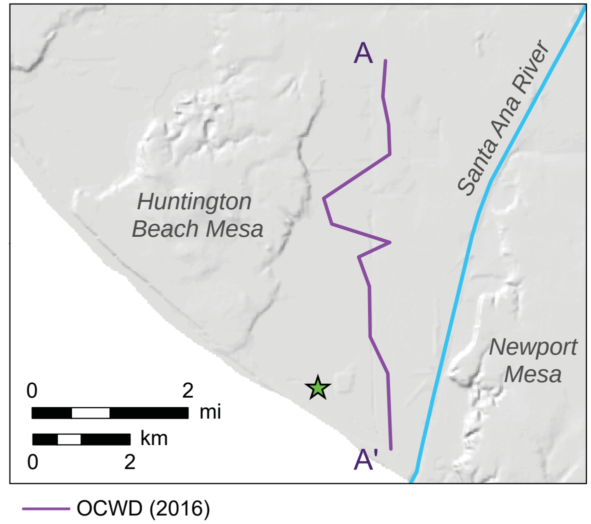
Note: Generalized north-south cross section through the Talbert Gap area. Sources: Callison (1992), Herndon (1992), and Orange County Water District (OCWD, 2004).

Edwards et al. (2009)
Generalized Cross-Section

OCCK ASSESSMENT SOUTH BRANCH NIFZ

Lettis Consultants International, Inc. | Figure 9





Note: Adapted from California Department of Water Resources Bulletin No. 147-1. “Santa Ana Gap Salinity Barrier, Orange County”, December 1966, Plate 5B.

OCWD (2016) Generalized Cross-Section

OCCK ASSESS SOUTH BRANCH NIFZ

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Quaternary fault trace (location inferred) USGS and CGS (2018)
fault trace (location inferred) Morton (2004)
Project Site

GLA 2002 borehole
GLA 2002 CPT
Ninyo & Moore 2011 borehole
Ninyo & Moore 2011 CPT
Geosyntec 2013 CPT
DOGGR oil & gas well

