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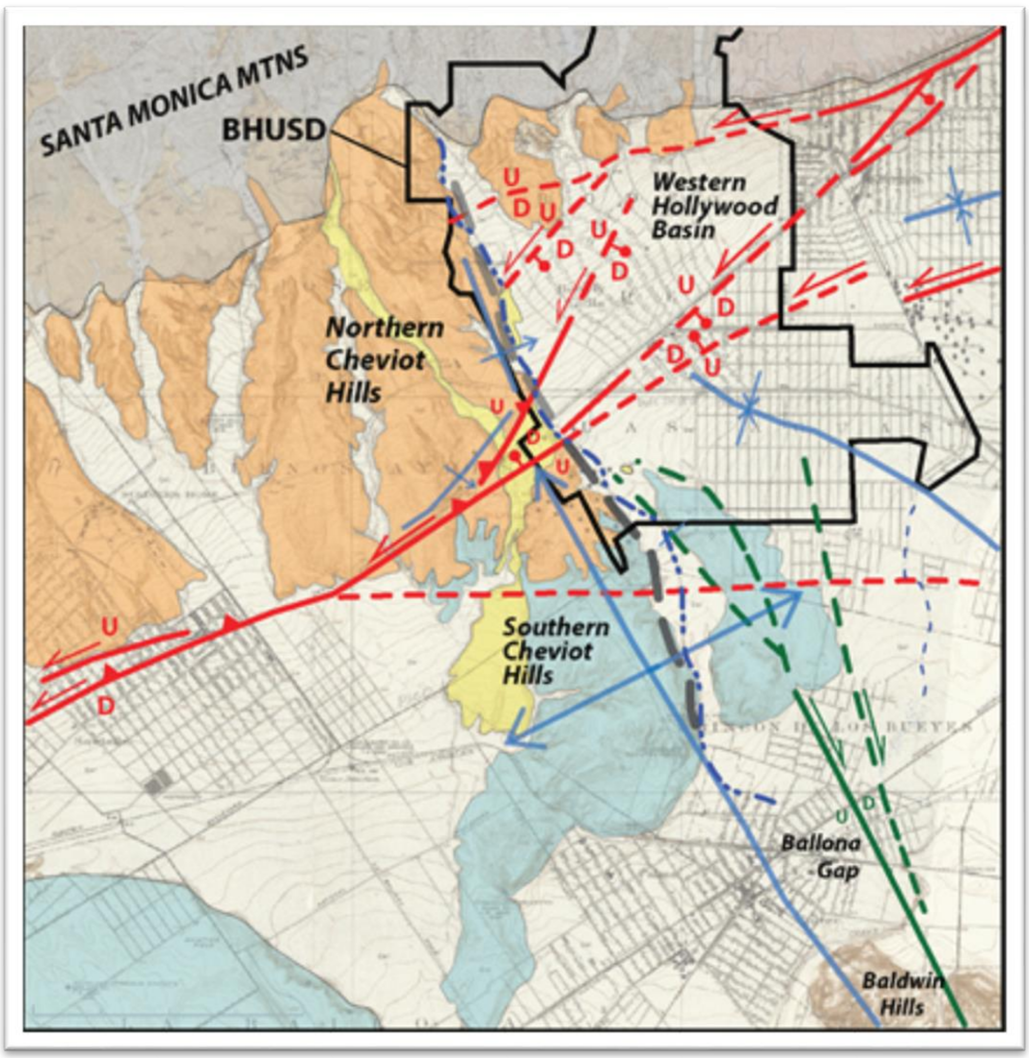
Report Number 2016-02-26

Evaluation of Regional and Local Seismic Issues Within the Beverly Hills Unified School District and their Public and Scientific Issues



Prepared For: Beverly Hills Unified School District

Report Date: March 30, 2016

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Beverly Hills Unified School District
Administrative Offices
255 South Lasky
Beverly Hills, CA 90201

Attention: Mr. Steve Kessler, Superintendent

Subject: **Evaluation of Regional and Local Seismic Issues Within the Beverly Hills Unified School District and their Public and Scientific Issues**

Mr. Kessler:

The Beverly Hills Unified School District (BHUSD) has long understood that it is in a seismically active area. BHUSD lost one of its five campuses during the Northridge earthquake. Over four years ago the Los Angeles County Metropolitan Transportation Authority (MTA) issued its Century City Fault Investigation Report (CCFIR, Parsons, 2011). That report was the first major seismic investigation in the area. The CCFIR concluded that two major active fault zones, the Santa Monica Fault Zone and the West Beverly Hills Fault Zone (which MTA concluded was an extension of the Newport-Inglewood Fault Zone), intersected with the BHUSD Beverly Hills High School and El Rodeo Elementary School campuses. Further, the CCFIR concluded that the Santa Monica- West Beverly Hills Lineament- Newport-Inglewood- Hollywood Fault Zones were all interconnected and crossing the west and northern sides of BHUSD creating a significant risk to the entire BHUSD and the City of Beverly Hills (Parsons, 2011).

A series of fault investigations, and stratigraphic-structural studies by the BHUSD and private property owners impacted by the CCFIR ensued and quickly began generating data that was inconsistent with the CCFIR findings and underlying theories (ECI 2012a, 2012b and 2015; Feffer-Geocon 2012; Geocon 2013 and 2014; LCI 2012a, 2012b, 2012c and 2015). Those inconsistencies prompted a detailed re-evaluation of the CCFIR data and analysis that reached conclusions more in line with the emerging data.

It was soon recognized that a skeptical CGS would only accept BHUSD's site fault investigation results if BHUSD could also successfully challenge the prevailing regional tectonic model. BHUSD then sponsored a series of analytical investigations to place the data being generated in context (KGS 2011, 2012, 2013 and 2014). The analytical work was conducted in parallel with the ongoing site investigations and kept expanding in the face of an ever widening gap between the results of the field investigations and the conventional wisdom as contained in the CCFIR and follow-on communication from MTA. BHUSD has now completed its field investigation at the El Rodeo Elementary School and has received final CGS clearance on all five campuses (CGS 2012, 2013 and 2016).

The results are unambiguous: no active faults have been identified on any of the five campuses, many of the faults identified by the CCFIR were not found at all, and evidence of the broad zones of active faulting predicted by the CCFIR is completely lacking.

MTA has never retracted or modified the conclusions in its CCFIR or the accompanying fault maps. To the contrary, it has continued to argue in repeated documents and technical reports that all of its conclusions remain valid (MTA-Parsons 2012a, TAP-Parsons 2013; Parsons-TAP 2013). When faced with contravening data such as BHHS trenches without any of the predicted faults, MTA shifted the positon of its faults to inaccessible areas or added new fault zones in areas outside of BHUSD control or access. Most recently, it conducted additional fault investigation work immediately adjacent to the Beverly Hills High School – and under the BHUSD Administrative Buildings. Although no formal fault investigation has been released, MTA has recently issued multiple technical reports that announce a conclusion that an active and broad strand of the Newport-Inglewood fault is present (MTA 2016). When the most recent seismic data and conclusions generated by MTA are released, they will undergo rigorous technical scrutiny, scrutiny that is likely to alter MTA's conclusions.

It appears that the impetus for this MTA work is the prevailing regional tectonic model, a model that is no longer consistent with the current emerging body of data and research.

This report contains an alternate model. It makes regional conclusions that includes the entire Beach Cities region and Santa Monica Bay. This report is based on the recent work done by BHUSD and others, and also upon an extensive review of all available research and data for the region: it is the first comprehensive review for the region to be published by anyone. The conclusions and model contained in this report have been debated and tested in the trenches by everyone working on the seismic questions at BHUSD.

Completion and release of the report was deferred to allow inclusion of the final round of work and CGS comments from the El Rodeo Elementary School investigation and from the latest MTA investigation conducted adjacent to the Beverly Hills High School. The El Rodeo Elementary School results confirmed important conclusions within the model.

The MTA investigation results released to date for the latest round of work failed to generate credible data to contradict the model and in fact corroborated several conclusions.

The support of the City of Beverly Hills should be noted. It was quickly realized that the seismic questions facing BHUSD were of even greater importance to the City of Beverly Hills as a whole, especially as the CGS began the process of updating Alquist-Priolo maps for the region including updated mapping of the Hollywood and Santa Monica faults and treatment of the West Beverly Hills Lineament. This report speaks directly to those issues and it is hoped will be a useful resource to the CGS and other agencies who must deal with a very complicated seismic area.

The entire BHUSD seismic investigation, evaluation and regulatory process has taken more than four years. The analysis behind this report began in concert with the BHUSD site work and has evolved as additional data and information became available. We thank the BHUSD for its support over the duration of this investigation and for the opportunity to be of service.

Respectfully,

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Beverly Hills Unified School District
March 30, 2016

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Acknowledgements

This report draws heavily from the work of numerous published papers that make up the body of work in this region and across southern California. Many authors generously provided additional insight and a modern context to their work, and also provided assistance with difficult to find or out of print source materials. Dr. Chris Sorlien provided an in depth review of an early version of this report, in addition to analysis and collaboration associated with offshore faulting and access to unpublished work that greatly improved this document. Dr. Mark Legg provided a critical review and analysis of seismic data in the Century City Data that greatly assisted in the understanding of local faulting. Dr. Robert Yeats provided a review and valuable critique of an early version of this report in late 2014. Eldon Gath provided a critical assessment of the model and the underlying work as it evolved, as well as a detailed review of the final report.

Most important of all were the contributions of the geologists from the many companies and agencies who generously exchanged new reports and data in the Century City-Beverly Hills – West Hollywood area as their work was completed The ability to clearly and confidently say that the Santa Monica Boulevard Fault, Fault Zone A and the West Beverly Hills Lineament faults either don't exist or are inactive was critical to this report and cannot be overstated.

The authors also wish to acknowledge the unique role taken by the Beverly Hills Unified School District who from the very beginning of this process insisted that transparency and the dissemination of knowledge and public education were as important as the investigations themselves. The preparation and distribution of this report is a direct result of those values. The direction given was to ensure that this report provide long term benefit to the surrounding communities.

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1.0 EXECUTIVE SUMMARY

The Beverly Hills Unified School District (BHUSD) is located within the Transverse Ranges Southern Boundary Fault System (TRSBFS), an active tectonic environment exhibiting numerous fault zones located both locally and regionally that could produce major earthquakes causing strong ground motions. An active fault zone with an approximate east-west trend and a strong left-lateral component of slip is presumed to occur along the entire length of the TRSBFS. However, it is also well known that the southern California region south of the San Andreas Fault, accommodates significant compressional strain via detachment faults, thrust ramp faults, and reverse faults, some of which are blind. This report begins by placing many regional fault structures into their temporal and spatial context, explaining when and how they were abandoned by subsequent geologic events, and concluding by identifying those faults (new and reactivated) that pose the most current seismic hazard to the BHUSD regionally.

Many Miocene-age (20-12 million years ago) normal extensional faults were reactivated as oblique left-lateral reverse faults during the early Pliocene (~5 million years ago). These fault zones include the Santa Monica Fault North and South, western San Vicente Fault, Rancho Fault, Las Cienegas, and the Hollywood Fault. It was during this time that appropriate structures were created to form the local oil fields. The late Miocene to early Pliocene tectonic transition along the TRSBFS is well documented in the literature, however, the tectonic transition occurring approximately 1 million years ago, has not been fully recognized or described until now.

Although many of the east-west trending fault systems along the TRSBFS accommodated oblique reverse left-lateral tectonic strain from the early Pliocene (4-5 million years ago) to early Pleistocene (~2 million years ago), this dramatically changed approximately 1 million years ago when these fault zones transitioned into a nearly pure left-lateral strike-slip system. Compressional deformation continued to occur but migrated north and south of the TRSBL as suggested by changes in tectonic strain rates in these regions during the early Pleistocene.

In the BHUSD region, the Quaternary kinematic evolution along the TRSBFS involved new fault zones being created and abandoned on the scale of hundreds of thousands of years. For example, the northward migration and retraction of the Newport-Inglewood Fault Zone during the Pleistocene at latitudes of the central and southern Cheviot Hills. Many ~east-west trending fault systems along the TRSBFS accommodated oblique reverse left-lateral tectonic strain from the early Pliocene to early Pleistocene. This dramatically changed approximately 1 million years ago when these fault zones transitioned into a nearly pure left-lateral strike-slip system (Figures ES1 and ES-2). Compressional deformation migrated north and south of the TRSBFS.

The Potrero Canyon-Santa Monica Boulevard Fault Zone System was created approximately 1 million years ago as surface rupturing faults stemming upwards from the underlying blind Santa Monica Fault Zone to accommodate dominantly left-lateral strike-slip displacement. Hence, the upper most strands of the blind oblique reverse left-lateral Santa Monica Fault Zone System became inactive at this time and the Potrero Canyon-Santa Monica Boulevard Faults developed in the hanging wall of the Santa Monica Fault Zone. Recent fault investigation in the central Cheviot Hills have determined that the left-lateral strike-slip Santa Monica Boulevard Fault became inactive approximately 200 thousand years ago. These findings led to two obvious conclusions: (1) compressional deformation occurring along this segment was required on other structures outside of the TRSBFS since the early Pleistocene (~1 Ma to present); and (2) active left-lateral fault displacement is required along the TRSBFS somewhere along the longitude of the Santa Monica Boulevard Fault Zone since it became inactive.

The primary tectonic kinematic findings of this report include:

- A kinematic change occurred approximately 1 million years ago (~1 Ma) along the TRSBFS involving previously oblique blind reverse left-lateral fault zones transitioning to dominantly surface rupturing left-lateral strike-slip faults in the BHUSD region.

- That change, occurring 1 million years ago along the TRSBFS, led to the creation of the Potrero Canyon, Santa Monica Boulevard, and cross faults in the western Hollywood Basin to accommodate dominantly left-lateral motion. The near surface strand of the North Salt Lake Fault is proposed to have developed on the hanging wall of the deeper and older normal fault to accommodate dominantly left-lateral motion as well during the early Pleistocene. The Hollywood Fault transitioned from an oblique reverse left-lateral fault zone to accommodate dominantly left-lateral motion utilizing for the most part the same fault strands within its system (Figure ES1).

- The dominantly left-lateral strike-slip Santa Monica Boulevard Fault and western Hollywood Basin cross faults became inactive approximately 200 thousand years ago. Hence, these fault zones were active approximately 1 to 0.2 million years ago.

- The Potrero Canyon Fault East was created within the past several hundred thousand years to accommodate dominantly left-lateral strike-slip motion no longer occurring on the Santa Monica Boulevard Fault and western Hollywood Basin cross faults (Figure ES2). Some left-lateral motion may also be occurring on the blind western San Vicente and Rancho Faults.

- The northwest trending right-lateral strike-slip Newport-Inglewood Fault Zone migrated northward to latitudes of the Santa Monica Boulevard Fault Zone several hundred thousand years ago, but has subsequently "retracted" due to the development of the Potrero Canyon Fault East that essentially cut-off the northern most strands at the central southern Cheviot Hills. The southern Cheviot Hills began to be uplifted once the Newport-Inglewood Fault migrated northward along the eastern side of the hills.

- Compressional deformation (strain) that ceased approximately 1 Ma along the TRSBFS (Santa Monica Fault Zone) led to the development of new blind thrust faults (thrust ramps) west of the Newport-Inglewood Fault Zone. These include the Culver City Fault (thrust ramp) in the Beach Cities Region, and the Dume Fault East in Santa Monica Bay. Compressional deformation east of the Newport-Inglewood Fault Zone was accommodated on previously documented blind compressional faults in the northern Los Angeles Basin.

- The Santa Monica Fault North, Santa Monica Fault South, and eastern San Vicente Fault should be considered inactive, and are recommended to be removed from future seismic hazard analysis and fault data bases.

- The western Hollywood Fault Zone is designated as Regulatory Potentially Active herein, but evidence is provided suggesting that this portion of the Hollywood Fault Zone may be inactive.

- Proposed Cross Fault No.1 in the western Hollywood Basin has been determined to be Regulatory Inactive by fault investigations in Century City.

- Both the blind Rancho Fault in the southwestern Cheviot Hills, and western San Vicente Fault in the southern BHUSD may be active, possibly accommodating a component of left-lateral slip in addition to reverse thrust motion (oblique).

- The San Vicente, Rancho, and North Salt Lake Fault Zones should be considered for future studies to ascertain their actual hazard.

Figure ES1 (same as Figure 42): Region view of active faulting in the northern Los Angeles Basin, Beach Cities Region and along the TRSBLL during the past several hundred thousand years. Active faults shown in the region of the BHUSD include those for the past 200 kya (Figure 43), and elsewhere fault activity since the mid-Pleistocene to the present time. The newly developed Dume Fault East thrust ramp developed as a new fault sometime soon before approximately 1 Ma.

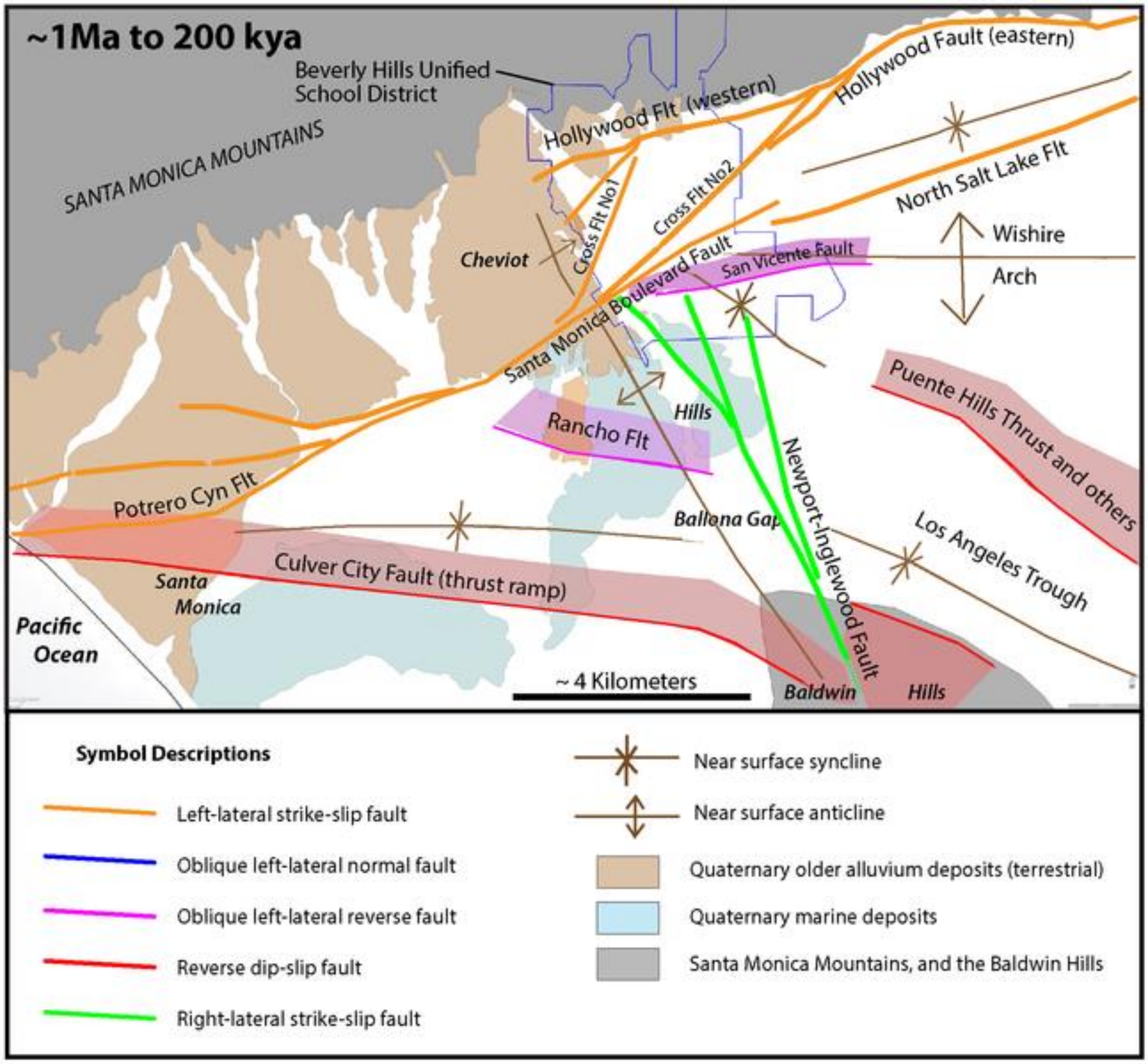
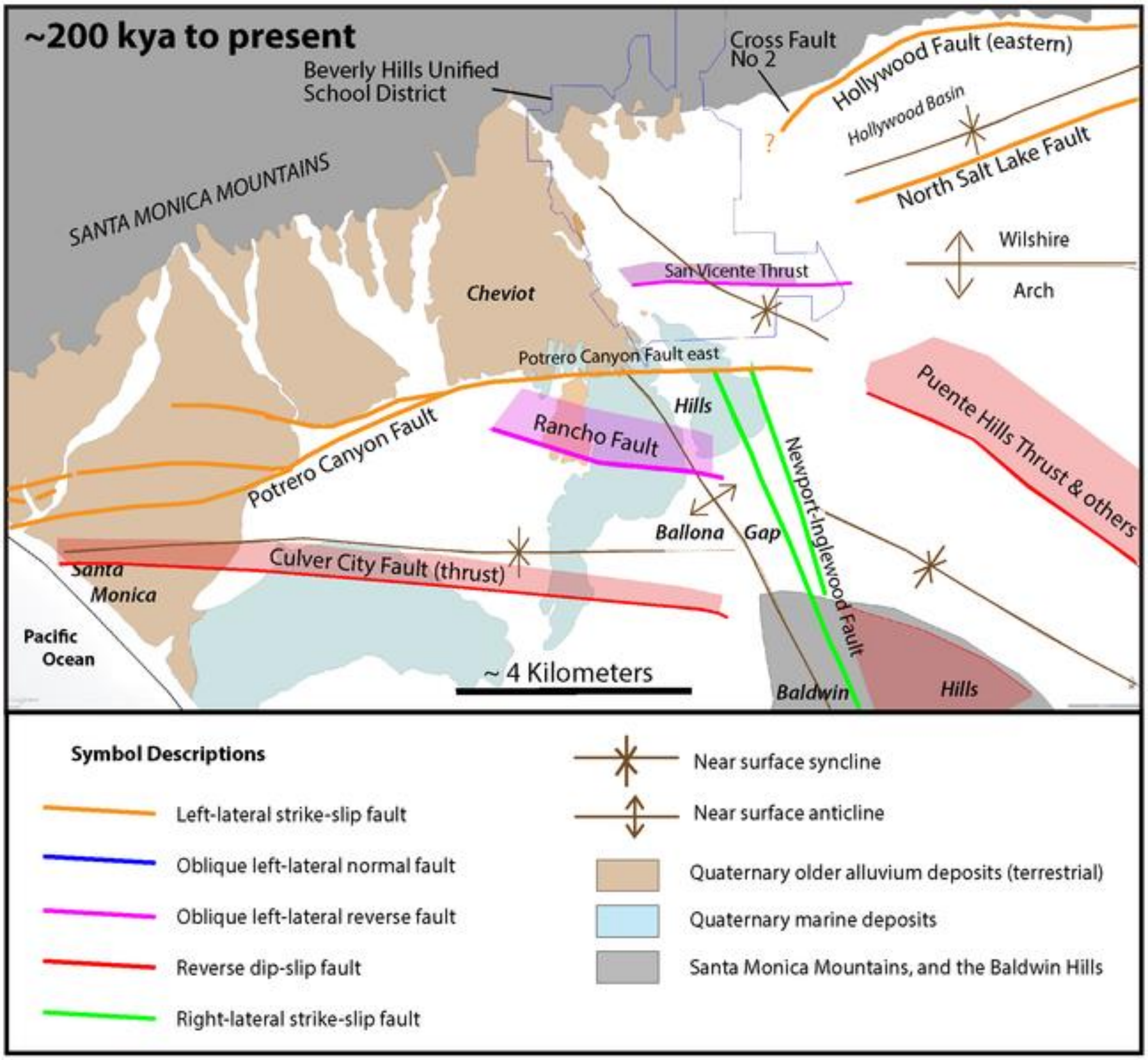


Figure ES2 (same as Figure 44): Active faults and their dominant style of displacement from approximately 200 kya to the present time. The dominantly left-lateral strike-slip Santa Monica Boulevard Fault, the western Hollywood Fault, and Cross Fault No.1 have all become inactive. The Potrero Canyon Fault remains active, but lengthens towards the east by the development of the Potrero Canyon Fault east. The northeast portion of Cross Fault No.2 and the newly developed Potrero Canyon Fault east accommodate left-lateral displacement from the now inactive Santa Monica Boulevard Fault along this section of the TRSBLL. The portion of the Newport-Inglewood Fault north of the Potrero Canyon East fault remains inactive. Minor left-lateral slip may also be accommodated on the Rancho and San Vicente Fault Zones.



The report also includes updated regional fault maps. These maps were produced because a comprehensive regional fault map utilizing current data is not readily accessible to the public and because many current fault hazard maps show faults that are considered inactive or exclude blind fault that are geologically active and which present a seismic risk to BHUSD region. Fault data is shown in a manner to assist in the evaluation of where faults occur in the region, whether they reach the surface or are blind, and how the faults project at depth (angle of dip).

For the most part, surface rupturing fault zones are designated with activity level terms generally consistent with the State of California Alquist-Priolo Act of 1972 and revised guidelines (SP-42). These include “Regulatory Active”, “Regulatory Potentially Active” and “Regulatory Inactive”. However, the AP-Act does not include blind faults, most of which are reverse detachment and thrust ramp fault zones. A set of criteria is provided in this report to designate blind faults as either “Geologically Active” or “Geologically Inactive”.

In summary, it is hoped that this report will serve as the basis for an understanding of local and regional fault systems in the BHUSD area and provide a platform for future studies and regulatory decision-making. The approach taken herein was to reference and organize data from reports and their conclusions and to assimilate these data in a comprehensive way where new insights regarding fault hazards may or may not occur. The report attempts to raise questions, identify areas for focused future studies, identify some potentially new seismic sources, and to suggest the removal of others. In particular, the Cross Fault No.2 strand of the western Hollywood Fault Zone may extend into the eastern BHUSD and additional investigation is required to confirm that the western Hollywood Fault Zone is inactive as proposed in this report.

This report also provides a resource for developing seismic hazard parameters for evaluating potential ground shaking from the numerous faults in the area of the BHUSD, and regionally. While the risk from surface fault rupture to BHUSD schools has been determined to be very low, there remains significant risk from amplified ground shaking from large regional earthquakes due to the deep alluvial basins upon which several of the schools were built.

2.0 PURPOSE, MOTIVATION, AND APPROACH FOR THIS STUDY

2.1 Purpose of study

The purpose of this study is to evaluate the seismic risk facing the BHUSD and City of Beverly Hills (CBH) and immediate area. BHUSD (whose boundaries match the City of Beverly Hills) straddles the Cheviot Hills to the west, and the northern Los Angeles basin to the east. It lies within the Transverse Ranges Southern Boundary Fault System (TRSB). It has long been recognized as a seismically active region but the precise nature and magnitude of the seismic risk remains poorly appreciated or understood. Complacency set in despite the loss of one of the BHUSD campuses during the Northridge earthquake. The main purpose of this study was to educate the BHUSD about the geologic component to their risk. Because BHUSD is an educational institution, a secondary purpose was to share the valuable information being gathered with the community at large.

2.2 Motivation for current study

BHUSD was shocked by the release in 2011 of the Los Angeles County Metropolitan Transportation Authority (MTA) Century City Area Fault Investigation report (CCFIR), a seismic investigation provided to MTA and conducted by Parsons (2011) that encompassed the Cheviot Hills and the west side of Beverly Hills, including two BHUSD campuses. The MTA fault map and accompanying analysis placed an active West Beverly Hills Lineament Fault zone and active Santa Monica Fault zone directly through two campuses. That report, plus other published papers, indicated several other potentially active faults in the area and effectively placed BHUSD in a seismic bull's eye.

BHUSD has five campuses with over 10,000 occupants per day. The safety of students, staff and visitors is paramount. The multiple questions raised by the MTA CCFIR and the Northridge experience (for example: why was only one school damaged and why this particular school?) prompted BHUSD to conduct a closer examination of local faulting and tectonics, essentially for the first time by BHUSD or anyone else in this geographic area. The questions are urgent for BHUSD because of student safety today and to design and build new schools with full knowledge of the potential seismic hazards impacting the school district. It matters now because fully understanding potential seismic hazards is important for development all across the City of Beverly Hills – home to the students and families of BHUSD and the tax base that supports the school district.

The MTA CCFIR (Parsons, 2011) led to numerous site-specific geologic investigations in the Century City area including fault investigations at the El Rodeo elementary school and the Beverly Hills high school (Borchardt, 2012a, Borchardt 2012b, Legg, 2012a, Legg 2012b, LCI, 2012a, LCI 2012b, LCI 2012c, LCI, 2015 and LCI, 2016) and at private properties (Feffer Geocon, 2012, Geocon, 2013, and Geocon, 2014). Those fault investigations cleared the sites of any active faults, and in many areas failed to find faults at all – findings in conflict with the CCFIR and common understanding of the region. This prompted additional investigation and analysis that embraced the greater Cheviot Hills area (ECI, 2012a, 2012b and 2015;, KGS, 2011, 2012, 2013 and 2014) and the conflicts between reports by different parties (Gath et al, 2013, Gath and Buresh, 2014, LCI et al 2012). An additional reason for evaluating the local and regional potential seismic sources (active and potentially active faults) now is the California Geological Survey's (CGS) imminent preparation of new Fault Hazard Zone Maps associated with the Alquist-Priolo Earthquake Fault Zoning Act of 1972 intended to assist in mitigating fault surface rupture for the Santa Monica and Hollywood Fault Zones. These maps will have a direct consequence on BHUSD and the surrounding community, and it is hoped that the contents of this report will assist the CGS in the preparation of these maps.

2.3 Study process initial steps

The two primary hazards associated with major earthquakes are fault surface rupture and ground shaking. Evaluating potential fault surface hazards involves knowing the location of active faults that could deform, or rupture, the surface of the earth. Per the Alquist-Priolo Act's definitions, an "active fault" is one which has ruptured the earth's surface at least once in about the last 11,000 years, now being defined as 11,700 years by CGS. A "potentially active fault" is commonly referred to as an identified fault that exhibits evidence of rupturing during the Quaternary, which is defined by Bryant and Hart (2007) as the past 1.6 million years. The Alquist-Priolo Act prohibits the construction of human habitation structures across the trace of an active fault. School buildings are prohibited within 50 feet of an active fault.

Evaluating potential ground shaking hazards involves understanding the location of seismically active faults regionally, the size of the earthquake that they may produce, and local geologic site conditions. The BHUSD investigative process was incremental. It was quickly realized that prior to the CCFIR, there was very little investigative work within the BHUSD that was useful to a seismic hazard assessment. Although many well-known faults were shown to be present or potentially present within BHUSD, the vast majority of investigation work on those faults was conducted outside of BHUSD facilities, indeed even outside of Beverly Hills proper.

BHUSD has now completed detailed site seismic investigations on five campuses. Private parties completed parallel site fault investigations in Beverly Hills, Century City and West Hollywood. As the various site investigations proceeded, their results were increasingly inconsistent with the CCFIR and other published fault maps and prevailing theories. Many of the findings in the CCFIR were directly refuted by these subsequent studies. To date, none of the recent studies has identified a single active fault in the area and in many cases no faults at all inside the CCFIR mapped fault zones.

This raised concern with the accuracy of the prevailing knowledge base and the most commonly accepted geologic models for the area. Initial literature research surprisingly revealed that very little is actually known about the location and activity of faults within or near to the BHUSD. This in turn led to the understanding that the published locations and activity levels of many faults in the BHUSD area were poorly understood, or simply assumed to be present with little or no direct evidence in the immediate area. Some assumed faults (e.g. faults that were never positively identified but instead interpreted solely from subsurface data), were called active although the available evidence supported at most a potentially active designation (meaning that there is no evidence for their being active but no evidence to show they are not either). Some faults have been mapped and called active without any supportive evidence that they even occur. And for some other faults, the mapped, or interpreted, location of the fault has changed over time without any new evidence to suggest either fault location is correct.

An in-depth search was conducted for pertinent publications that provided data assisting in understanding the age, location and style of Quaternary tectonic deformation in the BHUSD region. The search included data and analysis from a wide range of sources that partially include: land subsidence surveys, groundwater aquifers and barriers, oil field well log data, paleoseismic studies, earthquake hypocenters, upper crustal balanced cross sections, GPS plate motion vectors, structure contour maps, geomorphology, and stratigraphy.

The next step was to assimilate all this available information from published materials with the information gleaned from the most recent geologic investigations and reports, including the CCFIR, and to make the best determination possible on the most important seismic questions facing BHUSD.

2.4 Issues regarding interpretation, communication, and dogma of existing published findings

The assimilation and analysis process revealed numerous issues within the body of published research. There are numerous competing theories regarding local fault locations and activity, large variations and inconsistencies on the interpretation of data, and strongly held geologic paradigms regarding the activity and location of numerous fault zones. In addition, it was observed that no comprehensive study had been conducted to tie together findings from the many reports that include data across numerous disciplines and that extend back for many decades. Some of the major issues observed in the body of published materials include:

- Numerous relatively older geologic studies utilizing a wide spectrum of geologic data have not been fully utilized in the evaluation of potential seismic hazards during recent times. In many instances it appears that a model-driven paradigm influences the interpretation of scientific data, which has narrowed the spectrum of report findings. In some instances, older seismic models have been abandoned without sufficient justification.
- Fault investigation studies within the State of California designated Fault Surface Rupture Hazard zones (Alquist-Priolo Zones) have only recently begun to be utilized in the evaluation of potential seismic hazard on some faults. The body of direct investigation reports is very limited.
- There is confusion and inconsistency regarding the use of the term "active" fault: the State of California Geological Survey now defines an active fault as a fault demonstrating surface rupture during the past 11,000 years (a definition derived from the State Alquist-Priolo Act of 1972), and the scientific community often considers a fault "active" if it demonstrates evidence of late Quaternary deformation. Hence, there are variations in how the term "active" is utilized, and particularly for surface rupturing fault zones verses blind fault zones most of which are thrust (reverse) faults.
- There is inconsistency regarding how "fault investigations" have been conducted (standard of practice) and whether or not they were in a manner sufficient to fully support their findings regarding the determination of fault activity (active, potentially active, or inactive). For example, in some instances, fault zones were determined to be active without the positive identification of a fault, and with no numerical ages for offset and/or non-offset soils.
- There is a paucity of studies attempting to better understand the age and style of on-shore faulting utilizing the relatively extensive subsurface studies conducted offshore in the Pacific Ocean west of Santa Monica. Within the scientific community, various groups of scientists tend to study offshore "marine" Quaternary tectonics, and other groups primarily focus on the onshore "terrestrial" Quaternary tectonics. Very few studies have attempted to convolve this huge body of work. The type of data utilized for these studies also varies. Offshore studies commonly utilize relatively deep seismic line refraction and reflection transect data extending to depths of 2 to 4 kilometers; however, very little of these types of data exist for onshore studies. In contrast, onshore studies have been dominated by evaluation of oil well data that commonly extend to depths of 2 to 3 kilometers with a paucity of seismic line transect data.

A partitioning of scientific research groups evaluating onshore Quaternary tectonics also exists. Some researchers primarily evaluate blind faults that extend to depths up to 13 km, most of which are reverse (thrust), and other research groups primarily evaluate near surface rupturing faults. Few studies were identified during preparation of this report that attempt to convolve all these data into a single kinematic model.

- To date, there is no comprehensive study that has attempted to evaluate all existing data from both recent to relatively older publications and reports, including the full range of available data from groundwater reports, structure contour maps, oil field structure maps, seismicity, to scientific and geotechnical reports. One exception to this was the work conducted by Wright (1991) that resulted in a seminal study to understand regional tectonics in terms of fault activity history in the Los Angeles Basin region. However, no comprehensive fault map was identified for the region that identifies both near surface rupturing faults and blind thrust/reverse faults and décollement (detachment) faults at depth.
- Insufficient studies have been conducted evaluating the "historical" tectonic stress rates in the region between the San Fernando Valley and the northwestern Los Angeles Basin across the Santa Ana Mountains. These data, if they existed would assist in understanding whether or not the known active faults are capable of "absorbing" all of the regional stress; or if not, leading to the possibility that some unknown faults exist.
- Relatively few reports discuss the inherent difficulties in evaluating fault activity and potential seismic risk due to the relatively low magnitude tectonic stress rates in the region. The region's faults have relatively long recurrence intervals between major earthquakes. For example, the last major earthquakes to occur on the Santa Monica fault (~3-4 kya) and Hollywood Fault zones (~ 9 to 8 kya) are both poorly constrained, could be thousands of years off, and could have 10,000+ years between events.
- Insufficient studies have been conducted in the region between eastern Santa Monica Bay and the Newport-Inglewood Fault to evaluate potential blind faults in terms of location and activity. Blind faults have been identified in this region but are generally described as inactive because they appear to not disrupt sediments of middle to later Quaternary age. There is insufficient data to support this conclusion creating the potential for additional as yet unidentified blind faults in the area.
- Regarding blind thrust/reverse fault zones, there is inconsistency between published findings and published seismic hazard maps issued by both the scientific and regulatory communities. Some of these faults are shown on seismic risk-hazard maps suggesting they are active, when conclusions within the literature indicate that they are most likely inactive.

- The Santa Monica and Hollywood Fault Zones are generally described as left-lateral reverse (oblique); there is considerable data to suggest that these fault zones are dominantly left-lateral. Numerous scientific publications provide findings that these fault zones have recently exhibited dominantly left-lateral displacement; however, in many instances they continue to be described as oblique. This has led to confusion regarding evaluating seismic hazards in the region.
- Few studies have attempted to answer the question that if the Santa Monica Fault (Potrero Canyon and Santa Monica Boulevard Faults in this study) is dominantly left-lateral, then what structure is "absorbing" the presumed compressional tectonic stress in the area? This is particularly the case west of the Newport-Inglewood Fault and south of the Santa Monica Mountains.
- Some fault zones that were consistently shown on older geologic maps apparently "fell out of favor" and without justification were no longer identified in more recent studies. New tectonic models were proposed, became "universally" accepted by most researchers, and inconsistent modeling and mapping was often dropped without adequate scrutiny or justification.
- Few studies to date have attempted to compile regional data showing where fault surface rupture may occur in the area leading to both surface rupture and ground shaking hazard, and where potentially active blind faults may exist that result in dominantly a ground shaking hazard. CGS Alquist-Priolo fault maps only show active faults, defined as those that have presented surface rupture. In the immediate area of this study, there has been considerable recent attention regarding the CGS preparing Alquist-Priolo fault surface rupture study zone maps for the Hollywood and Santa Monica Fault Zones, which by excluding potentially active blind faults creates the perception that these are the two primary hazardous fault zones in the area.
- There is great reliance on maps by regulators and others dealing with the practical aspects of fault hazards. However, there is considerable confusion and inconsistency inherent in the process of converting 3-dimensional fault structures to 2-dimensional maps. A fault drawn as a simple line on a map, will typically exhibit numerous fault strands across a zone that can be tens of meters wide. A major fault zone like the Newport-Inglewood Fault often consists of multiple major fault splays, and upon closer inspection, each of these splays often exhibits multiple faults. For deeper faults (blind), does a line on a map represent the extension and projection of a fault plane to the surface, or the vertical location of a fault "tip" at depth? Using a single line to represent a low angle fault can be very misleading as it actually traverses a large swath of land below the surface. This report has used a model of mapping low angle faults that indicates their varying location by depth (i.e. Plate 1 and Plate 2). Another issue is ascribing too much precision to mapped fault lines. For example, was a

mapped fault line created from a string of hard data points, or from a single data point extended in a generally less precise fashion?

This report has attempted to resolve these issues to the greatest extent possible, or noted remaining questions.

2.5 Study Process – Assimilation and Iterative Analysis

Research for this study was an iterative process. BHUSD initially directed and requested a comprehensive review and analysis of the entire body of work related to this area. The initial direction was to approach all the reviewed data without bias toward pre-existing models by obtaining and reviewing the extensive literature utilizing a wide range of data sources that extend back to the early 1900's. The directive was to not dismiss what might be considered "older" data, but utilize it at face value and make an independent determination as to its current validity. In addition, this study utilized reports that evaluated both surficial sediments (i.e. typical fault investigations extending to depths <5 to 30 meters) and deep structures (i.e. oil well, seismic lines, balanced cross sections, and seismicity; all greater than > 1 km deep), many of which have not been utilized in the more recent fault hazard studies. These data include:

- Fault investigation reports to satisfy the State of California AP Act of 1972
- Published geologic maps (CGS, USGS, etc.)
- Continuous core borings
- Geotechnical borings
- Cone penetrometer (CPT) transects
- Groundwater borings
- Geomorphic and stratigraphic reports, some conducted by the author for the BHUSD
- Per-reviewed fault evaluation publications
- CGS Open File Reports (Fault Evaluation Reports) prepared to satisfy the State of California AP Act of 1972
- Soil stratigraphic reports (i.e. soil pedon ages)
- Reports providing isochore maps of fresh water aquifers, groundwater maps elevations, and barriers
- Reports utilizing survey data to evaluate subsidence over many years

- Seismic focal mechanisms and earthquake locations
- Topographic maps constructed prior to major urbanization in the northern Los Angeles Basin exhibiting 5-foot contours
- Geophysical seismic profile lines
- Local and regional stratigraphic reports
- Geomorphic evaluation reports
- INSAR data
- LiDAR data
- Red-flagged building data from the 1994 Northridge earthquake
- Reports that evaluate isostatic subsidence on an upper crustal scale

The Reference list (Appendix B) of this report lists the most significant sources that were part of the review process. To the authors' knowledge, this is the first comprehensive listing of all such reports for the region.

The initial data review identified areas in which different reports essentially used the same data, but arrived at different interpretations. These include not only fault investigation reports (near surface), but also studies evaluating relatively deep structures. The review process noted that original data often remain valid and useful even where the interpretations or conclusions based on that data were judged to be in error or flawed, or focused on an unrelated topic (e.g. water resource measurement, oil field production).

Initial analysis focused on the Santa Monica Boulevard Fault (i.e. commonly referred to as the Santa Monica Fault) in the Century City area because it was commonly perceived to pose the greatest seismic threat in the BHUSD. This analysis led to the conclusion that the Santa Monica Boulevard Fault is inactive. At the same time, new field investigations concluded that the West Beverly Hills Lineament was also not an active fault zone. The conclusions regarding the Santa Monica Boulevard Fault and the West Beverly Hills Lineament were at odds with the prevailing wisdom regarding area tectonics. This led to the production of a regional fault activity map for the northwestern Los Angeles Basin area that shows potential "surface rupturing" faults, blind thrust ramps, and décollement (detachment) faults. This map was produced via collaboration with Dr. Chris Sorlien. A kinematic structural model was then built for the region of the BHUSD to place these faults into context, and to help in the evaluation of potential seismic hazards and insights regarding hazards to the BHUSD, and thoughts for future investigations to confirm, refute, and/or quantify these potential hazards.

The overall goal and direction throughout these iterations remained to deliver a comprehensive assessment of potential seismic risk facing the BHUSD based on the totality of information available.

2.6 An active fault - Varying uses of the term

There are variations within the scientific literature, seismic hazard maps, and regulatory agencies regarding what is an "active" fault. For the State of California's Alquist-Priolo Act, the definition of an "active" fault defined by Bryant and Hart (2007) is one which has "had surface displacement within the Holocene time (about the last 11,000 years)". This definition of Holocene has recently been increased and more rigidly defined to 11,700 years by the CGS. In a strict sense, the State's definition only applies to faults that rupture to the surface and does not include blind thrust-reverse faults. In many scientific publications evaluating regional blind thrust faults both offshore and onshore, the authors often describe a fault zone as "active" if it appears to deform middle to late Quaternary sediments. For these types of studies, there is no accepted or adopted definition of an "active" fault from which they adhere and it is difficult to evaluate their activity because latest Quaternary and Holocene sediments are only deformed and not displaced by a discrete shear across a fault.

From a scientific point of view, an active fault could be considered one that is actively acquiring tectonic stress that will eventually rupture (strain). However, some faults have remarkably slow slip rates in regions of slow stress rates, which lead to recurrence intervals of many thousands of years. In terms of evaluating seismic hazard risk, not all active faults are the same. It is clear that some known active faults have an order of magnitude increased probability of rupturing during the next 100 years (i.e. San Andreas fault), whereas others during the next thousand years (i.e. Puente Hills Thrust - Blind). The reader is referred to Appendix C for a further discussion regarding fault activity designation terms.