N E S W

0 250 500 ft
0 75 150 m

Map projection and scale:
NAD83 StatePlane Zone 5 feet, 1:4,600

base image: Google Earth 4-2-2018

Previous Subsurface Investigations

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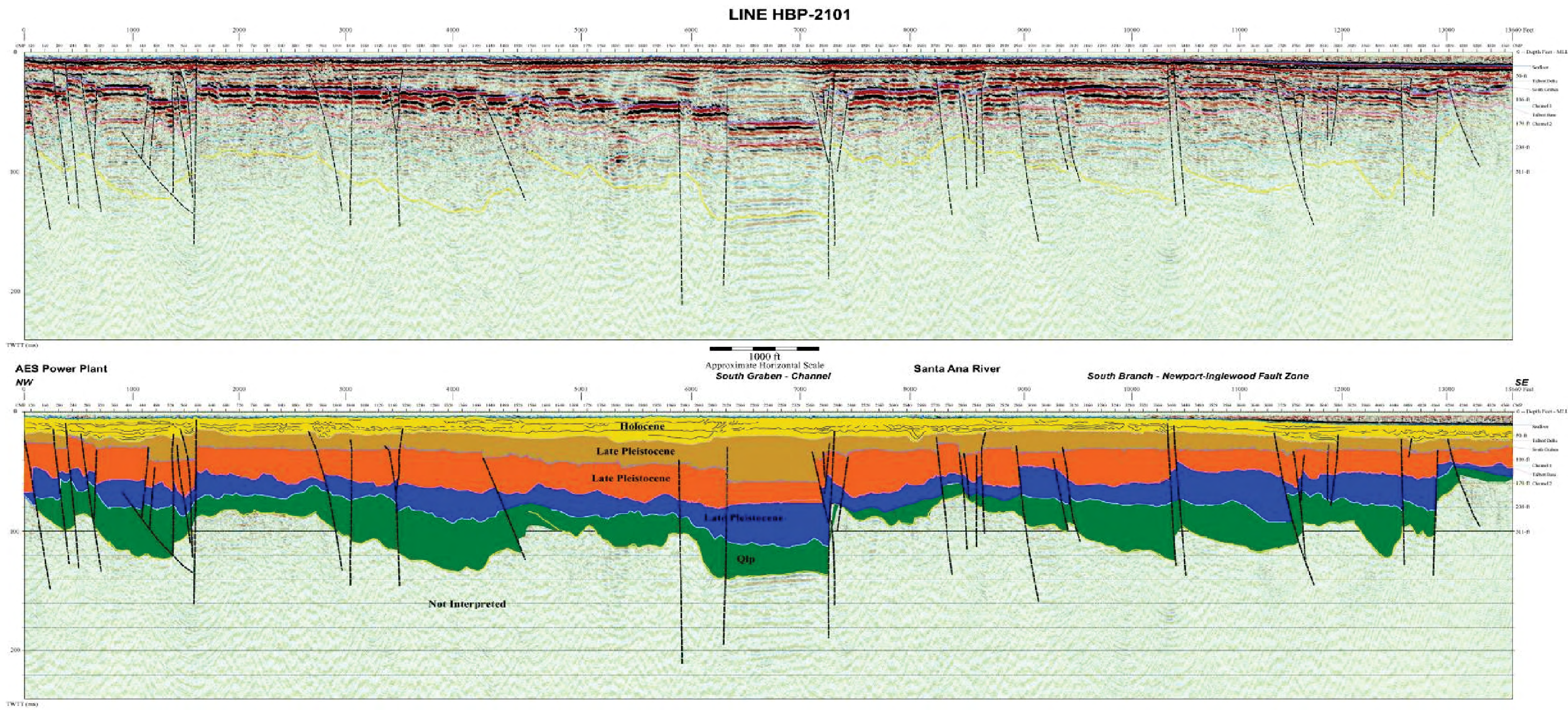
LCI Lettis Consultants International, Inc. | Figure 11

File path: I:\Projects\1966.000 OCCK Assess South Branch NIFZ\0700 GIS\9 - Previous Explorations.mxd; Date: 04/23/2020; User: hemphill, LCI; Rev.1



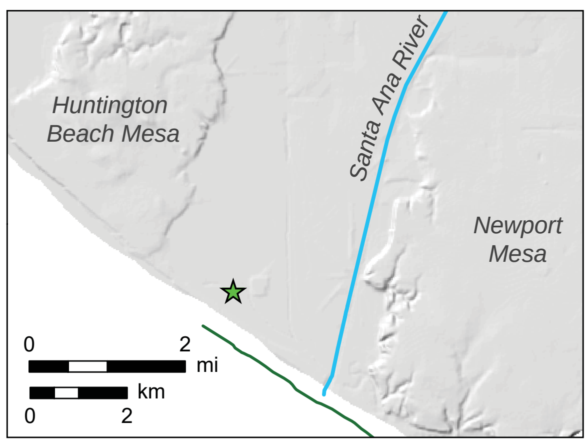
Holocene - Sand, silt, silty sand, some clay in interchannel areas, gravel in channels

Late Pleistocene - Layered sand, silt, silty sand, some clay in interchannel areas, gravel in channels (Talbert Delta)

Late Pleistocene - Talbert gravels, highly reflective seismic sequence with obscure reflectors below (South Graben)

Late Pleistocene - Layered sand, silt, silty sand, some clay in interchannel areas, gravel lag deposit at base (Channel1)

Late Pleistocene - Layered sand, silt, silty sand, some clay in interchannel areas, gravel lag deposit at base (Channel2)



EMA (2015)

Seismic Profile HBP-2101 from EMA (2015)

OCCK ASSESS SOUTH BRANCH NIFZ

Lettis Consultants International, Inc. | Figure **12**