2.6 Geologic time designations utilized in this report

The age of most geologic events discussed in this report occurred during the Neogene and Quaternary Periods. The Neogene Period is subdivided into the Pliocene and Miocene Epochs and the Quaternary Period is subdivided into the Holocene and Pleistocene Epochs. With the exception of the Holocene, the Pleistocene, Pliocene and Miocene Epochs are also subdivided to early, middle and late stages. The time intervals include:

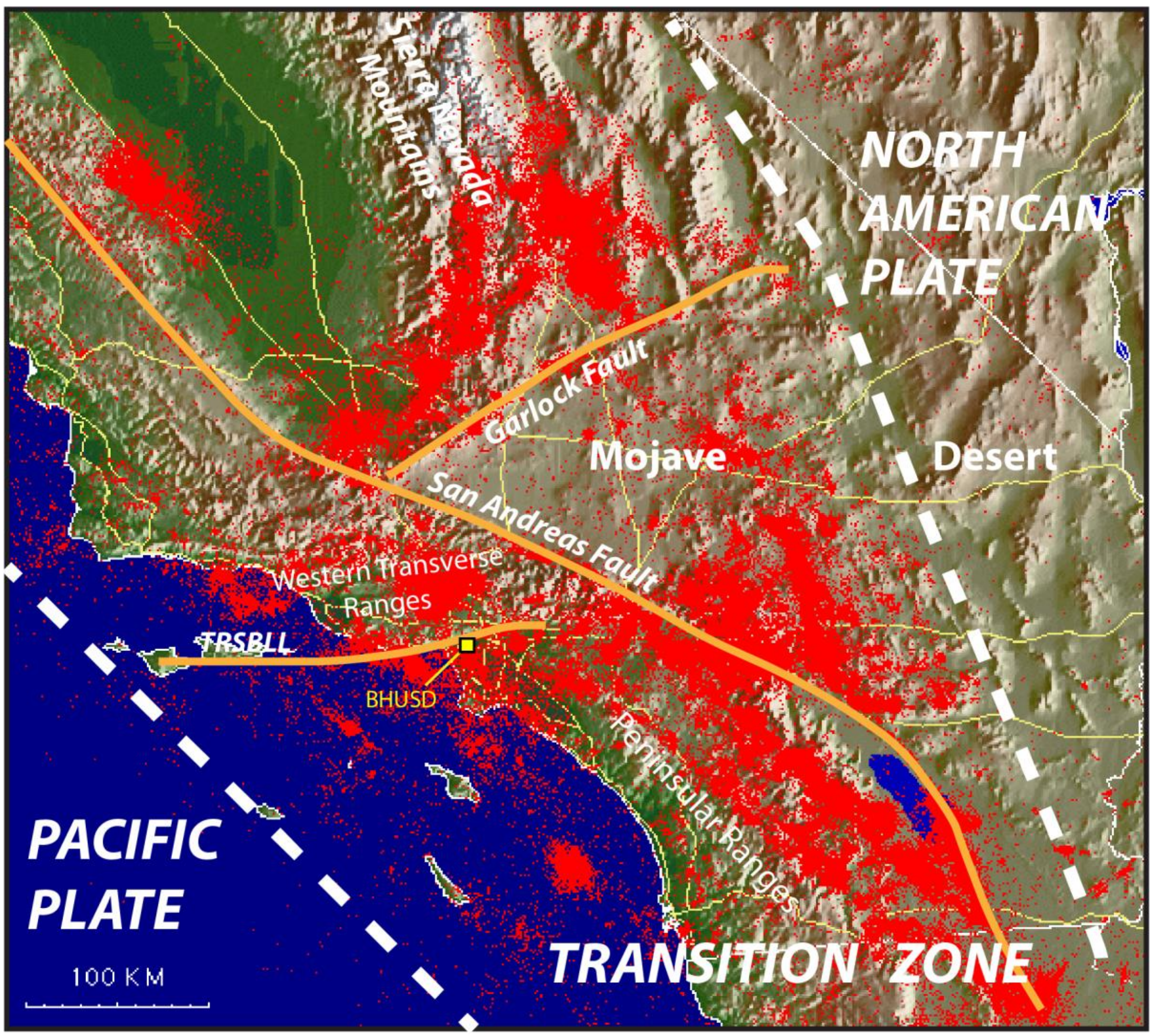
Period	Epoch	Time Period
Quaternary	Holocene	11.7 kya to present
	Latest Pleistocene	20 to 11.7 kya
	Late Pleistocene	125 to 20 kya
	Middle Pleistocene	670 to 125 kya
	Early Pleistocene	~2.6 Ma to 670 kya
Neogene	*Late* Pliocene	3.6 to 2.6 Ma
	Early Pliocene	5.3 to 3.6 Ma
	Late Miocene	11.6 to 5.3 Ma
	Middle Miocene	16 to 11.6 Ma
	Early Miocene	23 to 16 Ma

Although not of critical importance to this study, it should be pointed out that the time of the boundary between the Pliocene and Pleistocene varies considerably in the literature. This dilemma has resulted from the definition of the boundary of the Pliocene/Pleistocene, which is supposed to coincide with the onset of the first northern hemisphere glaciation. The Pleistocene is the period of time when Earth experienced major glaciations. Hence, the date has changed as new studies refine this age and there are disagreements within the scientific community regarding what the age should be and published ages for the Pliocene/Pleistocene boundary vary from 2.6 to 1.6 Ma. There is also disagreement regarding the end of the Pleistocene as it was a gradual transition from about 12–10 kya. However, the CGS has recently adopted 11.7 kya as the "official" definition of the Holocene based on a proposal to the International Stratigraphic Commission reflecting a change in Oxygen isotopic ($O^{18/16}$) composition of an ice core from Greenland.

3.0 GENERAL TECTONIC SETTING

The Beverly Hills Unified School District (BHUSD) is located within the zone of deformation associated with the tectonic boundary between the North American and Pacific Plates. The transition zone is at least 300 km wide and extends from the continental margin offshore east to the middle of the Mojave Desert (Figure 1). The relative motion between the North American and Pacific Plates is right-lateral, meaning, that the Pacific Plate moves northwest relative to the North American Plate.

Figure 1: Map shows epicenters of recorded seismic events (red dots - earthquakes) in southern California occurring between 1932 and 1996. The seismicity demonstrates that tectonic strain (deformation) is occurring throughout southern California. Numerous areas, though not all, that express a strong clustering of earthquakes represent aftershocks after a moderate to major earthquake in that area.



The relative displacement rate between the two plates is approximately 50 mm/yr, which equates to right-lateral displacement of 50 kilometers in 1 million years (Antonelis et al., 1999). Although the San Andreas Fault is possibly the most famous fault in the world, it only accommodates about 50 percent of the right-lateral displacement (25 to 35 mm/yr) between the North American and Pacific plates. Numerous other northwest trending right-lateral strike slip faults, mostly to the west of the San Andreas, accommodate the remainder of the relative plate motion. This entire wide zone of faulting associated with transform motion between the North American and Pacific Plates is collectively referred to as the San Andreas Fault System.

3.1 The Big Bend in the San Andreas Fault and local tectonic stress rates

Although the relative motion between the North American and Pacific Plates is right-lateral strike-slip, the faulting observed in the region is remarkably more complex. The primary cause for these complexities is associated with what is referred to as the Big Bend in the San Andreas Fault, which extends from Tejon Pass to Banning Pass (Figure 2), a distance of approximately 270 km. The Big Bend represents a 115 km wide restraining bend along the San Andreas Fault causing southern California south of the fault to collide with the San Andreas Fault itself, which behaves somewhat as a buttress and resulting in the formation of reverse-thrust faults to accommodate this compression. The Big Bend is believed to have resulted due to 40 to 60 km of left-lateral motion on the east-west trending Garlock fault located at the southern end of the Sierra Nevada Mountains and northern Mojave Desert (Figure 2).

Most of the compressional deformation associated with the Big Bend is accommodated south of the San Andreas Fault between the Tejon Pass and the northern Los Angeles Basin. Faults in this region commonly trend east-west, and are oblique left-lateral reverse. This region is referred to as the Western Transverse Ranges (Figure 2), which is discussed in Appendix A and in Section 3.2. A notable compressional earthquake in the northern Los Angeles basin was the 1987, M 5.9 Whittier Narrows earthquake, which caused widespread strong ground motions throughout the region (Figure 3).

Figure 2: Deformation associated with the Big Bend in the San Andreas Fault has resulted in a wide zone of deformation associated with the North American and Pacific Plate boundary that extends from offshore to the central Mojave Desert (Eastern California Shear Zone). The Big Bend in the southern San Andreas Fault that extends from Tejon Pass to Banning Pass, a distance of approximately 270 km. The Big Bend represents a regional restraining bend within the San Andreas Fault that results in compressional (reverse and thrust faults) south of the Big Bend. Many of the compressional faults also have a strike-slip component of displacement (oblique faults). The general region of the Western Transverse Ranges shown accommodates a large component of the compressional deformation associated with the Big Bend. Compressional strain also occurs south of the Western Transverse Ranges in the northern Peninsular Ranges. Tectonics of the Western Transverse Ranges and Peninsular Ranges are discussed in more detail in Appendix A.

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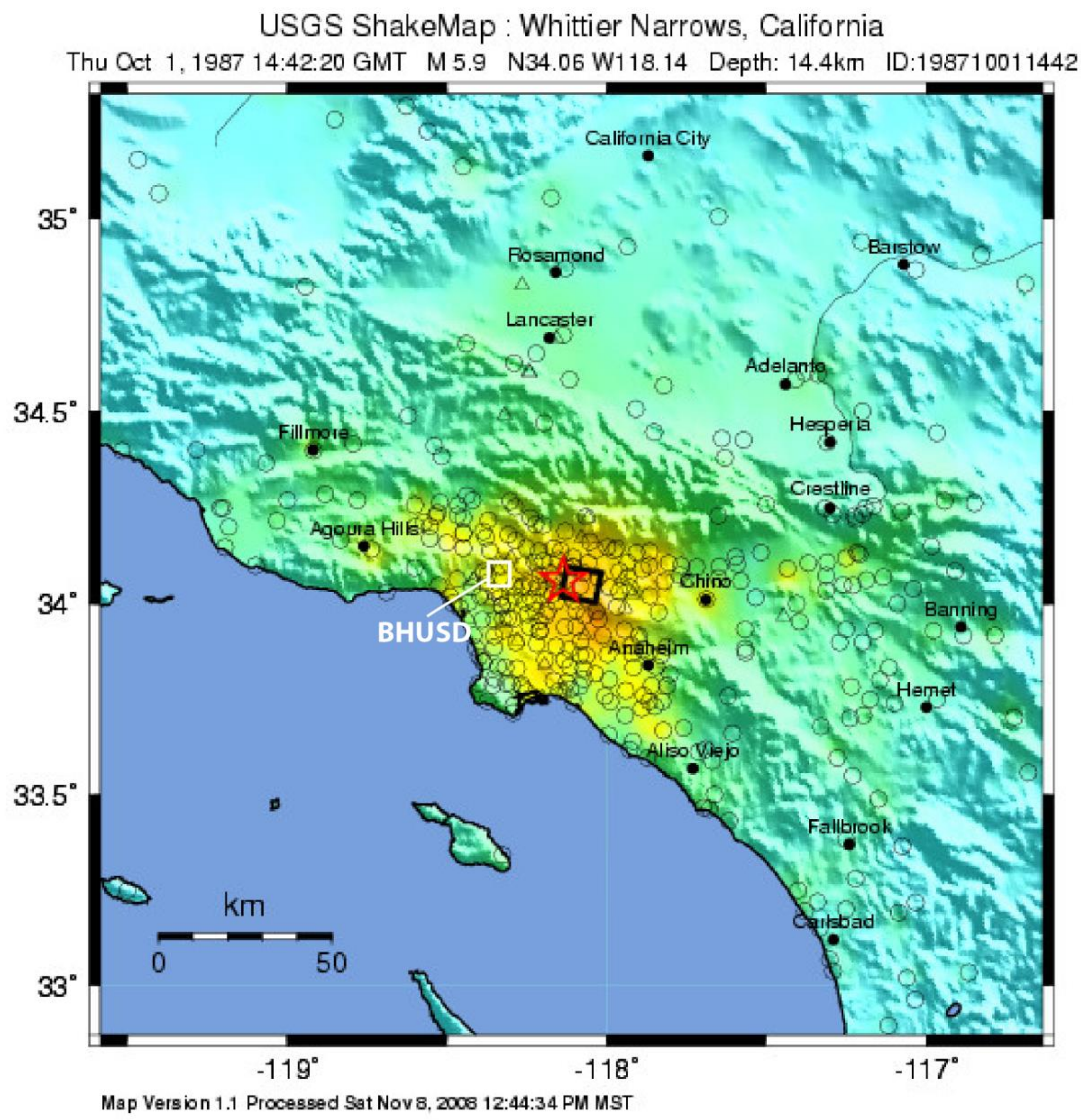
Figure 3: USGS ShakeMap for the M 5.9, 1987 Whittier Narrows Earthquake showing relative ground shaking utilizing the Mercalli Intensity Scale. It is observed on this map that the area of the BHUSD experienced "strong" ground shaking with "light" damage during this event.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

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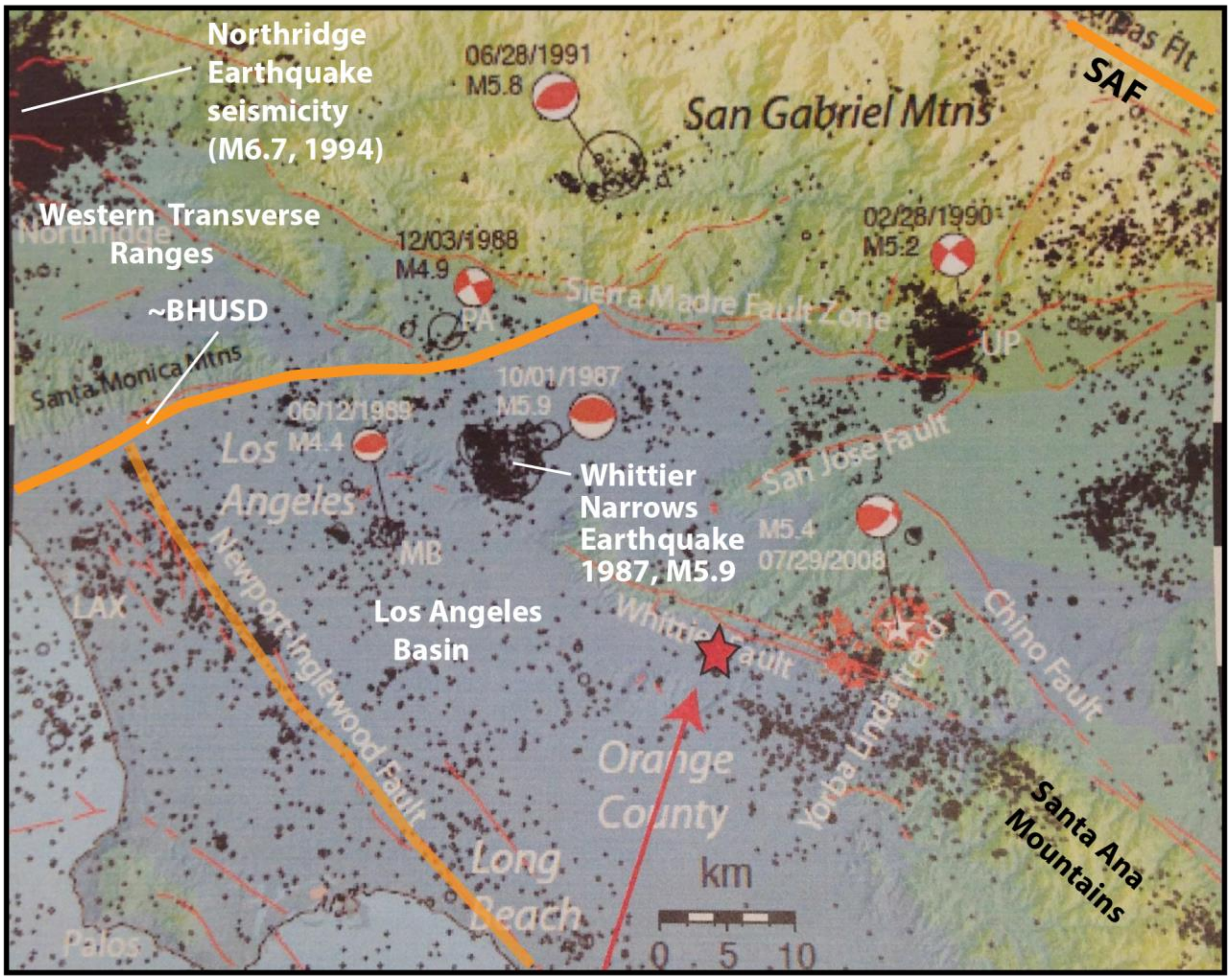
Recent earthquakes clearly indicate that compressional deformation associated with the Big Bend is occurring in the region south of the Western Transverse Ranges and northern Los Angeles Basin (Figure 4). This is the tectonic environment in which the BHUSD resides.

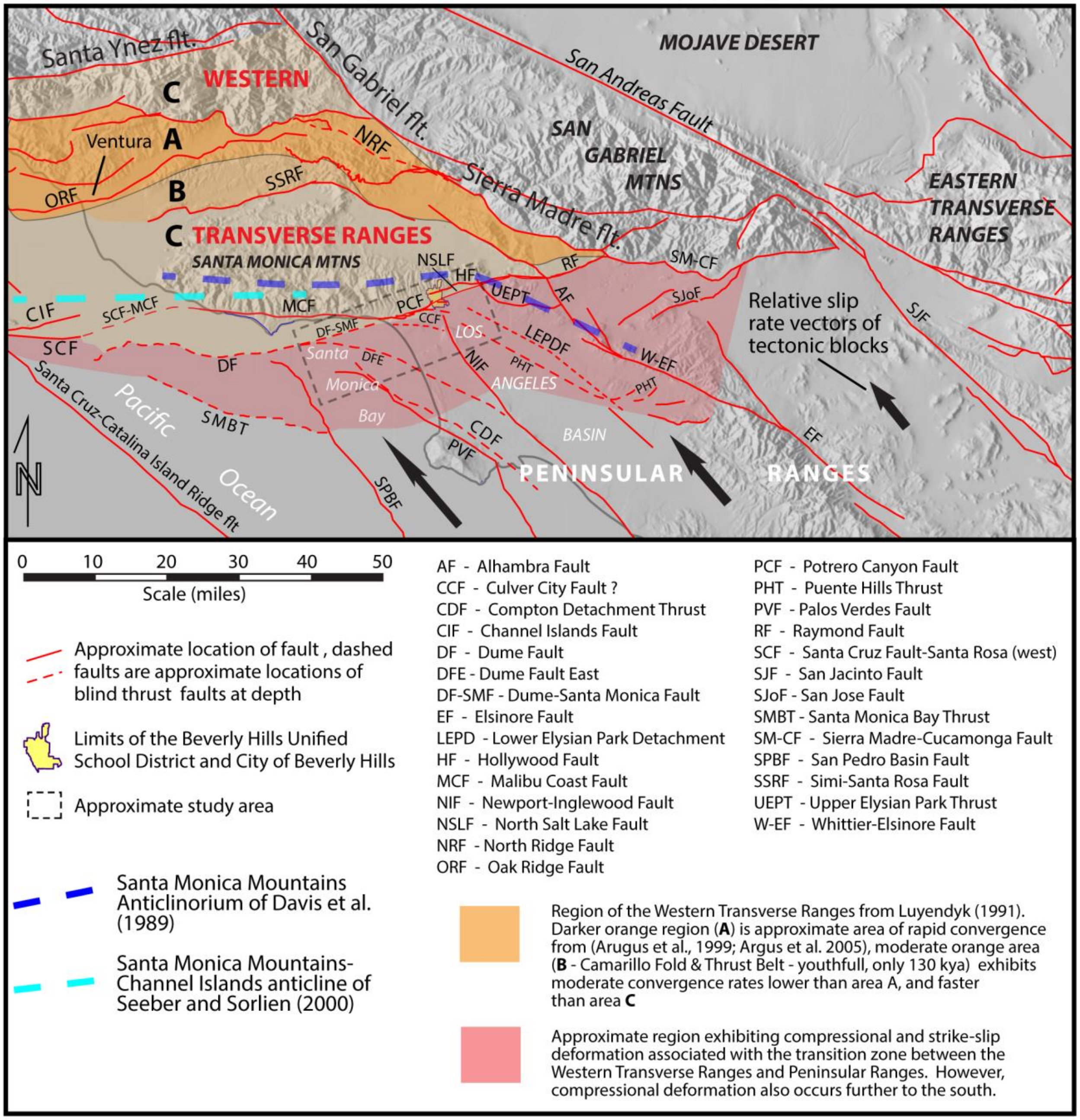
Figure 4: Recent significant earthquakes in the Los Angeles – southern California area (source: Los Angeles Times).



3.1.1 Low tectonic stress and strain rates in the region of Beverly Hills Unified School District

No direct compressional tectonic stress rates were identified specifically in the region of the BHUSD. However stress rates have been determined regionally for southern California and for areas to the north and the east that suggests most of the north-south compressional deformation is occurring north of the BHUSD within the Western Transverse Ranges (dark orange area of Figure 5), and to the east and southeast. The data for regional stress rates are provided in Appendix A.

Figure 5: Map showing approximate regions of relatively high compressional deformational rates in southern California within the Western Transverse Ranges (orange area) and the northern Los Angeles Basin (red area). The dark orange region shown within the Western Transverse Ranges is an area accommodating a relatively large magnitude of compressional strain, relative to the southern regions. The Puente Hills Thrust and Lower Elysian Park Thrust accommodate most of the strain in the red region of the northeastern Los Angeles Basin. Active compressional thrusts have not been positively identified west of the Newport-Inglewood Fault, however, two new compressional faults are postulated in this area (Culver City Fault and the Dume Fault East) later in this report.



3.2 The Transverse Ranges Southern Boundary Fault System (TRSB)

The BHUSD resides within a tectonic transition zone between the Western Transverse Ranges and the Peninsular Ranges. The Western Transverse Ranges, described in detail in Appendix A, exhibits a series of east-west trending oblique, left-lateral reverse faults, whereas the Peninsular Ranges primarily exhibits northwest trending right-lateral strike-slip faults, all of which occur to varying degrees. The BHUSD resides within this complex boundary, exhibiting east-west trending left-lateral faults along the southern boundary of the Western Transverse Ranges (Santa Monica Boulevard and Hollywood Fault Zones), and northwest trending right lateral strike-slip faults associated with the northern Peninsular Ranges (Newport-Inglewood Fault Zone). In addition, compressional faults (thrust ramps, reverse) also occur at different times during the past 5 million years and in various locations along the boundary.

For the purposes of this report, the tectonic boundary between Western Transverse Ranges and Peninsular Ranges adopts the terminology of Dolan et al. (2000a), which defined a west-trending fault system of reverse, oblique-slip, and left-lateral strike-slip faults that extends for >200 km along the southern edge of the Western Transverse Ranges as the Transverse Ranges Southern Boundary Fault System (TRSB). These fault zones include those shown on Figure 6.

As described later in this report, the fault zones shown on Figure 6 and originally described as oblique left-lateral reverse faults associated with the TRSB, will be referred to in this report as the Transverse Ranges Southern Boundary Fault System "Left-Lateral" (TRSBLL, Plate 1). These fault zones include, from west to east: Santa Rosa, Santa Cruz, Malibu Coast, Dume, Santa Monica (Potrero Canyon of Wright, 1991), Hollywood and Raymond. These fault zones are dominantly left-lateral and, as such, do not currently accommodate a significant component of compressional strain. Therefore, the TRSB's compressional strain must be accommodated on other faults. This is an important point because it changes the parameters in which seismic hazard assessments are made, the estimates of anticipated ground shaking, and consideration of future studies to attempt to understand where the compressional faults (reverse, thrust) may be located. This issue became a major investigative aspect of this report.

3.2.1 The Transverse Ranges Southern Boundary Fault System – Left-Lateral (TRSBLL)

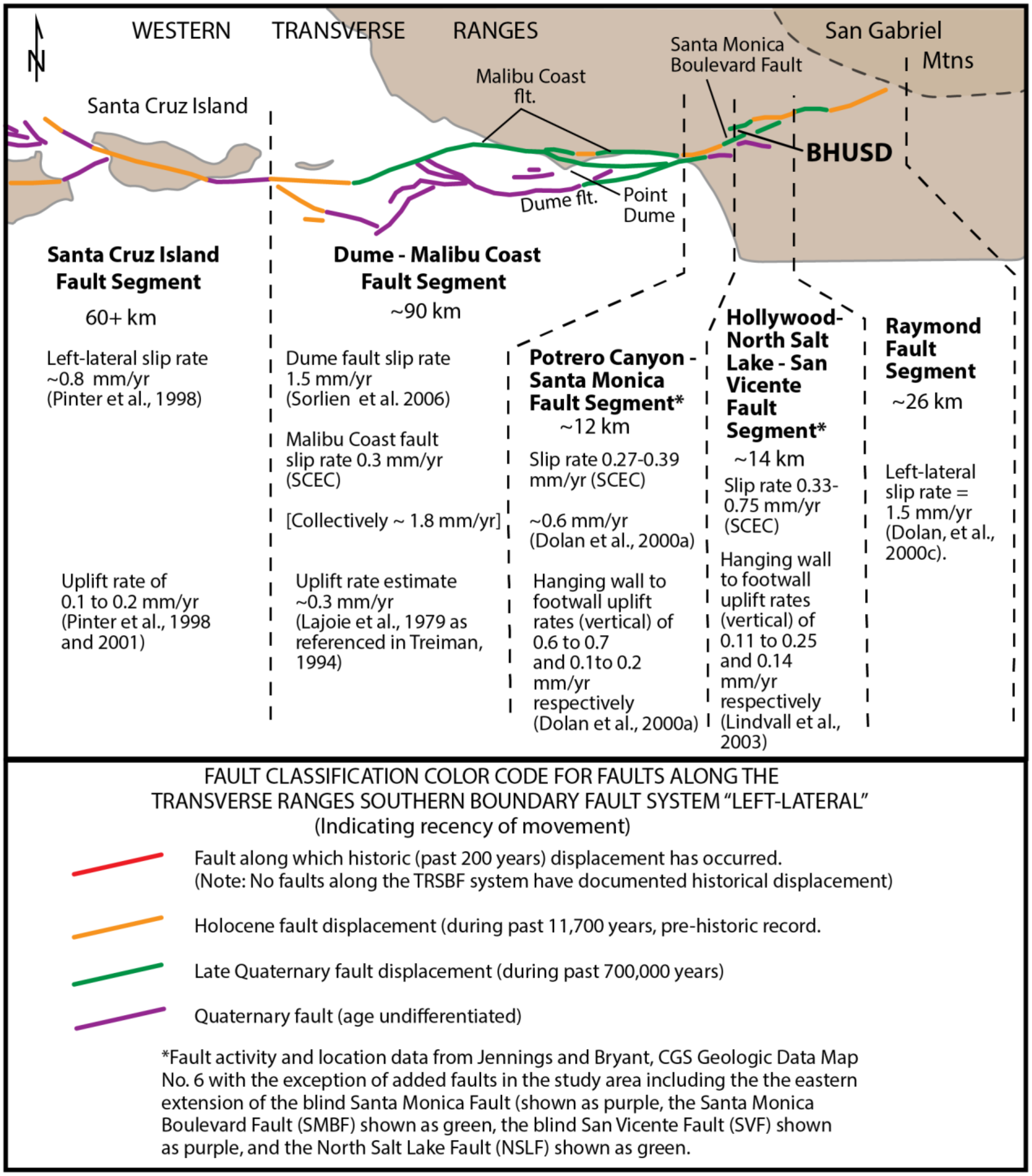
For the purpose of this report, tectonic structures along the TRSB are divided into numerous fault segments primarily based on established fault zone names associated with the TRSBLL (Figure 6). From west to east, the TRSBLL fault segments include: the

Santa Cruz (~100 km long), the Dume-Malibu Coast (~90 km), Potrero Canyon-Santa Monica (~12 km), Hollywood-North Salt Lake-San Vicente (~14 km), and the Raymond (~26 km).

Mapped traces of these fault zones could connect, suggesting that they are a system of faults accommodating similar styles and timing of deformation consistent with the findings of Seeber and Sorlien (2000). Wright (1991) indicates that the TRSBLL fault system was a relatively linear and likely a more singular connected fault zone prior to the Quaternary when the fault system was deformed by the northward propagation of northwest trending strike-slip strain from the Peninsular Ranges (i.e. Newport Inglewood Fault and Elsinore/Whittier Fault Zones to name two).

No faults in the TRSBLL are known to have ruptured during historic time (past 200 years; Figure 3); however, all fault segments do exhibit strands documented to have ruptured during the Holocene (~past 11,700 years) but not across the entire TRSBLL. At least on a regional scale, the TRSBLL should still be considered an active fault system. Each fault zone will be described in detail in the following sections of this report.

Figure 6: Fault Activity Map of the Transverse Ranges Southern Boundary Fault System – "Left-Lateral" (TRSBLL). Most fault activity designations shown are from Jennings and Bryant CGS Fault Activity Map No. 6. No fault along the TRSBLL has experienced a Historical surface-rupture, but each Fault Segment exhibits Holocene age faulting, and numerous portions of the TRSBLL Fault System are still poorly constrained in terms of past events (green and purple faults).



4.0 SANTA MONICA BOULEVARD FAULT

This portion of the report details the evolution in terminology, geomorphology, style of faulting, history of activity of what has been identified as the Santa Monica Fault Zone extending from the coast near Potrero Canyon to the western Hollywood Basin. The Santa Monica Fault as a structural feature has been mapped for decades (i.e. Junger and Wagner, 1977; Hill et al., 1978; Hill et al., 1979; Wright, 1991; Crook and Proctor, 1992; Dolan and Sieh, 1992). However, there is confusion as the "Santa Monica Fault Zone", identified decades ago by the Oil Industry, is a thrust fault with a north and south strand, occurs at depth, is blind, and is generally considered inactive (CDOG, 1960; Wright, 1991; Tsutsumi et al., 2001). But the "Santa Monica Fault" that occurs at the surface west of the Cheviot Hills has been documented to be active (Dolan et al., 2000a). For this reason, the surface-rupturing fault of Dolan et al. (2000a) from the coast to the western Cheviot Hills will adopt the name "Potrero Canyon Fault" provided by Wright (1991), while the "Santa Monica Fault" in the Cheviot Hills including Century City and Beverly Hills is referred to as the Santa Monica Boulevard Fault as proposed by Kenney GeoScience (2012). Distinguishing between the older, blind oblique reverse left-lateral Santa Monica Fault North and South fault zones verses the dominantly left-lateral, more recently active, Potrero Canyon and Santa Monica Boulevard fault zones is critical to appropriately understand the structural evolution of the overall Santa Monica Fault zone, and is a key aspect of this report.

Wright (1991), and Crook and Proctor (1992) mapped the "Potrero Canyon Fault" from the coast at Potrero Canyon to the western Cheviot Hills based on geomorphology, fault outcrops, groundwater barriers, and fault trench exposures. Crook and Proctor (1992) extended the fault eastward through the Cheviot Hills to the western Hollywood Basin near the location of Santa Monica Boulevard. Dolan and Sieh (1992) mapped what they called the Santa Monica Fault from the coast near Potrero Canyon to the eastern Cheviot Hills based on interpreted geomorphic fault scarps. This is essentially in the same location as Wright (1991) with the exception of within the Cheviot Hills-Century City area proper.

Within the Cheviot Hills, Dolan and Sieh (1992) interpreted fault scarps primarily along the immediate north side of Santa Monica Boulevard. This fault zone was considered part of the Transverse Ranges Southern Boundary System (TRSBS) by Dolan et al. (1997) that described it as an oblique left-lateral reverse fault. Hence, their Santa Monica Fault in the Cheviot Hills accommodated compressional deformation as well as strike slip. This interpretation was consistent with oil well structures that showed compressional reverse deformation across the Santa Monica Fault; however, the compressional Santa Monica Fault responsible for the oil fields is considered both blind and inactive (Wright, 1991; Tsutsumi et al., 2001).

KGS (2011, 2012 and 2014) based on a geomorphic analysis of preserved fan-terrace surfaces in the Cheviot Hills (Century City) proposed that the near surface Santa Monica Fault identified by Dolan and Sieh (1992) did not exhibit a reverse component (north-side up) and was dominantly a strike-slip fault. The KGS (2011) study also recognized that many of the identified "fault scarps" by Dolan and Sieh (1992) associated with the Santa Monica Fault were actually erosional features along the fault zone and not fault scarps. The KGS (2011) report described this portion of the "Santa Monica Fault Zone" as the Santa Monica Fault Lineament as it appeared to be more of an erosional feature compared to a feature developed primarily from fault displacement. Data from studies in the Cheviot Hills - Century City area completed after the KGS (2011) report support this erosional interpretation (MACTEC, 2010b; Parson, 2011, LCI, 2012a). The geomorphic analysis is updated in the following section.

KGS (2012) proposed that the previously named Santa Monica Fault extending through Cheviot Hills along Santa Monica Boulevard from the Mormon Temple to Beverly Hills High School be renamed the Santa Monica Boulevard Fault (SMBF) (Figure 7). The primary motivation to call the "Santa Monica Fault" in Century City (central Cheviot Hills) by a new name results from the interpretation that the Santa Monica Boulevard Fault is dominantly a strike-slip fault zone and is not exhibiting a strong reverse component as did the older Santa Monica Fault at depth, and that the fault zone developed only about 1 Ma. The other motivation is that the term "Santa Monica Fault" applies to the deeper, blind, and inactive oblique reverse left-lateral fault identified from oil well data (see Wright, 1991; Tsutsumi et al., 2001).

The Santa Monica Boulevard Fault likely extends eastward to the northwestern end of the Salt Lake Oil Field where it is proposed to step over to the North Salt Lake Fault. In addition, it is proposed that the Santa Monica Boulevard Fault extends westward to connect with the Potrero Canyon Fault of Wright (1991) near the Mormon Temple (Plate 3).

4.1 Geomorphic analysis of the Santa Monica Boulevard Fault and Cheviot Hills Region

A geomorphic analysis of the Cheviot Hills, updated from KGS (2011, 2012), provides information about fault location, local folding, and relative age of preserved fan-terrace surfaces. The topographic map used for the analysis is from Hoots (1931) with 5-foot contours produced prior to dense urbanization. The Hoots (1931) map portrays the geology of the Santa Monica Mountains area, extending from the Pacific Ocean on the west to the Los Angeles River on the east.

4.1.1 Abandoned fan-terrace surfaces – The Northern and Southern Cheviot Hills

Most of the Cheviot Hills exhibits well-preserved abandoned alluvial fan terraces that were all connected similar to the planar fan surface east of the Cheviot Hills (Figure 7) prior to Pleistocene uplift and dissection. With uplift, the fan-terraces have been eroded away in the southern Cheviot Hills exposing marine sediments. Relatively higher elevation exposures of the marine sediments are also eroding, and some marine terraces probably occur at lower elevations in the southern Cheviot Hills (Figure 7).

The preserved Qt-BC2 alluvial fan-terraces estimated to be 350 to 200 kya, coincide with the time that uplift of the Cheviot Hills was sufficient to allow erosional processes to outpace depositional fan processes (KGS, 2014). However, as discussed later in this report, the age of the dominant preserved fan-terraces (Qt-BC2) are now considered approximately 580 kya. This age coincides with cessation of deposition of the older Benedict Canyon Wash Deposits (BCWD2).

The geomorphic map of Figure 7 identifies a sharp change in contour style across Santa Monica Boulevard Fault suggesting that these two geomorphic areas have deformed differently since the fan-terrace abandonment. North of Santa Monica Boulevard, the contours exhibit those typical for alluvial fan surfaces, suggesting that this area has not been deformed internally but may have been uplifted collectively. South of the Santa Monica Boulevard Fault the fan-terraces are deformed into a north trending antiform. Primarily based on this variation, regions the Cheviot Hills are referred to herein as northern and southern across the Santa Monica Boulevard Fault. These observations have ramifications for the development of the West Beverly Hills Lineament, which is discussed later in the report.

The fan-terrace geomorphology in the northern Cheviot Hills is fairly well preserved and only moderately dissected. However, there are two exceptions. The first exception is in the southwest Cheviot Hills between Ohio Street and Santa Monica Boulevard (Figure 7). Here the fan-terraces are topographically lower and may represent a younger inset fan surface, folding, or possibly faulting near the 300-foot contour line. The second exception is to the north where the contours widen on strike with the projection of the Hollywood fault to the east. This is consistent with the western Hollywood Fault possibly extending west of the West Beverly Hills Lineament and under the northern Cheviot Hills as a blind fault that does not reach the surface. Crook and Proctor (1992) similarly continue the Hollywood Fault Zone westward to the Pacific Ocean connecting it to an apparent reverse fault identified on the University of California Los Angeles (Plate

3). If this observation is correct, then it indicates that the western Hollywood Fault was active for some period of time after abandonment of the Qt-BC2 surface.

The preserved fan-terrace contours north of the SMBF exhibit typical fan geomorphology indicating that a relatively large fan "lobe" occurred that would not necessarily require much uplift to exhibit topographic relief from the regions to the east. The northern Cheviot Hills alluvial fan (BCWD2 deposits and Qt-BC2 fan-terraces) developed from detrital material emanating from numerous relatively large watershed canyons in the local Santa Monica Mountains. Benedict Canyon (Moreno Creek) eroded the eastern margin of this fan, thereby forming the topographic lineament identified as the West Beverly Hills Lineament (Dolan and Sieh, 1992). The development of the West Beverly Hills Lineament is discussed later in the report.

The change from fan-terrace contours north of the Santa Monica Boulevard Fault Zone to an antiform structure to the south suggests that variations of deformation occur north and south of the fault zone. South of the SMBF Zone, the southern Cheviot Hills have apparently experienced approximate east-west shortening to allow for the development of the open antiform, which as discussed later deforms the upper contact of the approximately 1 million year old San Pedro Formation approximately the same as the Pleistocene Qt-BC2 surfaces (Figure 7; Plate 3). The age of the abandoned Qt-BC2 fan-terrace surface coincides with the development of the anticlinal uplift of the southern Cheviot Hills. Toward the east, the eastern limb of the fan extends across the Newport-Inglewood Fault and develops into a syncline associated with the development of the Beverly Hills Sub-Basin (Figure 14; Plate 5). Wright (1991), shows the Beverly Hills Sub-basin as a Holocene age structure that trends parallel (northward) to the Newport-Inglewood Fault (Figure 37). Hence, a Quaternary anticline-syncline pair that occurs from the southern Cheviot Hills across the Newport-Inglewood Fault into the Beverly Hills Sub-basin may still be active.

A slope inflection point of the preserved fan-terraces occurs along the Santa Monica Boulevard Fault (Figure 8). Hence, the slope inflection likely developed associated with motion across the Santa Monica Boulevard Fault.

4.1.2 The Santa Monica Boulevard Fault "scarps"

Dolan and Sieh (1992) and Dolan et al. (2000a) proposed that south-facing slopes along Santa Monica Boulevard in Century City, ranging in height from 7- to 12-meters (~23 to 40 feet), owe their origin to reverse faulting associated with the Santa Monica Fault Zone. To test the hypothesis whether or not the Santa Monica Boulevard Fault had experienced numerous reverse displacements since inception of the Qt-BC2 fan-terraces, two cross sections were evaluated across the fault zone (KGS, 2011). Cross-section A-A' and B-B' are shown on Figure 8 and Figure 9 respectively and their locations are provided on Figure 7.

Figure 7: Geomorphic and geologic map of the Cheviot Hills (modified from KGS, 2011, 2012 and 2014). Cross Sections A-A' and B-B' are provided on Figure 8 and Figure 9 respectively. Cross Section C-C′ is provided on Figure 31. The location of the MACTEC (2010b) seismic study and approximate location of their identified faults are shown.

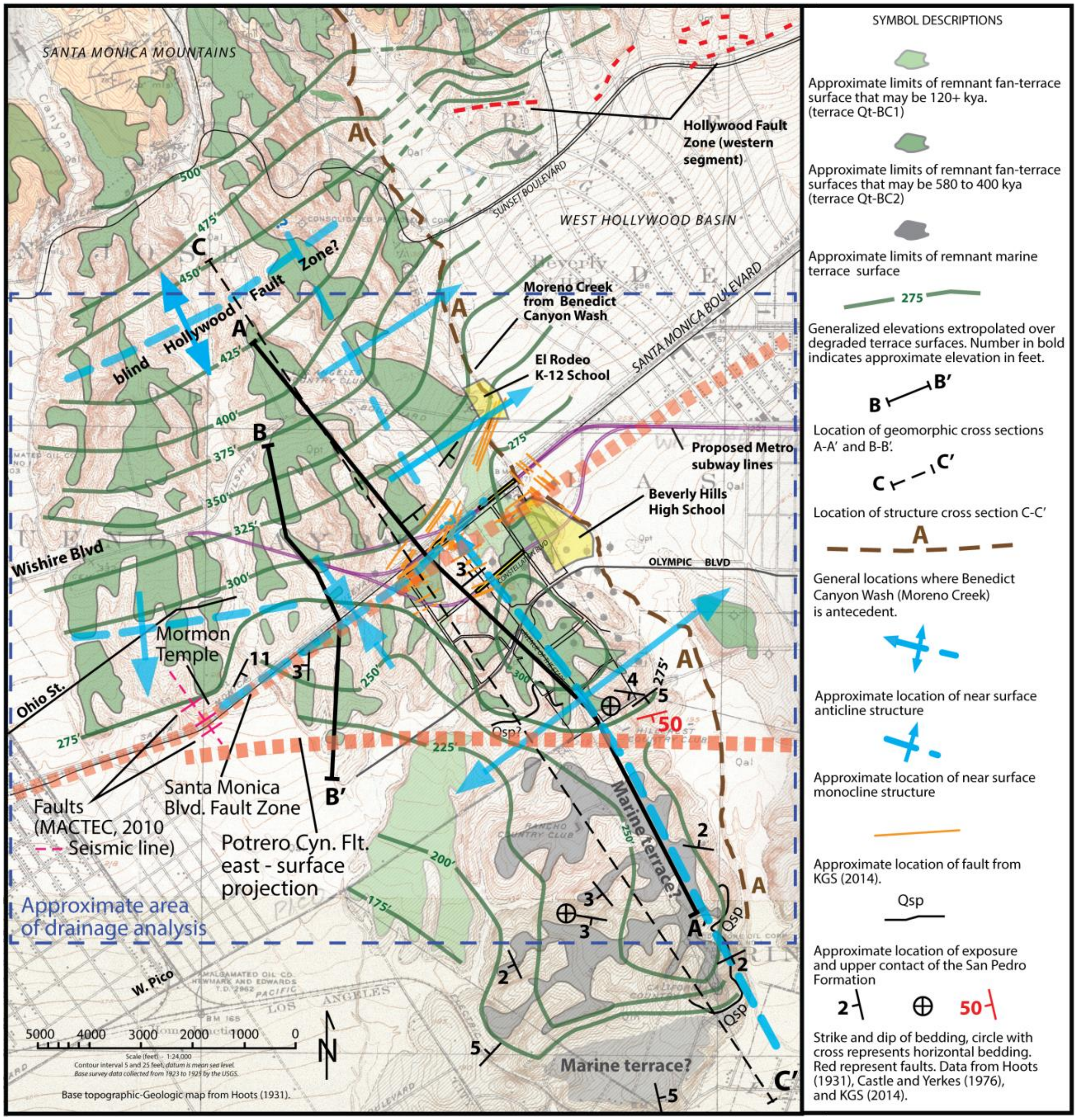
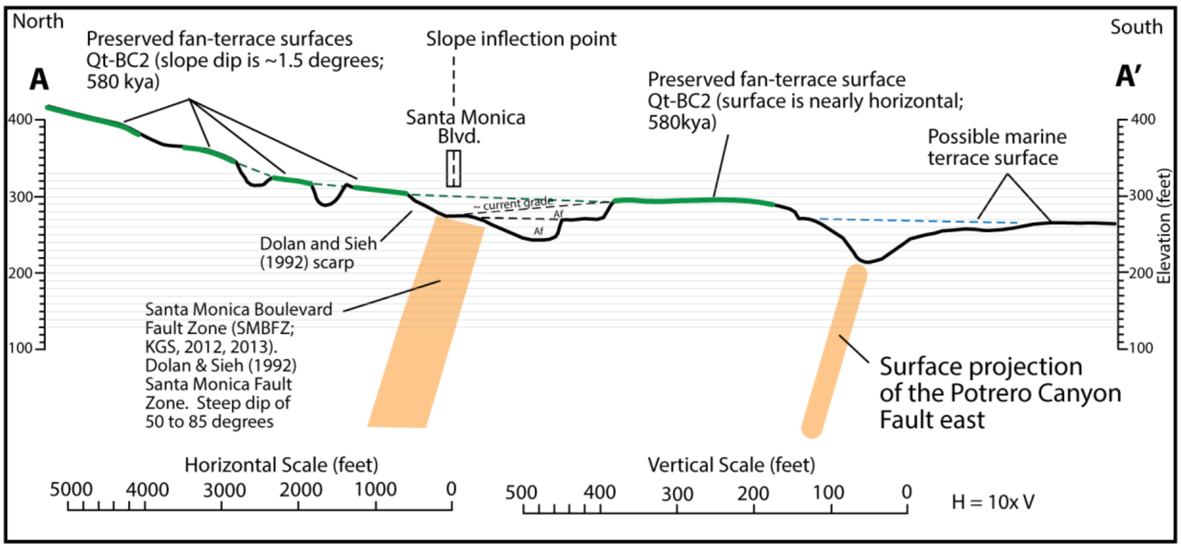


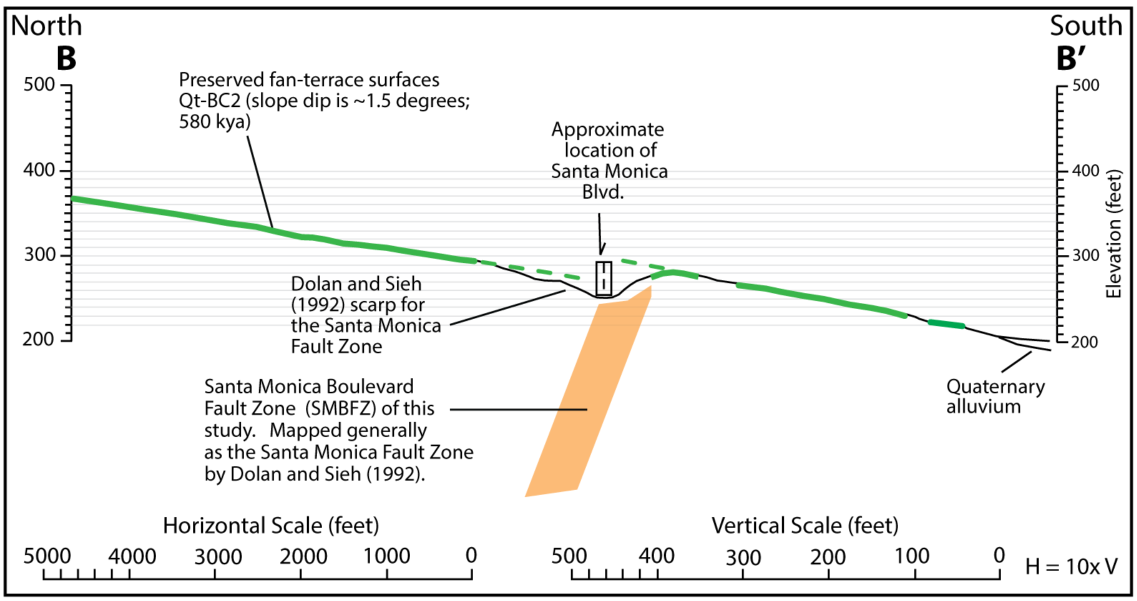
Figure 8: Cross Section A-A' modified from KGS (2011, 2012 and 2014) evaluating geomorphology of the Qt-BC2 preserved fan-terraces estimated to be 580 to 400 kya across the Santa Monica Boulevard Fault (see Figure 7 for location). As evaluated in KGS (2011, 2012 and 2014), the preserved fan-terraces of Qt-BC2 do not exhibit a reverse, up to the north sense of displacement but do show a "kink" (inflection point) across the Santa Monica Boulevard Fault. The proposed scarp of Dolan and Sieh (1992) was interpreted by KGS (2011) to represent an erosional feature along the Santa Monica Boulevard Fault (previously referred to as the Santa Monica Fault) and not a true "fault scarp". KGS (2011) proposed that the Santa Monica Fault (more recently referred to as the Santa Monica Boulevard Fault (KGS, 2012) was dominantly a strike-slip fault and not an oblique left-lateral reverse fault as typically described in most published literature and maps (also supported by KGS (2012, 2014) and finding provided in this report).



Cross-section A-A' indicates that the Qt-BC2 fan-terrace surface geomorphically correlates across the Santa Monica Boulevard Fault geomorphically (Figure 8) and that this surface is not displaced vertically across the Santa Monica Boulevard Fault. Soil evaluations of the Qt-BC2 surfaces north and south of the Santa Monica Boulevard Fault indicate that they exhibit similar age soils (see KGS, 2012 and KGS, 2014). Cross section B-B' shows similar correlated fan-terraces across the Santa Monica Boulevard Fault Zone where a topographic escarpment of these surfaces shows probable normal apparent separation (north side down) for north-dipping faults (Figure 9). The apparent normal separation could result from lateral motion that places fan-terraces surfaces of varying heights juxtaposed across the strike-slip Santa Monica Boulevard Fault Zone.

The geologic constructions on cross sections A-A' and B-B' indicate that the Santa Monica Boulevard Fault Zone has not exhibited repeated events over thousands of years with a strong vertical (dip-slip) component. This indicates that the original "fault scarps" mapped by Dolan and Sieh (1992) along the north side of Santa Monica Boulevard are attributed to differential erosion along the Santa Monica Boulevard Fault, which includes the ancestral channel of Benedict Canyon (Figure 7; KGS, 2012; KGS, 2014).

Figure 9: Cross Section B-B' modified from KGS (2011, 2012 and 2014) evaluating geomorphology of the Qt-BC2 preserved fan-terraces estimated herein to be 580 to 400 kya across the Santa Monica Boulevard Fault (see Figure 7 for location). As evaluated in KGS (2011, 2012 and 2014), the preserved fan-terraces Qt-BC2 do not exhibit a reverse, up to the north sense of displacement and in fact exhibit a down to the north sense of apparent vertical separation across the Santa Monica Boulevard Fault. The proposed scarp of Dolan and Sieh (1992) was interpreted by KGS (2011) to represent an erosional feature along the Santa Monica Boulevard Fault (previously referred to as the Santa Monica Fault) and not a true "fault scarp". KGS (2011) proposed that the Santa Monica Fault (more recently referred to as the Santa Monica Boulevard Fault (KGS, 2012) was dominantly a strike-slip fault zone and not an oblique left-lateral reverse fault as typically described in most published literature and maps (also supported by KGS (2012, 2014) and finding provided in this report).



4.1.3 Geomorphic drainage analysis of the Cheviot Hills

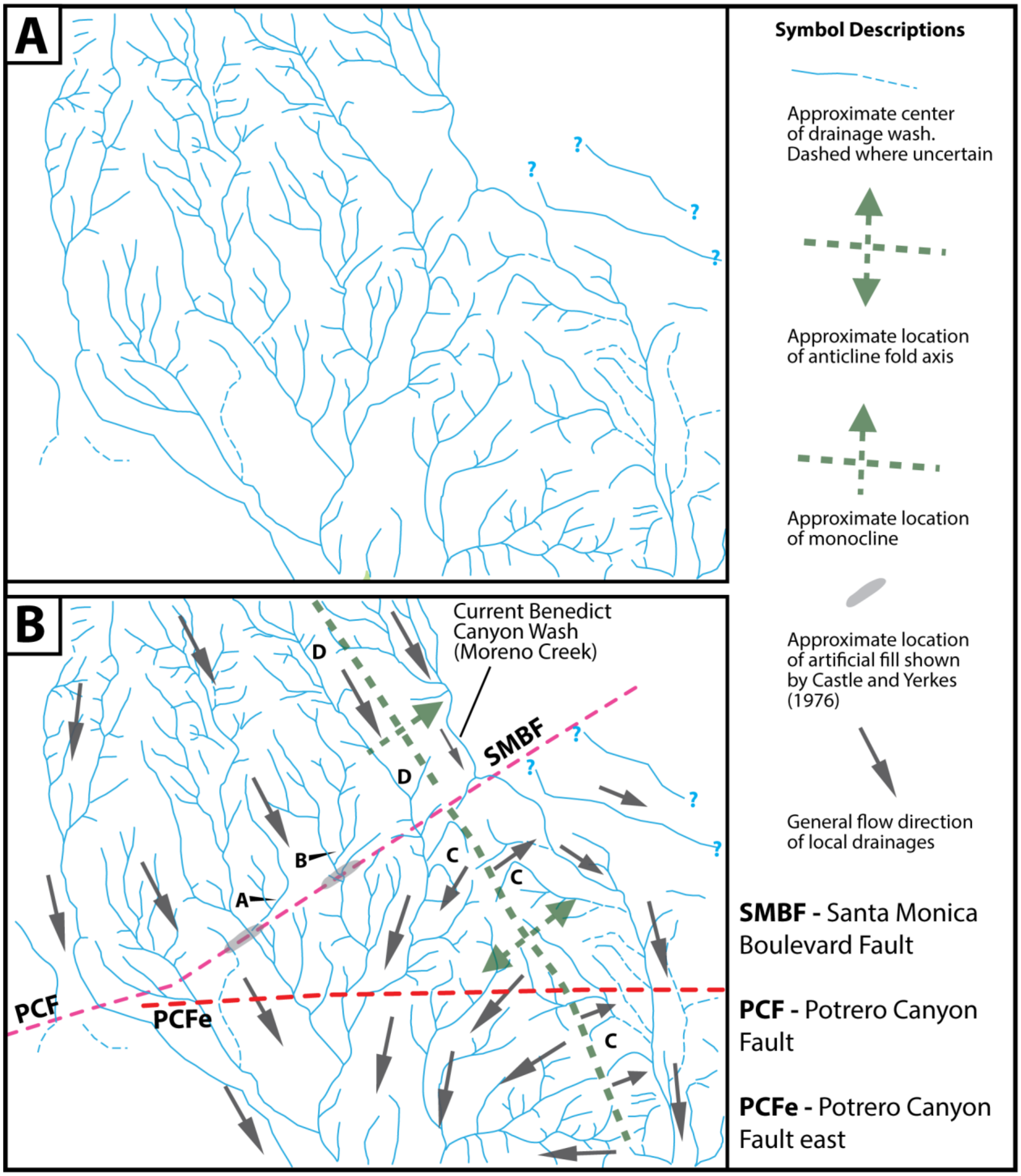
A re-evaluation of a previous drainage geomorphic analysis by KGS (2012, 2014) was conducted for this study utilizing the Hoots (1931), 5-foot contour map based on early 1920's USGS contours (Figure 10). The drainage courses in the central Cheviot Hills are shown on Figure 10, diagram A without any other structures, which essentially shows a tributary drainage system across the hills. This indicates that the hills are eroding and not continuing to deposit because actively depositing alluvial fans typically exhibit a network of distributary channels. The drainages began to form near the time of the development of the Qt-BC2 preserved fan-terraces sometime between 580 to 350 kya, and likely closer to the 580 kya age.

In KGS (2012), it was indicated that two possible drainages (A and B on Diagram B of Figure 10) may be right-deflected streams, and that these drainages likely contained artificial fill associated with the rail road line along Santa Monica Boulevard. A geologic map by Castle and Yerkes (1976) shows that artificial fill does occur in these drainages making an evaluation of potential fault displacement across the Santa Monica Boulevard Fault along Santa Monica Boulevard problematic. Most of the drainages appear to extend across the Santa Monica Boulevard Fault without deflection, consistent with the findings by LCI (2012c) and Geocon (2013) that determined that the Santa Monica Boulevard Fault likely ceased activity between 250 to 200 kya. However, as discussed later in this report, the Santa Monica Boulevard Fault offset drainages when the fault zone was active during the time of 580 kya (age of drainage development) to 200 kya (age the Santa Monica Boulevard Fault became inactive). These data also indicate that the drainages have had approximately 200,000 years to erode into the landscape without displacement occurring on the Santa Monica Boulevard Fault Zone, which would provide significant time for potential left-lateral deflected stream geomorphology to become subdued if not eliminated. A left-lateral displacement evaluation of the Santa Monica Boulevard Fault is discussed in Section 4.4 of this report.

Drainages in the northern Cheviot Hills, defined as the area north of Santa Monica Boulevard, and consequently, the Santa Monica Boulevard Fault Zone, generally flow in a south-southeast direction consistent with Moreno Creek and other drainages to the west and east of this area. Hence, these drainages flow consistent with local alluvial fan drainage directions suggesting that the region was simply regionally uplifted as a "block".

The drainage analysis provides evidence of the existence of the northward trending antiform in the southern Cheviot Hills consistent with the findings of KGS (2012). The extrapolated contours (dark green lines of Figure 7) exhibit a bull's eye pattern consistent with an antiformal structure. The "hook" drainage systems in the areas labeled "C" in Figure 10, Diagram B are consistent with their location near the axis of an antiform, which has also been identified via subsurface data (KGS, 2012). Very linear drainages in the areas labeled "D" in Figure 10, Diagram B are consistent with development of a northwest trending monocline, as discussed in KGS (2012, 2014). In addition, drainages in the southern Cheviot Hills are generally nearly perpendicular to the axis of the geomorphic expression of the north-northwest trending antiform. This provides additional evidence that the antiform has deformed the abandoned fan-terrace surfaces in this area. The antiform is also documented with subsurface data in the northern region of the southern Cheviot Hills (Figure 28).

Figure 10: Geomorphic Drainage analysis of the central Cheviot Hills (see Figure 7 for region of analysis). Areas of features A, B and C are discussed in the text. Small gray areas along the Santa Monica Boulevard Fault Zone denote mapped areas of artificial fill by Castle and Yerkes (1976). Dark gray arrows denote general flow direction of local inset drainages within the Cheviot Hills. Within the Cheviot Hills, the location of Santa Monica Boulevard is very close to the location of the Santa Monica Boulevard Fault Zone.



4.2 Stratigraphic and structural analysis across the Santa Monica Boulevard Fault

A detailed stratigraphic and structural evaluation of the Century City area was conducted by KGS (2012, 2014) providing a general stratigraphy for the area and interpreting numerous fault zones. Simplified versions of Transects 1, 3 and 7 from KGS (2014) are shown in Figure 12 with their transect locations shown on Figure 11. These cross sections extend nearly perpendicular across the Santa Monica Boulevard Fault Zone, and demonstrate that the top of the San Pedro Formation does not exhibit a net vertical displacement north and south of the zone of faulting. The minimum age of the uppermost members of the San Pedro Formation (Qsp) if not the age of the overlying Qeb member in the Century City area is estimated to be approximately 1 Ma old locally (KGS, 2014). This age is similar to the 1.0 to 0.8 Ma marine gravels mapped by Hummon et al. (1994), however those marine gravels are generally deeper than the top of the Qsp (Plate 5) identified in the Century City area. Hence, the marine gravels mapped by Hummon et al. (1994) are likely older than they indicate at least locally. The water bearing zones mapped by Poland et al. (1959) shown on Plate 6 also occur within the San Pedro Formation (Qsp). These maps (Poland et al., 1959; Hummon et al., 1994) shown on Plates 5 and 6 respectively show approximate structure contours of the San Pedro Formation in the region.

Fault Zone F (Figure 11) represents the dominant style of displacement of the Santa Monica Boulevard Fault, extending from the Mormon Temple into the western Hollywood Basin (KGS, 2014). KGS (2011) determined based on a geomorphic evaluation of the Cheviot Hills that Fault Zone F exhibited dominantly strike-slip displacement and not a strong component of reverse slip (also see KGS, 2014). As discussed later in this report, Fault Zone F is a dominantly left-lateral fault zone that exhibits apparent normal separation across steeply north-dipping faults. The northeast trending Fault Zone A (Cross Fault No.1 on Plate 3), which extends from Fault Zone F near the intersection of the Avenue of the Stars and Santa Monica Boulevard to the El Rodeo elementary school, exhibits apparent reverse separation and folding (Figure 12). Left-lateral motion across Fault Zone A created localized compression near its intersection with Fault Zone F due to the bend in the intersection between Fault Zone A and Fault Zone F (Figure 12 Transects 1 and 3).

Both of these fault zones have been inactive for over 150 kya (Geocon, 2014; LCI, 2015; LCI, 2016). Geocon (2014) and ECI (2015) identified some relatively small scale faults occurring between Fault Zone A and Fault Zone F and determined that these faults were also inactive for over 100 kya.

Figure 11: Fault zone location map from KGS (2014) in Century City. Location of cross section transects (orange lines) from KGS (2014), which are provided in Figure 12.

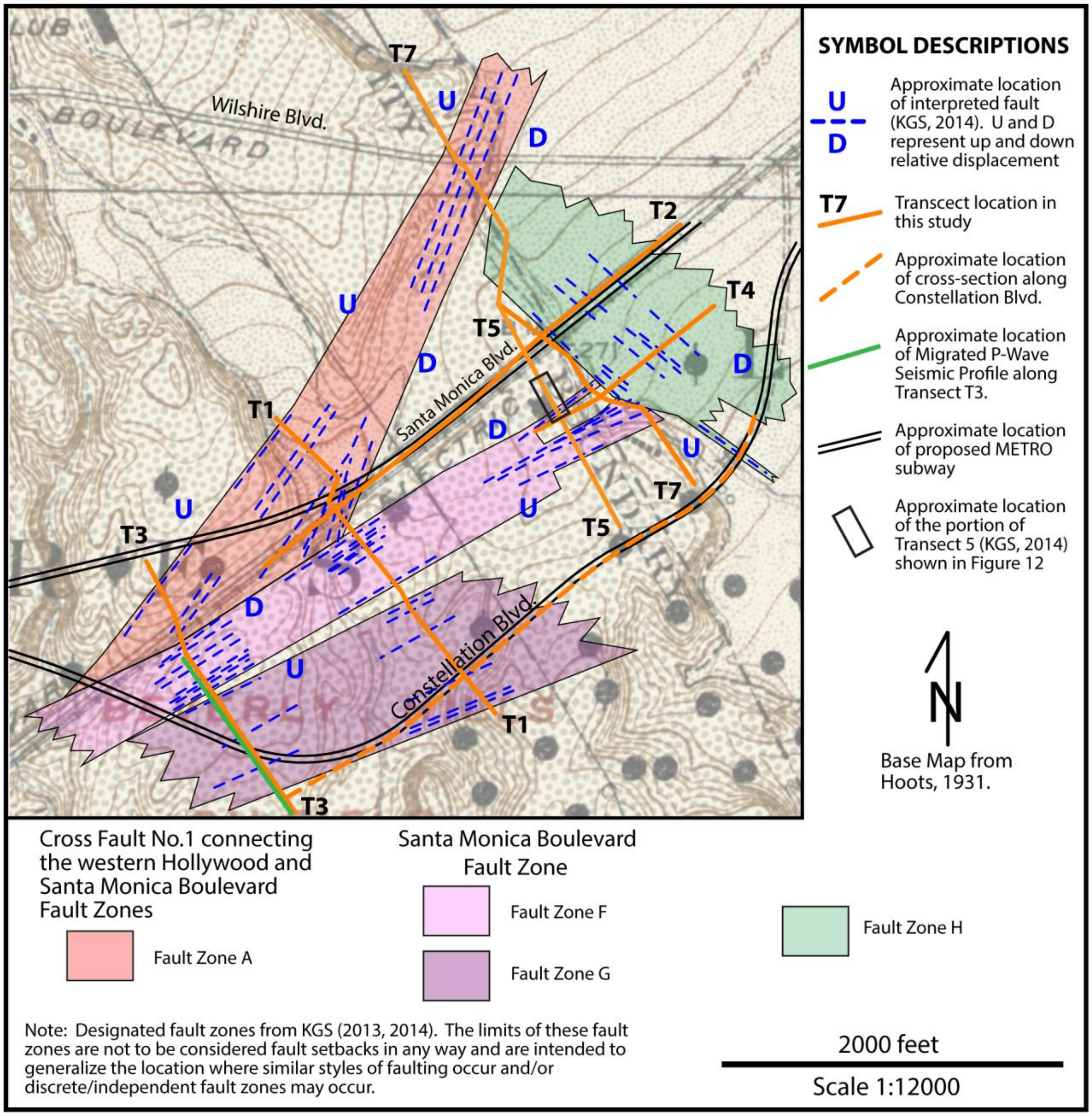
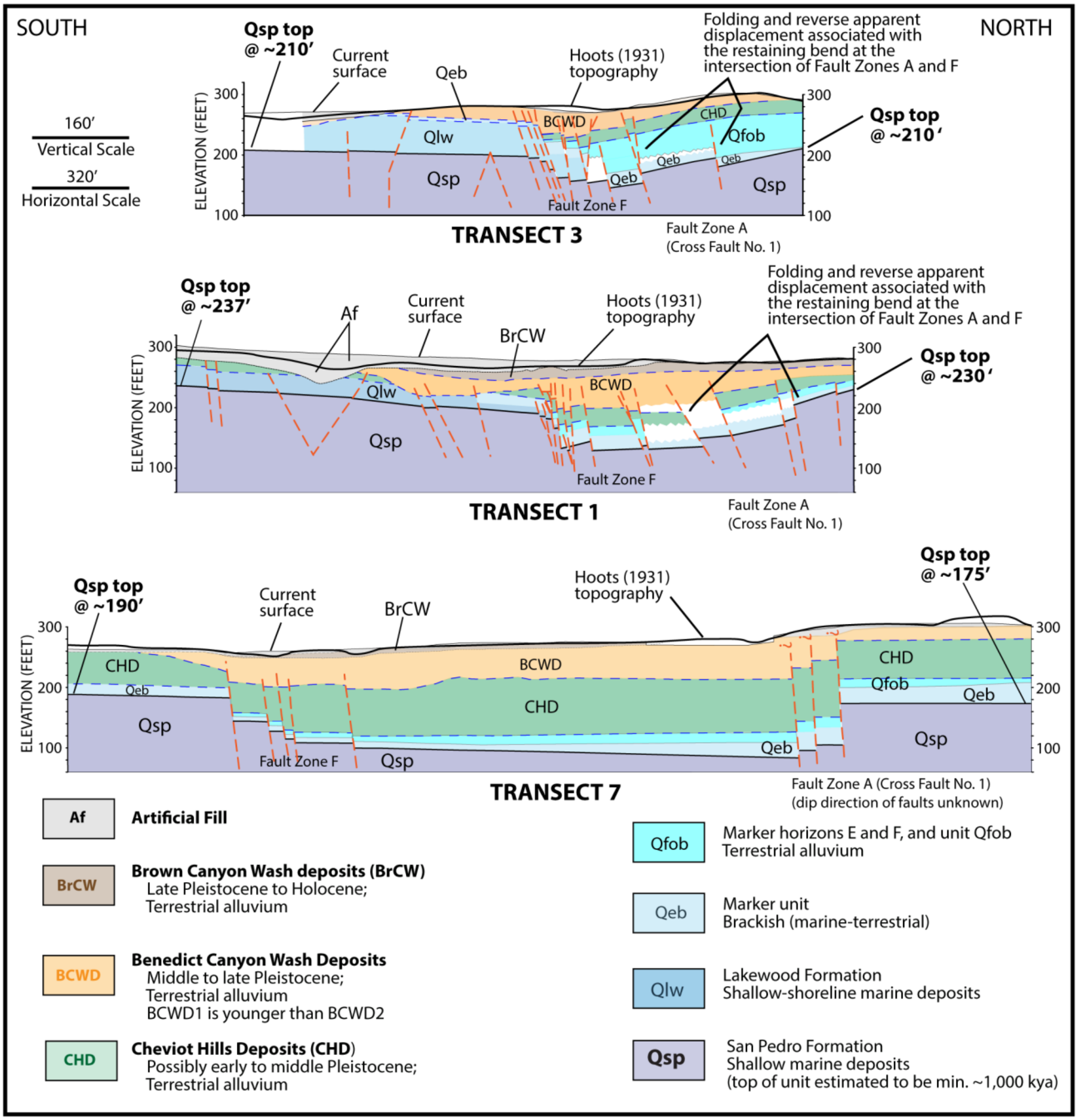


Figure 12: Simplified and modified cross sections of Transects 1, 3 and 7 from KGS (2014) showing major stratigraphic units and interpreted faults across the Santa Monica Boulevard Fault Zone in Century City. The location of the Transect cross sections is provided on Figure 11. Note the general expression of a negative "flower structure" across the Santa Monica Boulevard Fault Zone (Fault Zones A and F) produced a graben type structure, and that nearly zero vertical apparent displacement of the top of the San Pedro Formation occurs across all transects (north to south).

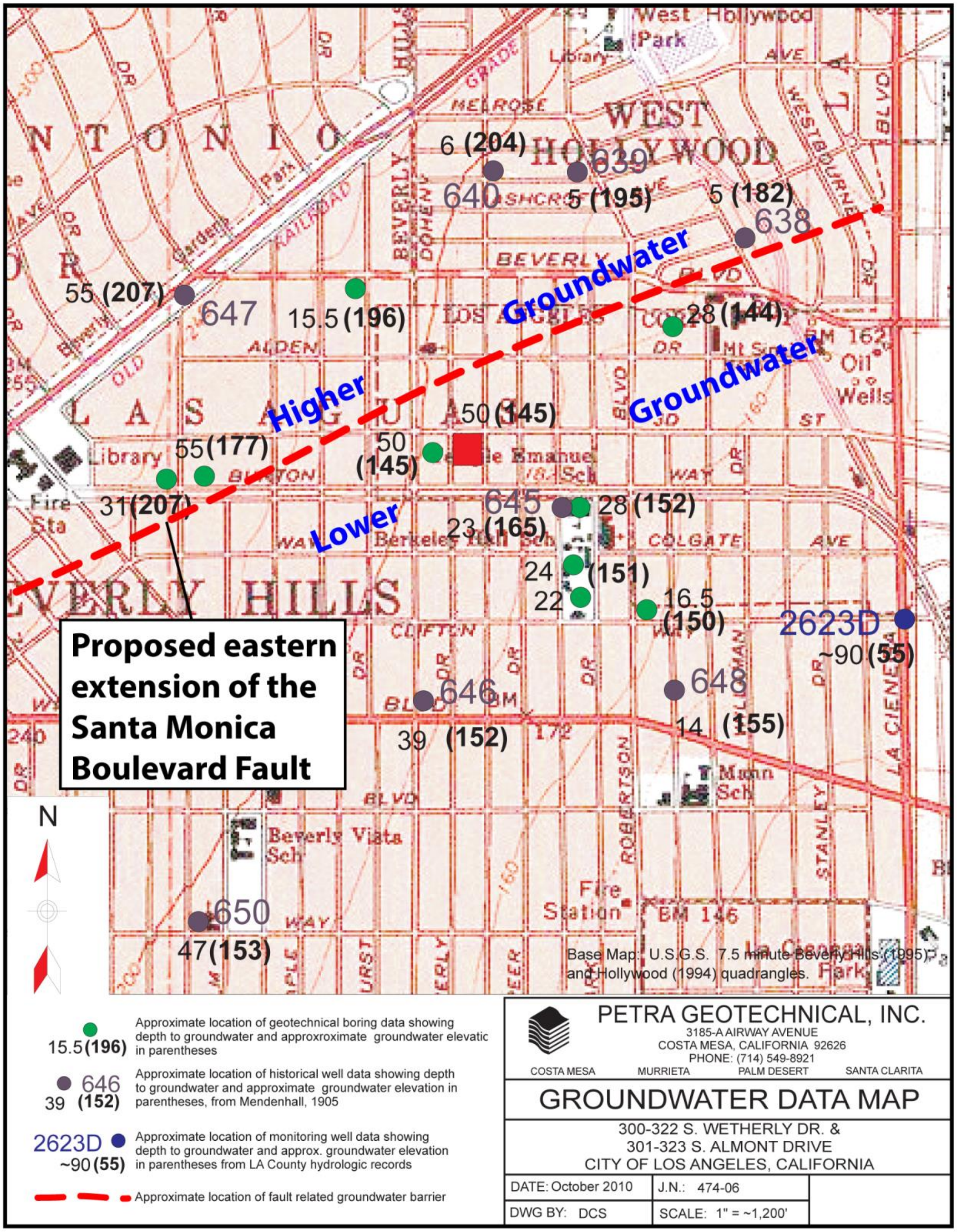


4.3 Lateral extent of the Santa Monica Boulevard Fault

The Santa Monica Boulevard Fault has been identified in the Cheviot Hills between the Mormon Temple and Century City (KGS, 2012, 2014) and proposed to extend eastward across Moreno Creek along the southern boundary of the Hollywood Basin (Figure 7; KGS, 2014). In this region the fault zone, referred to as Fault Zone F (Figure 11) in KGS (2012, 2014), trends approximately N55E, dips steeply to the north, and exhibits dominantly left-lateral strike-slip displacement. MACTEC (2010b) identified a steeply north dipping fault zone (~3 strands) at the Mormon Temple that is included here as the Santa Monica Boulevard Fault (Figure 7). Petra Geotechnical Inc. (Petra; 2010) identified a groundwater drop (south side down) across a zone in a region east of Moreno Creek (Benedict Canyon Wash) and proposed that a fault striking approximately N62E to N69E occurred in the area (Figure 13). The Petra fault is on strike with the Santa Monica Boulevard Fault and it is interpreted herein as an eastern extension of this fault zone.

Farther to the east, the Santa Monica Boulevard Fault is proposed to connect with the steeply north-dipping, N65E striking fault identified along the northern boundary of the San Vicente oil field (California Division of Oil and Gas, 1974, pg. 456). The fault shown bounding the San Vicente oil field is shown to be reverse, however, this report assumes that this fault was re-activated as a dominantly left-lateral strike-slip fault in the early to mid-Pleistocene similar to the re-activation proposed for the Santa Monica Boulevard Fault relative to the Santa Monica Fault North in the Cheviot Hills. Additional data supporting the extension of the Santa Monica Boulevard Fault east of the Cheviot Hills is from the INSAR modeling provided by Earth Consultants International (ECI). Their analysis identified a subsidence bowl that coincides with the boundary between the west-southwest trending Hollywood Basin (western portion) and the northwest trending Beverly Hills sub-basin to the south (Figure 14). Historical subsidence data shown as average annual rates of elevation change measured from 1925 to 1938 (Castle and Yerkes, 1976) also suggest that the Santa Monica Boulevard Fault extends to the northwestern Salt Lake Oil Field (Figure 14) and may step southeastward to the North Salt Lake Fault (Figure 15), which is discussed in more detail in the next section.

Figure 13: Groundwater data map from Petra Geotechnical Inc. (2010) showing their interpretation of a proposed fault based on a groundwater drop in the western Hollywood Basin. This fault is proposed to be the eastern extension of the Santa Monica Boulevard Fault.


6 (204)
640
639
5 (195)
5 (182)
638
55 (207)
647
15.5 (196)
Groundwater
28 (144)
Higher
Groundwater
50 (145)
55 (177)
50
(145)
31 (207)
645
28 (152)
23 (165)
Lower
24
(151)
22
16.5
(150)
2623D
~90 (55)
Proposed eastern extension of the Santa Monica Boulevard Fault
646
39 (152)
648
14 (155)
N
650
47 (153)
Base Map: U.S.G.S. 7.5 minute Beverly Hills (1995) and Hollywood (1994) quadrangles.
15.5 (196) Approximate location of geotechnical boring data showing depth to groundwater and approxroximate groundwater elevatic in parentheses
646
39 (152) Approximate location of historical well data showing depth to groundwater and approximate groundwater elevation in parentheses, from Mendenhall, 1905
2623D
~90 (55) Approximate location of monitoring well data showing depth to groundwater and approx. groundwater elevation in parentheses from LA County hydrologic records
Approximate location of fault related groundwater barrier
PETRA GEOTECHNICAL, INC.
3185-A AIRWAY AVENUE
COSTA MESA, CALIFORNIA 92626
PHONE: (714) 549-8921
COSTA MESA MURRIETA PALM DESERT SANTA CLARITA
GROUNDWATER DATA MAP
300-322 S. WETHERLY DR. &
301-323 S. ALMONT DRIVE
CITY OF LOS ANGELES, CALIFORNIA
DATE: October 2010
J.N.: 474-06
DWG BY: DCS
SCALE: 1" = ~1,200'

4.3.1 The Santa Monica Boulevard and North Salt Lake Fault System

Understanding that the Santa Monica Boulevard Fault Zone was a dominantly left-lateral strike-slip fault created approximately 1 Ma provides insights regarding the style of faulting and kinematics of the Hollywood and North Salt Lake Fault Zones to the east. It is proposed that the Hollywood Fault and North Salt Lake Fault also underwent a change in slip history similar to the change in slip history for the Potrero Canyon and the Santa Monica Boulevard Fault System. The Hollywood Fault Zone transitioned at this time from an oblique reverse left-lateral fault zone to a dominantly left-lateral strike-slip fault zone. Similarly, the North Salt Lake Fault Zone transitioned or was re-activated from a dominantly normal dip-slip fault to a dominantly left-lateral strike-slip fault.

In this model, the North Salt Lake Fault located along the southern boundary of the eastern Hollywood Basin is the eastern extension of the Santa Monica Boulevard Fault Zone. Tsutsumi et al. (2001), evaluating well data, suggests that the North Salt Lake Fault may extend westward all the way to the eastern Cheviot Hills but that insufficient well data exists to fully evaluate the westward extent of the North Salt Lake Fault. In the model presented herein, the North Salt Lake Fault does not extend to the Cheviot Hills, but instead steps over to the Santa Monica Boulevard Fault allowing the most recent phase of deformation associated with the North Salt Lake Fault to extend to and westward through the Cheviot Hills via a dominantly left-lateral strike-slip fault system (Figure 27).

Wright (1991) indicates that the North Salt Lake Fault exhibits approximately 300 meters of normal component of displacement of Pliocene age sediments. Wright (1991) also provides data indicating that soil horizons identified in geotechnical borings are displaced near the surface by the North Salt Lake Fault. The boring data and possible fault scarps suggest that the North Salt Lake Fault was active sometime in the mid- to late Pleistocene. Hill et al., (1979) provided groundwater, stratigraphic and subsidence data suggesting that the North Salt Lake Fault extends to relatively shallow depths, presumably displacing sediments with a minimum age of mid-Pleistocene. Hummon (1994) indicates that there is insufficient evidence to evaluate the Quaternary activity of the North Salt Lake Fault, but that the fault may have had a left-lateral strike-slip history. Historical subsidence data (Figure 19) and isochore maps of fresh water aquifers (see Figure 27) suggest that the North Salt Lake Fault extends up into water bearing Pleistocene sediments suggesting that the North Salt Lake Fault was active during the Quaternary (Pleistocene). If the North Salt Lake Fault is the eastern segment of the Santa Monica Boulevard Fault, the North Salt Lake Fault may also have become inactive approximately 200 thousand years ago.

Wright (1991) examined relatively shallow geotechnical borings (tens of feet) to identify offset soil contacts along the strike of the surface projection location of the structure contour fault plane at depth (Figure 32). The offset soil contacts occur immediately above where the North Salt Fault plane is indicated to be 0.5 km deep (Figure 32). This suggests that a younger fault strand of the North Salt Lake Fault developed in the hanging wall of the North Salt Lake Fault. A similar structural history is proposed herein for the development of the Potrero Canyon Fault overlying the Santa Monica Fault South, and the Santa Monica Boulevard Fault overlying the Santa Monica Fault North shown on Figure 6. In all of these instances a younger, steeply dipping, and shallow (near surface) fault connects at depth with an older fault and the younger fault displays a different style of displacement reflecting the transition from oblique to dominantly left lateral strike-slip.

The Santa Monica Fault North and Santa Monica Fault South of Wright (1991) exhibited reverse left-lateral slip in the Pliocene to possibly early Pleistocene, and the North Salt Lake Fault exhibited normal (left-lateral too?) displacement. The displacement style of these faults changed during the early Pleistocene to dominantly left-lateral, which led to the development of a new steeper dipping fault to emanate from the deeper older fault to the surface, the Potrero Canyon and Santa Monica Boulevard fault zones.

The eastern Santa Monica Boulevard Fault and North Salt Lake Fault may not connect as a single continuous fault zone. As mapped, the western North Salt Lake Fault would have to step right (north) in the region of the northwestern Salt Lake Oil Field to connect with the Santa Monica Boulevard Fault, along the north side of the San Vicente Oil Field (Figure 14). The right step-over would form a restraining bend in a left-lateral fault zone that may have deformed the northwestern Salt Lake Oil field during left-lateral motion across the Santa Monica Boulevard Fault – North Salt Lake Fault System. Hummon et al. (1994) shows a cross section (Figure 21) that extends approximately north-south through this right-step (see Figure 20 for cross section location). Although Hummon et al. (1994) did not show the North Salt Lake Fault in cross section A-A' (Figure 21), the structures and location of well data in section A indicate that step-over deformation occurs.

Figure 14: Modified InSAR modeling of a subsidence bowl in the Beverly Hills area east of the Cheviot Hills referred herein as the Beverly Hills Sub-basin. This sub-basin is located above a Holocene age syncline shown by Wright (1991, see Figure 37). This syncline is the eastern counterpart of the northward anticline in the southern Cheviot Hills (labeled as ANTICLINE in white lettering) and both are proposed to have resulted primarily from compression associated with the Newport-Inglewood Fault plus left-lateral motion on the Santa Monica Boulevard Fault Zone between approximately 1 to 0.2 Ma, and subsequent left-lateral motion across the Potrero Canyon Fault East (PCFe) since approximately 0.2 Ma (see text for details). This suggests that the southern Cheviot Hills anticline is still active in the southern most Cheviot Hills, and is inactive in the northern portion of the southern Cheviot Hills. CHOF – Cheviot Hills Oil Field, SLOF – Salt Lake Oil Field, SOF – Sawtelle Oil Field, WBHOF – West Beverly Hills Oil Field, EBHOF – East Beverly Hills Oil Field. White "U" and "D" represent regions/areas of Uplift and Downward motion respectively. The white "Ua" represents the area of uplift of the southern Cheviot Hills Anticline south of the proposed Potrero Canyon Fault East. InSAR based map provided by Earth Consultants International.

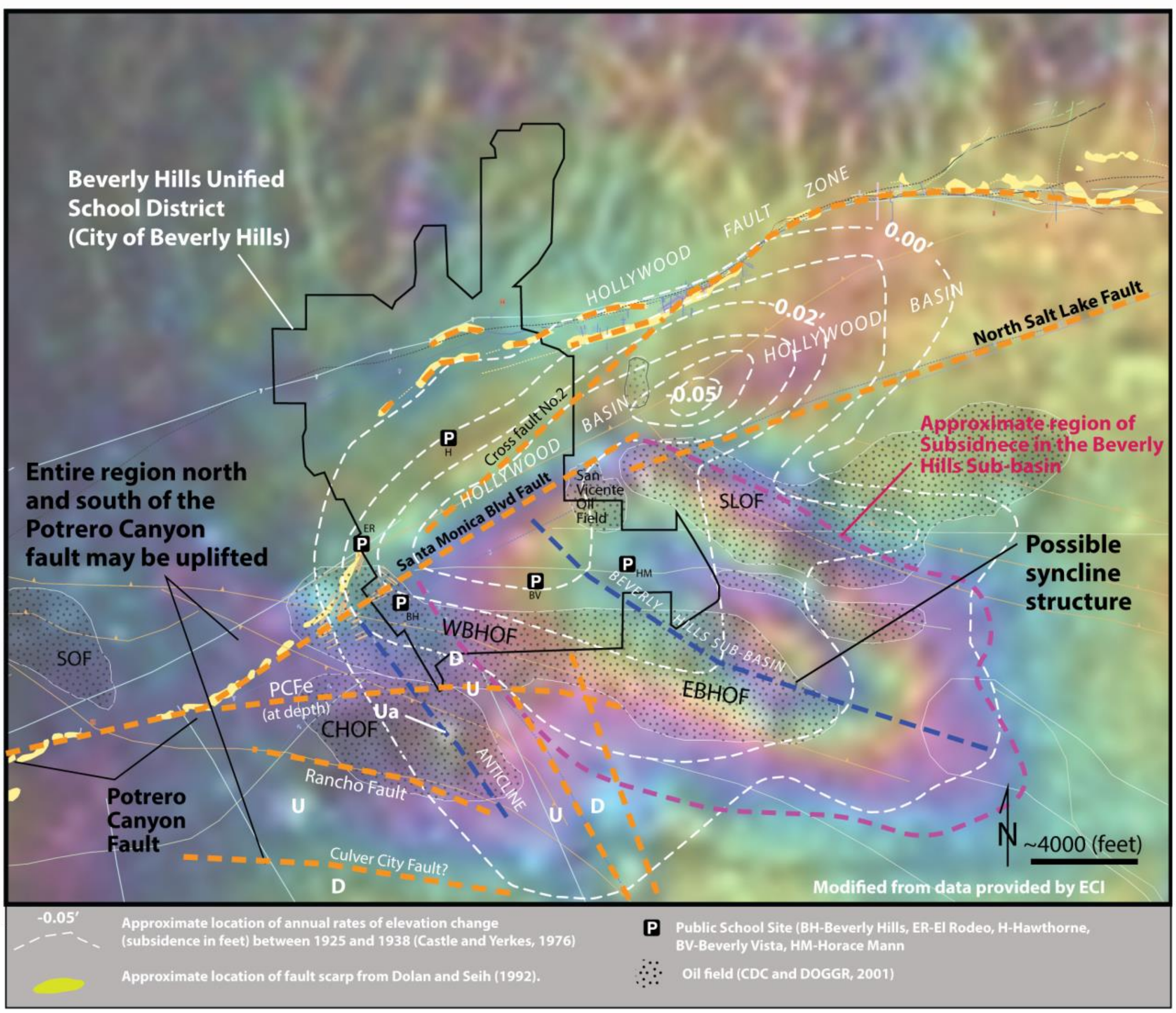
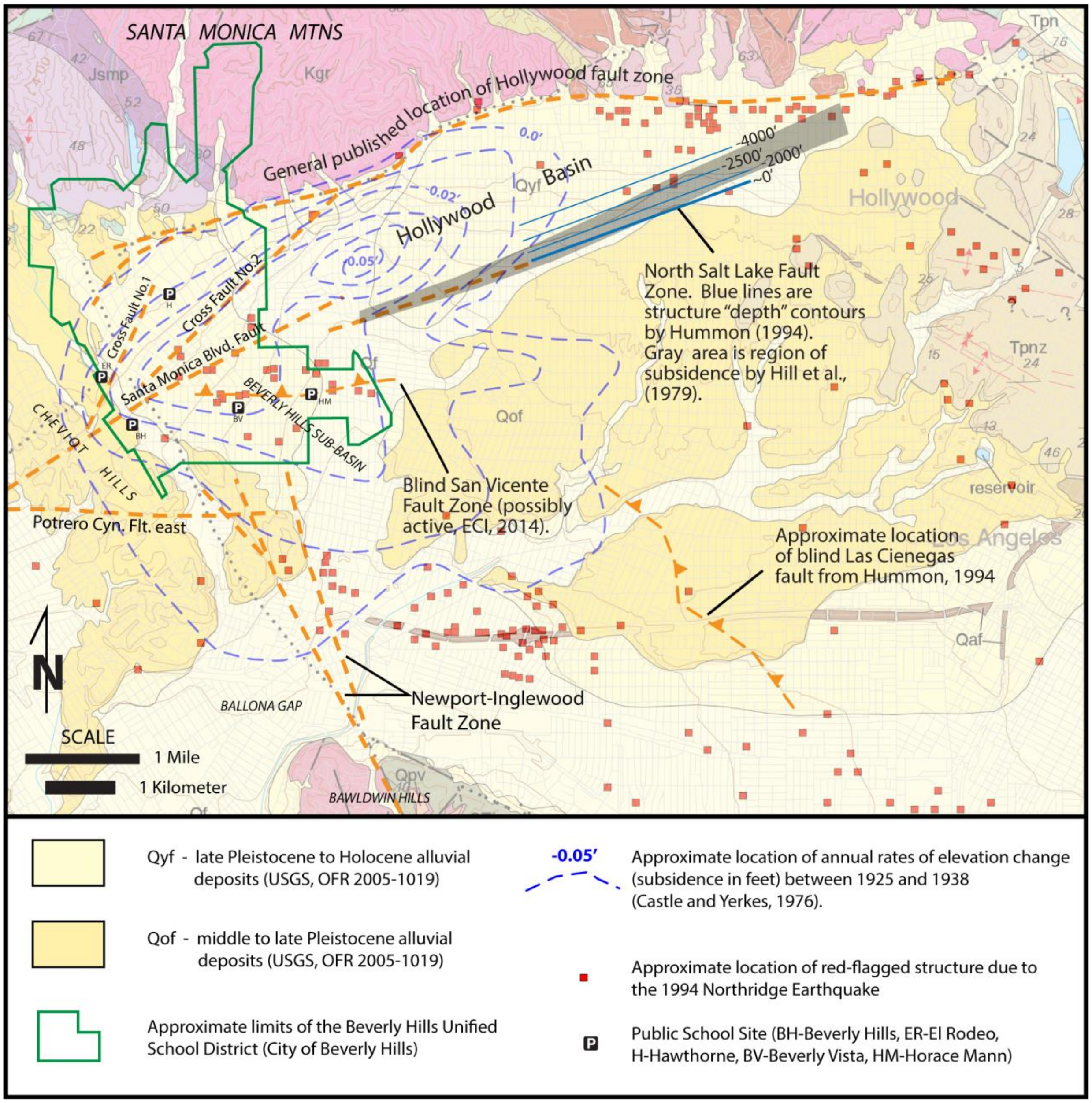


Figure 15: Geologic Map of the Cheviot Hills and Hollywood Basin region showing subsidence data from Castle and Yerkes (1976) that delineates the approximate limits of the Hollywood Basin and Beverly Hills Sub-Basin.



4.3.2 Westward lateral extent of the Santa Monica Boulevard Fault

The western extent of the Santa Monica Boulevard Fault System forms a connection with the eastern Potrero Canyon Fault of Wright (1991) near the Mormon Temple. As discussed earlier, the Potrero Canyon Fault is more commonly referred to as the Santa

Monica Fault (Dolan et al., 1995; Dolan and Pratt, 1997; Dolan et al., 2000a; Tsutsumi et al., 2001; Catchings et al., 2008). Wright (1991) indicates that the Santa Monica Fault South (SMFS) is approximately 1 to 2 km deep beneath the Potrero Canyon Fault from the coast to approximately the Mormon Temple in the western Cheviot Hills (Figure 33). The Potrero Canyon Fault trends approximately N76E whereas the Santa Monica Boulevard Fault in the Cheviot Hills trends approximately N55E.

The turn from the Potrero Canyon Fault to the Santa Monica Boulevard Fault near the Mormon Temple occurs, not coincidentally, close to the intersection and similar turn in strike of the Santa Monica Fault South and Santa Monica Fault North of Wright (1991). The Santa Monica Boulevard Fault occurs above the location where the Santa Monica Fault North of Wright (1991) is approximately 1 km deep. It is proposed that the Santa Monica Fault South and Santa Monica Fault North at depth transitioned from oblique reverse left-lateral displacement to left-lateral displacement during the early Quaternary (~1 Ma).

In this model, the local uplifts associated with the Potrero Canyon Fault between the Veterans Administration Hospital and the coast (Potrero Canyon) are due to the more northwest strike of the fault zone, resulting in local restraining bends (Plate 3). The near surface fault structures identified by Dolan and Pratt (1997) and Pratt et al. (1998) represent a positive flower structure. At depth, Pratt et al. (1998) indicate that the Santa Monica Fault (Potrero Canyon Fault in this study) dips between 30 and 55 degrees to a depth of 300 meters, and then exhibits a steeper dip of 60 to 70 degrees at deeper depths. These variations in fault dip angle with depth may be explained by a flower structure along this segment of the Potrero Canyon Fault.

It should be pointed out that the fault identified as Potrero Canyon at the coast may very well be a landslide structure (see Wright, 1991). If true, the location of the Potrero Canyon Fault west of University High School remains uncertain, the vertical slip rate (Dolan et al., 1997) may not reflect tectonic displacement, and the youthful Potrero Canyon Fault may be blind west of the University High School.

This kinematic model is consistent with offshore faulting along the TRSB west of the City of Santa Monica. Sorlien et al. (2006) has evaluated Quaternary motion across the Malibu Coast and Dume faults to be hanging wall, dominantly left-lateral faults that connect with the “Santa Monica Fault” (Potrero Canyon Fault and Wright, 1991) onshore toward the east. Hence, the Malibu Coast and Dume Faults would be considered part of the TRSBLL in this study.

Figure 16: Map of the northern Los Angeles Basin showing structure contours of 0.8 to 1.0 Ma base of marine gravels and tectonic structures from Hummon (1994) and Hummon et al. (1994), the generalized location of the Potrero Canyon Fault, Santa Monica Fault South, Hollywood, Newport-Inglewood, North Salt Lake, San Vicente, Las Cienegas, and Elysian Park deep trace faults. Short cyan-dashed fault shown within the eastern Hollywood Basin is estimated from Hildenbrand et al. (2001). It is observed that the Beverly Hills Unified School District (BHUSD) resides in a region not exhibiting significant uplift or down dropping (subsidence) during the past ~0.8 Ma and that more significant tectonic deformation has occurred in surrounding areas. CF1 – Cross Fault No.1; CF2 – Cross Fault No.2; RF- Rancho Fault; SMBF – Santa Monica Boulevard Fault; SVF – San Vicente Fault.

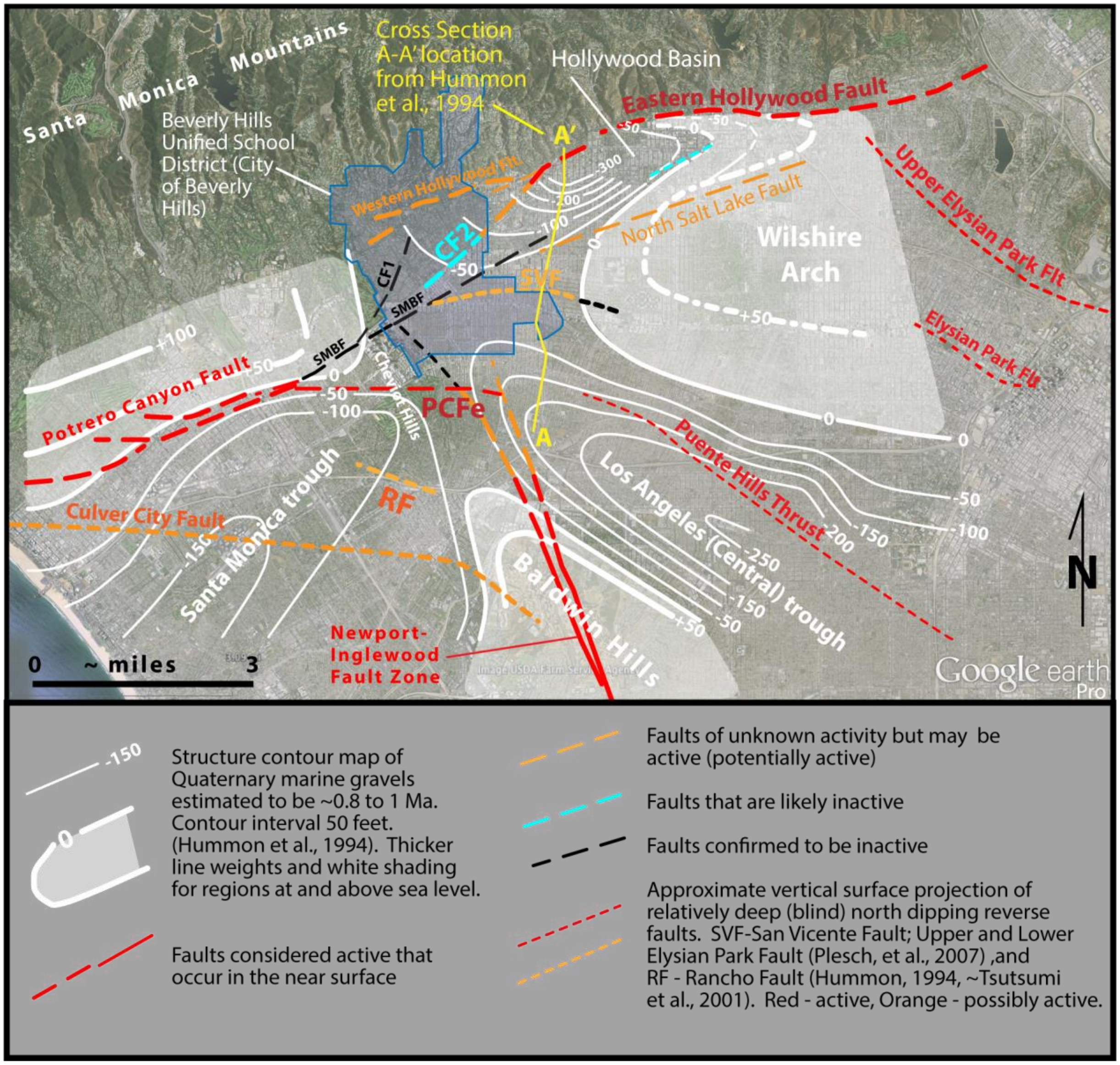
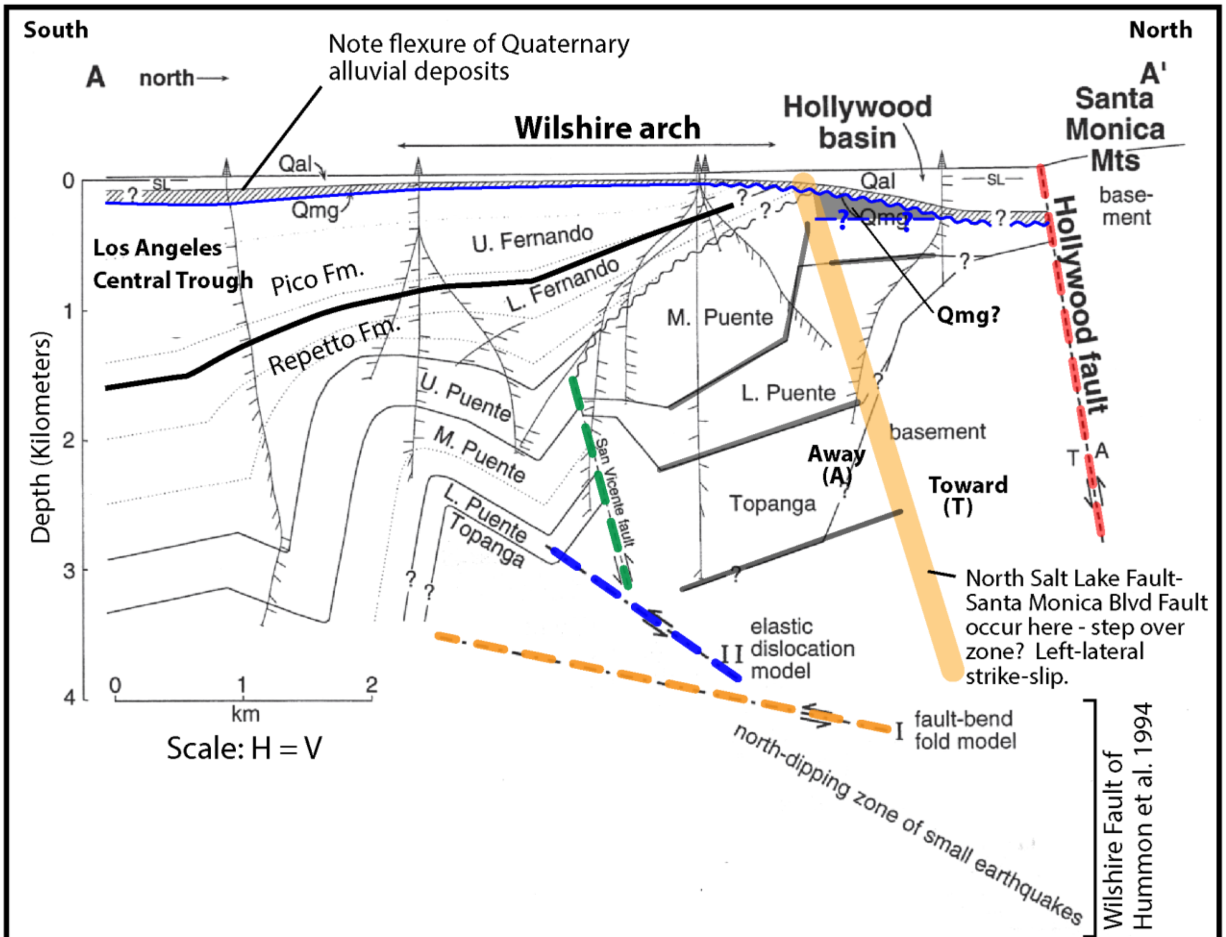


Figure 17: Modified cross section A-A' of Hummon et al. (1994) showing possible location of the North Salt Lake Fault and/or deformation zone associated with the Santa Monica Boulevard-North Salt Lake Fault step over zone. Some formational contacts are re-interpreted to demonstrate possible location of the North Salt Lake Fault and its associated apparent vertical displacement.



Question marks indicate inferred contacts. Tick marks on wells represent dipmeter data. Arrows indicate relative motion on faults. T-toward viewer; A-Away from viewer; Qmg - Quaternary marine gravesl (diagonal rule); Qal 0 Quaternary Alluvium; SL - sea level. Orange dash line shows fault-ramp location of Wilshire fault as determined by geometric fault-bend fold model (based on Suppe, 1983). Dashed blue line shows Wilshire fault location as determined by elastic-dislocation model. Green dashed line is the San Vicente fault. Red dashed line is the Hollywood fault. Possible location of the North Salt Lake fault or deformation associated with the step over of the North Salt Lake fault to the Santa Monica Boulevard fault shown as thick orange line.

Industry seismic reflection data show the offshore blind Santa Monica-Dume Fault to dip moderately north (Sorlien et al., 2006). They also indicate that compressional strain is accommodated by a deeper, blind thrust that extends beneath and south of the TRSBLL (Santa Monica Bay Fault of Sorlien et al., 2006). However, it is unclear whether or not the blind Santa Monica Bay Fault is active. Sorlien et al. (2006) show an approximately 1 Ma surface deformed by their blind Santa Monica-Dume Fault, and a ~75 kya surface apparently not deformed. These findings are consistent with those of Pinter et al. (1998; 2001) and Pinter and Sorlien (1991) for the Santa Cruz Island Fault that evaluated faulting along the TRSB in the Channel Islands region. These findings are also consistent with the early to late Quaternary tectonic history for the Santa Monica Fault South and North representing inactive oblique reverse left-lateral faults. Therefore, it appears that the kinematic model presented in this report for the Cheviot Hills for the past 2 million years onshore also occurred offshore. This topic is discussed in more detail later in this report.

4.3.3 The SMBF and Hollywood Fault connectivity and faulting in the Hollywood Basin area

The Hollywood Fault occurs approximately along the base of the Santa Monica Mountains and the northern edge of the Hollywood Basin (Plate 3). Dolan et al. (1997; 2000b) determined that an early Holocene event has occurred on the eastern Hollywood Fault. Dolan et al. (1997) concluded that the “eastern” Hollywood Fault is a strike-slip left-lateral fault zone based on subsurface data that showed juxtaposing dip-slip apparent displacements. It is proposed that the complex dip-slip separations across the eastern Hollywood Fault Zone may be associated with its nearly east-west trend which is restraining along the general left-lateral strike of the Transverse Ranges Southern Boundary System “left-lateral” (TRSBLL). In this model, the northeast trending portion of the Hollywood Fault west of the area Dolan et al. (1997) investigated would likely exhibit a more left-lateral style of displacement (Plate 3). These two regions of the Hollywood Fault are referred to herein as the “eastern” and “western” Hollywood Fault (Plate 3).

It is proposed that the western Hollywood Fault Zone splays toward the southwest and that these fault splays extend across the western Hollywood Basin (Plate 3; KGS, 2012). The proposed faults would essentially provide the structural connection between the Hollywood and Santa Monica Boulevard Fault Zones. Two possible faults connecting the Hollywood and Santa Monica Fault Zones in the western Hollywood Basin are referred to as Cross Fault No. 1 and Cross Fault No. 2 (Plate 3). Cross Fault No. 1 is also Fault Zone A in KGS (2012, 2014; Figure 11).

Although neither of these faults has been positively identified across the western Hollywood Basin at depth, Fault Zone A (Cross Fault No. 1) has been identified from high-density continuous core and CPT data in the Cheviot Hills (Parsons, 2011; Geocon, 2014; KGS, 2014; LCI, 2015). This fault zone has been demonstrated to be inactive from recent studies within and near the El Rodeo middle school (LCI, 2016; LCI, 2015; ECI, 2015). In this area, the magnitude of apparent dip-slip displacement of the approximately 1 million year old San Pedro Formation (upper members) across Fault Zone A (Cross Fault No. 1) is tens of feet suggesting that Fault Zone A likely continued northeastward across the Moreno Creek (Benedict Canyon Wash) and into the western Hollywood Basin (KGS, 2014; Plate 3). The apparent dip-slip separation of the upper contact of the San Pedro Formation (~75 feet) across Fault Zone A is constant from its southwest end near Santa Monica Boulevard to the El Rodeo middle school. Fault Zone A exhibits a modified fault scarp (partly eroded by fluvial deposits, KGS, 2011) over 35 feet tall in the Los Angeles Country Club that formed soon after deposition of upper Benedict Canyon Wash Deposits older member (BCWD2), sometime between 580 to 350 kya (age of the Qt-BC2 fan-terrace).

Toward the northeast across Moreno Creek, Cross Fault No. 1 does not exhibit any geomorphic expression, and in this area, sediments that are approximately 40 to 70 kya occur at depths of only 10 to 15 feet (LCI, 2016). This confirms that Cross Fault No. 1 is inactive.

Cross Fault No. 2 is proposed to extend from the area of the central Hollywood Fault Zone across the western Hollywood Basin to connect with the Santa Monica Boulevard Fault (Plate 3). Numerous fault investigations in the central Hollywood Fault Zone have interpreted various strands, some of which were determined to be active (Plate 3; see Hernandez and Treiman, 2014). One fault strand, identified as Fault No. 1 by work conducted by Lettis Consultants International (see Hernandez and Treiman, 2014 for review) trends N46E, extends across the trend of the typical orientation of the Hollywood Fault, and projects southwesterly across the western Hollywood Basin.

In addition, several fault investigations indicate that the main “Hollywood Fault Zone” likely resided south of their investigations (see Hernandez and Treiman, 2014 for review). It is proposed that the Fault No. 1 of Lettis Consultants International investigation may extend across the western Hollywood Basin (see Cross Fault No. 2, Plate 3). Along the trend of Cross Fault No. 2 there is a subtle change in slope (inflection point) across the alluvial fan observed on the Hoots (1931) geologic map (Plate 3), which generally coincides with Santa Monica Boulevard. Mendenhall (1905) shows a region of near saturated conditions immediately south of this Cross Fault No. 2 and north of the Santa Monica Boulevard Fault (Plate 3) indicating a possible fault bounded region (Plate 3). Cross Fault No. 2 also trends parallel to annual subsidence rates of elevation change lines shown by Castle and Yerkes (1976; Figure 15).

West of the intersection of Cross Fault No. 2 and the Hollywood fault, Dolan and Sieh (1992) and Dolan et al. (1997) identified a series of geomorphic slopes believed to be fault scarps associated with the Hollywood Fault. The identification of the scarps by Dolan et al. (1997) as fault scarps is reasonable. However, numerous fault investigations of the western Hollywood Fault (Plate 3) have failed to identify active fault strands associated with the Hollywood Fault in the near surface. This suggests that the western Hollywood Fault Zone may be inactive.

A geomorphic analysis conducted by KGS (2011) suggested that a strand of the Hollywood Fault may have extended into the northern Cheviot Hills as a blind fault. Data to support this is the interpreted deformed preserved fan-terraces in the northern Cheviot Hills shown on Figure 7 that are a minimum of 580 to 350 kya (Figure 7). Hoots (1931) mapped a fault zone near the base of the Santa Monica Mountains in the northern most Cheviot Hills (Plate 3). This fault trends toward the northeast-east and was shown to offset Miocene Modelo Formation, but not the overlying alluvium. As pointed out by Crook and Proctor (1992), the southwest projection of this fault lines up with a fault striking N63E identified at UCLA that places Miocene Modelo Formation over Pleistocene older alluvium (Plate 3). It is possible that the proposed blind Hollywood fault strand in the northern Cheviot Hills was active as an oblique left-lateral reverse fault prior to the tectonic transition in the region occurring approximately 1 Ma to 800 kya when the Hollywood Fault-Santa Monica Boulevard Fault-Potrero Canyon Fault System switched to primarily left-lateral (see report for details). In this model, the western Hollywood Fault Zone became inactive and left-lateral motion occurred on the newly developed Cross Fault No. 1 and Cross Fault No. 2, which would have assisted in the development of the western Hollywood Basin and the West Beverly Hills Lineament. However, note that Cross Fault No. 1 and the Santa Monica Boulevard Fault Zones both became inactive between 200 and 150 kya (LCI, 2012a; Geocon, 2013; LCI, 2015).

4.4 Left-lateral strike-slip displacement and slip rate evaluation

This section provides findings for estimates of the early to mid-Pleistocene left-lateral displacement and slip rate of the Santa Monica Boulevard Fault in the Cheviot Hills. The Santa Monica Boulevard Fault is estimated to have become active and essentially been created between 1 to 0.75 Mya, and then become inactive approximately 200 kya, however the initiation age for the Santa Monica Boulevard Fault is poorly constrained in terms of evaluating accurate total displacement values.

The Potrero Canyon Fault to the west formed at approximately the same time (~0.9 Ma; based on evaluation of data provided in Tsutsumi et al., 2001) as the Santa Monica Boulevard Fault but has apparently remained active. Hence, there are clear complications in evaluating slip rate and total displacement values for the Santa Monica

Boulevard Fault-Potrero Canyon Fault System, but the exercise of the calculations is insightful in a number of ways. The analysis does indicate that the estimated total left-lateral displacement values are consistent with total apparent vertical displacement of Miocene to Quaternary age sediments along the Potrero Canyon Fault associated with the local restraining bend along this fault segment as evaluated on cross sections by Tsutsumi et al. (2001).

If it is presumed that the slip rate of the Santa Monica Boulevard Fault - Potrero Canyon Fault System is similar to the slip rate observed for other left-lateral fault segments along the Transverse Ranges Southern Boundary System Left-lateral (TRSBLL), which is about 1.5 to 2.0 mm/yr, then the results provided below suggest that the fan-terraces in the Cheviot Hills (Qt-BC2) may be over a half million years old (i.e. ~580 kya). This finding suggests that tectonic strain rates in the area, for example uplift rates of the southern Cheviot Hills, are slower than originally estimated by KGS (2014). In addition, the left-lateral evaluation of the Santa Monica Boulevard Fault also suggests that the Benedict Canyon Wash younger deposit (BCWD1, Qt-BC1) discussed in KGS (2012, 2014) is likely older than previously reported (KGS, 2014), and that it may have been fed primarily by Brown Canyon Wash west (Figure 18).

Reconstructing relatively major and minor drainages within the Cheviot Hills across the Santa Monica Boulevard Fault allows an estimate of the magnitude of total displacement since the creation of the drainages. The age of the drainages is estimated to be the same as the age of the preserved fan-terraces in the central and southern Cheviot Hills. These fan-terraces are designated as the Qt-BC2 surfaces in the KGS (2014) report and represent the upper member of the older Benedict Canyon Wash Deposits older (BCWD2; Figure 22). The soil associated with this surface is referred to as Soil Marker A (Figure 22). This soil was estimated to be 400 to 350 kya (KGS, 2014), but as discussed below, is likely older and in the range of ~580 to 320 kya (average of ~450 kya).

This analysis also raises the question as to whether or not currently unrecognized deformation may be occurring associated with the Santa Monica Boulevard Fault being inactive and the Potrero Canyon Fault remaining active. Namely, this analysis among others in this report lead to the identification that a new left-lateral strike-slip fault is developing in the southern Cheviot Hills, referred herein as the Potrero Canyon Fault east (see Figure 26). Within this report, the Potrero Canyon and its eastern extension to the Potrero Canyon Fault east are referred to as the Potrero Canyon Fault System, which has been the zone of left-lateral slip along this segment of TRSBLL during the past several hundred thousand years.

4.4.1 Left-lateral strike-slip displacement of channels in the Cheviot Hills across the SMBF

This section provides an analysis of left-lateral strike slip displacement of the Santa Monica Boulevard Fault and the Potrero Canyon Fault. To assist the reader, a summary of the results and insights of this section include:

- The Potrero Canyon-Santa Monica Boulevard Fault Zone System accommodated between 1.18 and 0.64 km of left-lateral strike-slip motion during the past 580 kya.
- The Potrero Canyon-Santa Monica Boulevard Fault Zone System accommodated a total of approximately 2.43 to 1.35 km total displacement since their inception 900 kya.
- The older Benedict Canyon Wash Deposits (BCWD2) fan-terraces in the central Cheviot Hills are a minimum of 580 kya. This unit and the local drainages in the Cheviot Hills are considerably older than originally proposed by KGS (2014).
- The left-lateral slip rate of the Santa Monica Boulevard Fault is in the range of 1.6 to 2.7 mm/yr, but likely closer to the 1.6 mm/yr estimate.
- Provided additional evidence that the Potrero Canyon Fault is youthful having developed approximately 1 Ma.
- All of the apparent reverse dip-slip displacement observed on the Potrero Canyon Fault can be explained by restraining bend compression associated with a change in strike of the Potrero Canyon Fault along the TRSBLL

Left-lateral displacement values across the Santa Monica Boulevard Fault were evaluated based on reconstructing potentially offset drainages within the Cheviot Hills utilizing the topographic-geologic map of Hoots (1931). A total of 7 local south flowing drainages (A through G on Figure 18 and Figure 19) were identified north of the SMBF that presumably cross the fault within the Cheviot Hills. Drainages A, C, F, and G, are considered relatively major because their headwaters occur in the Santa Monica Mountains to the north. Some of these major drainages were previously identified by Jerry Treiman of the California Geological Survey (personal communication), and during independent conversations between the author and Eldon Gath of Earth Consultants International. These early propositions of left-lateral offset within the Cheviot Hills across the Santa Monica Boulevard Fault correlated major drainages and the readily apparent outside edges of the Cheviot Hills, and in particular, the western edge, that exhibit a clear apparent left-lateral offset along Santa Monica Boulevard.

From west to east, the major drainages A, C, F and G coincide with Stope Canyon Wash, Brown Canyon Wash (west), Brown Canyon Wash (east), and Benedict Canyon Wash (modern Moreno Creek) respectively. Major drainages A and G delineate the western and eastern edges of the Cheviot Hills (Figure 22). Drainages B, D and E are considered relatively minor because their headwaters occur within the northern Cheviot Hills. The analysis identified two reasonable fault displacement reconstructions, which are assumed to estimate minimum and maximum displacement values since the age of the local fan-terrace abandonment of the Qt-BC2 surface. These include: Fault Displacement Model 1 (1.18 km) and Fault Displacement Model 2 (0.64km) as discussed in the following sections.

The Qt-BC2 fan-terrace surface in this region is evaluated to be faulted and overlain by the younger ~120 kya+ Benedict Canyon Wash (BCWD1) deposits (see KGS, 2014; Figure 22). As shown in Figure 22 utilizing John Helms (2012) data, the uppermost soil of the BCWD1 is estimated to be 235 to 113 kya (average of 170 kya), with a total cumulative age for the unit of 480 to 251 kya (average of 370 kya). This indicates that the BCWD1 likely ceased deposition around the time of cessation of activity of the Santa Monica Fault Zone, and initiated deposition during uplift of the Cheviot Hills and left-lateral motion across the Santa Monica Fault Zone. This indicates that multiple drainages fed the ancestral BCWD1 paleo-channel (Figure 18).

Fault Displacement Model 1

This model reconstructs left-lateral fault-slip by moving the northern Cheviot Hills north of the Santa Monica Boulevard Fault, toward the northeast parallel to the strike of the Santa Monica Boulevard Fault to align the approximately north-south trending western limits of the Cheviot Hills coinciding with major drainage A (Figure 18, Diagrams A and B). This produced a net left-lateral displacement of 1.18 km (Figure 18, Diagram B). The Model 1 reconstruction also aligned major drainage C with a major drainage in the southern Cheviot Hills, and minor drainages B and D north of the Santa Monica Boulevard Fault with drainages to the south and major drainage G with the eastern edge of the southeastern Cheviot Hills. Minor drainage E and major drainage F (Brown Canyon Wash east) in the model's reconstruction flows into a lowland south of the Santa Monica Boulevard Fault that resulted from local faulting along Fault Zones A, F, and H (Figure 11, Diagram B).

This analysis indicates that major drainage C associated with Brown Canyon Wash west was the dominant source of sediments during the early stages of deposition of the younger Benedict Canyon Wash Deposits younger (BCWD1; Figure 18, Diagram B). Model 1 indicates that as left-lateral motion continued across the Santa Monica

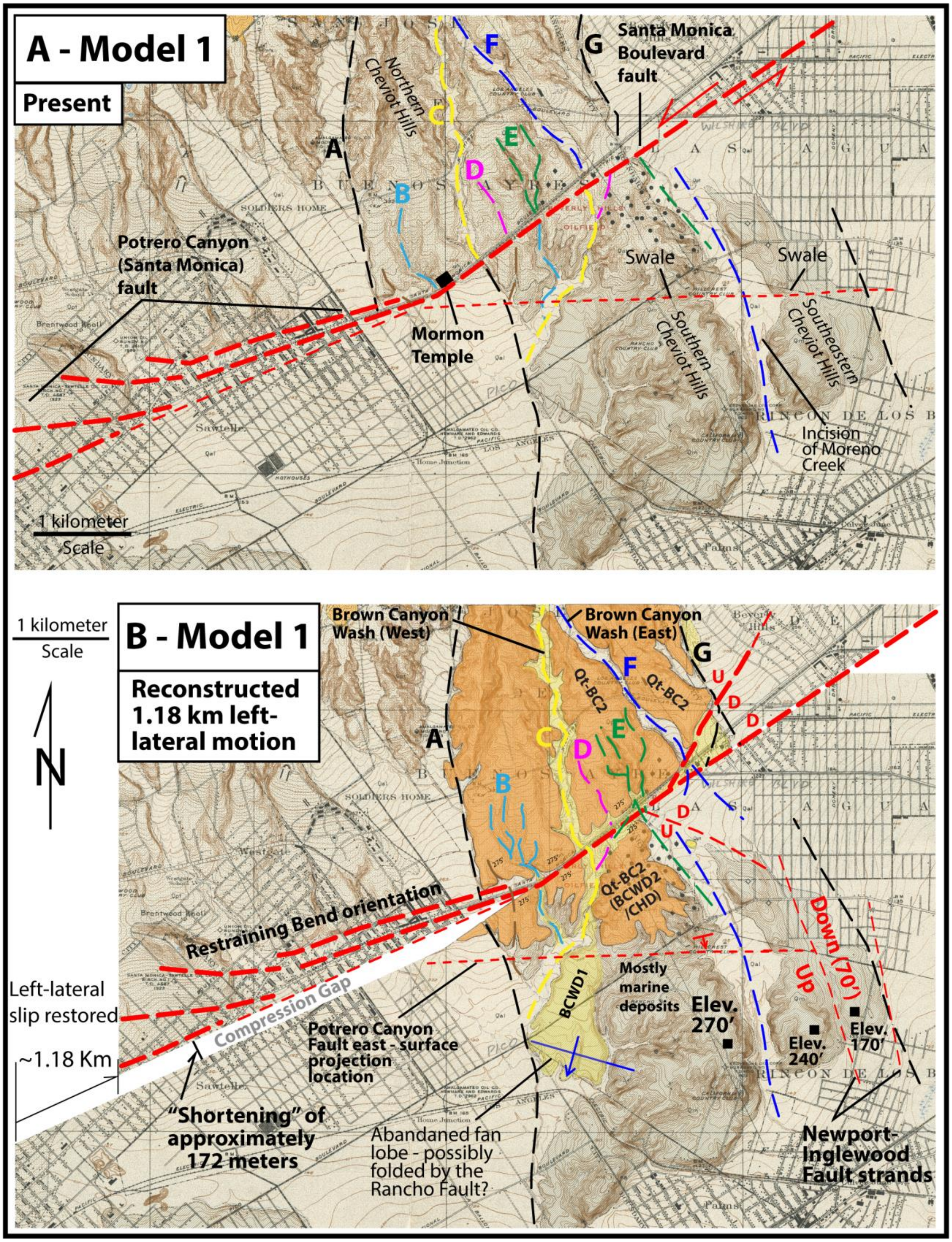
Boulevard Fault, that drainages E and F began to provide sediments into the BCWD1 paleo-channel possibly during its latter stages of deposition.

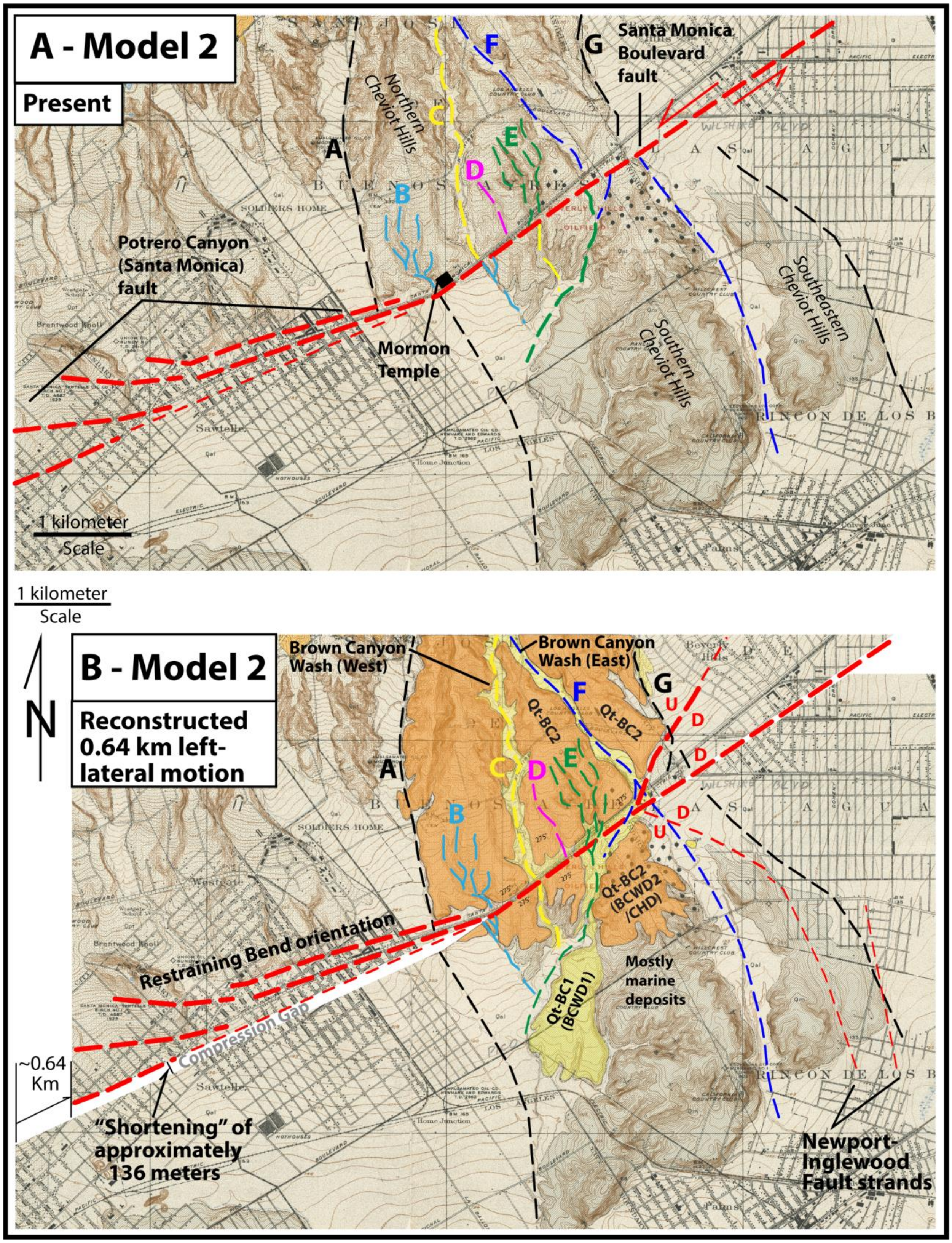
Fault Displacement Model 2

This model reconstructs left-lateral fault slip across the Santa Monica Boulevard Fault by moving the northern Cheviot Hills to align the major and relatively linear drainage F (Brown Wash east) with the antecedent drainage along the eastern edge of the Cheviot Hills (Figure 19, diagrams A and B). This results in approximately 0.64 km of left-lateral displacement across the Santa Monica Boulevard Fault. Minor drainage B aligns fairly well with a minor drainage to the south. Major drainage C aligns with a moderately developed drainage south of the fault that in this model would have provided sediments to the BCWD1 paleo-channel. Minor drainage D terminates in an elevated area south of the fault in a region exhibiting BCWD2 sediments indicating that it developed after some left-lateral displacement had already occurred. Minor drainage system E aligns with a major drainage system exhibiting the BCWD1 sediments to the south. However, with minor left-lateral motion, major drainage F would have likely provided sediments for the BCWD1 as well. This model aligns major drainage A immediately west of a small outcrop of older alluvium south of the fault mapped by Hoots (1931). Major drainage G along the eastern side of the Cheviot Hills extends to the down-faulted region presumably to flow either in the antecedent drainage (blue line) or along the southeastern edge of the Cheviot Hills (black line) south of the Santa Monica Boulevard Fault.

Figure 18: Left-lateral displacement Model 1 of the Santa Monica Boulevard Fault in the Cheviot Hills. This model exhibits 1.18 km of left-lateral displacement since inception of the drainage system within the Cheviot Hills. BCWD2 and CHD indicate Benedict Canyon Wash deposits "older," and Cheviot Hills Deposits respectively. Various areas of the Cheviot Hills are designated as the Northern Cheviot Hills, Southern Cheviot Hills and Southeastern Cheviot Hills. Red lines represent the approximate location of faults. Note that the location of the Newport-Inglewood Fault in the latitudes of the Cheviot Hills has not been confirmed. The base geologic-topographic map is from Hoots (1931).

Figure 19: Left-lateral displacement Model 2 of the Santa Monica Boulevard Fault in the Cheviot Hills. This model exhibits 0.64 km of left-lateral displacement since inception of the drainage system within the Cheviot Hills. BCWD2 and CHD respectively indicate Benedict Canyon Wash deposits and Cheviot Hills Deposits "older". Geomorphic regions of the Cheviot Hills are shown as the Northern Cheviot Hills, Southern Cheviot Hills and Southeastern Cheviot Hills. Red lines represent the approximate location of faults. Note that the location of the Newport-Inglewood Fault in the latitudes of the Cheviot Hills has not been confirmed. The base geologic-topographic map is from Hoots (1931).


A - Model 1
Present
Santa Monica Boulevard fault
Northern Cheviot Hills
Potrero Canyon (Santa Monica) fault
Mormon Temple
Swale
Swale
Southern Cheviot Hills
Southeastern Cheviot Hills
Incision of Moreno Creek
1 kilometer Scale
B - Model 1
Reconstructed 1.18 km left-lateral motion
1 kilometer Scale
Brown Canyon Wash (West)
Brown Canyon Wash (East)
Qt-BC2
Qt-BC2
Qt-BC2 (BCWD2 /CHD)
Restraining Bend orientation
Compression Gap
Left-lateral slip restored
~1.18 Km
"Shortening" of approximately 172 meters
Potrero Canyon Fault east - surface projection location
BCWD1
Mostly marine deposits
Elev. 270'
Elev. 240'
Elev. 170'
Down (70')
Up
Abandaned fan lobe - possibly folded by the Rancho Fault?
Newport-Inglewood Fault strands


A - Model 2
Present
Santa Monica Boulevard fault
Northern Cheviot Hills
Potrero Canyon (Santa Monica) fault
Mormon Temple
Southern Cheviot Hills
Southeastern Cheviot Hills
1 kilometer Scale
1 kilometer Scale
B - Model 2
Reconstructed 0.64 km left-lateral motion
Brown Canyon Wash (West)
Brown Canyon Wash (East)
Qt-BC2
Qt-BC2
Qt-BC2 (BCWD2 /CHD)
Qt-BC1 (BCWD1)
Mostly marine deposits
Restraining Bend orientation
Compression Gap
~0.64 Km
"Shortening" of approximately 136 meters
Newport-Inglewood Fault strands
N

4.4.2 Left-lateral slip rate and total displacement on the Santa Monica Boulevard Fault

Total displacement estimates for the Santa Monica Boulevard Fault-Potrero Canyon Fault System during the early to mid-Pleistocene is dependent on knowing when this fault system was created. The stratigraphy evaluation by KGS (2014) indicates that members of the Cheviot Hills Deposits change thickness quite dramatically across the Santa Monica Boulevard Fault indicating that the Santa Monica Boulevard Fault developed prior to or during the early stages of Cheviot Hills Deposits deposition (Figure 12). Marker horizons in the upper members of the marine San Pedro Formation remain a common depth below the top of the San Pedro Formation suggesting that the Santa Monica Boulevard Fault formed after cessation of the San Pedro Formation deposition (see KGS, 2014 transects). Cessation of the San Pedro Formation deposition is estimated at 1Ma.

The brackish unit Qeb that overlies the San Pedro Formation generally maintains a common thickness across fault strands of the Santa Monica Boulevard Fault zone indicating deposition prior to fault genesis (Figure 12). The terrestrial unit Qfob, which immediately overlies unit Qeb, does change thickness across numerous strands of the Santa Monica Boulevard Fault suggesting that the fault zone initiated movement during its deposition (Figure 12). This suggests that the Santa Monica Boulevard Fault developed soon around the time that the ocean receded from the area.

The age of unit Qfob is poorly constrained, but Qfob was deposited soon after deposition of the San Pedro Formation and is overlain by a thick sequence of the terrestrial Cheviot Hills Deposits and the older Benedict Canyon Wash Deposits (BCWD2). The upper member of the Benedict Canyon Wash Deposits (Marker Bed A of unit BCWD2) is now estimated to be 580 kya, and the cumulative age of soils within the Cheviot Hills Deposits places its lower members at a minimum age of over 770 kya (see ECI soils report in LCI, 2012a). This age of 770 kya for the lower members of the Cheviot Hills Deposits is clearly a minimum because they utilized a much younger age for the uppermost soil evaluated which was the Qt-BC2 surface (Soil Marker A). The interpretation of these data indicate that the Santa Monica Boulevard Fault formed a minimum of 0.8 Ma, but more likely closer to 1 Ma, which is consistent with the estimated age of the inception of the Potrero Canyon Fault by Tsutsumi et al. (2001) 0.9 Ma.

Dramatic changes in thickness of the Cheviot Hills Deposits (CHD) across the Santa Monica Boulevard Fault Zone (Figure 12) confirm that the fault was active during its deposition. Similar stratigraphic changes occur for members of the overlying older Benedict Canyon Wash Deposits (BCWD2) implying that the Santa Monica Boulevard

Fault was active for hundreds of thousands of years prior to the development of the local drainages in the Cheviot Hills. Active about 0.8 to 1.0 Ma to around 0.2 Ma indicates that this fault zone had an active lifespan of only about 700 kya.

An estimate of slip rate for the Santa Monica Boulevard Fault can be evaluated based on the age and total displacement of the drainages developed in the Qt-BC2 preserved fan-terraces in the Cheviot Hills. The period of time of offset of the local drainages is then determined by subtracting the age that the fault zone became inactive (200 kya) from the age of the local drainages. KGS (2014) calculated that the age of the development of the drainages in the Cheviot Hills (local uplift) coincided with the abandonment of the Qt-BC2 surfaces (Soil Marker A) occurring a minimum of 400 to 350 kya (Average of 375 kya, Figure 20). KGS (2014) noted than an evaluation of soil ages provided by Helms (2012) yielded an alternative age range for the Qt-BC2 surfaces of approximately 580 to 320 kya (Figure 22). The older age range is due to the observation of Helms (2012) that the sediments and soils developed in the inset channel within the younger Benedict Canyon Wash Deposits (BCWD1) formed after the underlying BCWD1 sediments and soils formed (see Feffer and Geocon, 2012, Fault Trench 1). Hence, the cumulative age of the underlying sediments of unit BCWD1 should be added to the cumulative age of the channel soils and deposits (Figure 22). The revised older age of 580 kya is utilized for fault slip rate estimates (Figure 22).

Slip rate estimates for Fault Displacement Model 1 (1.18 km) range from 5.9 to 2.7 mm/yr (Figure 20 and Figure 21) with an average value of 4.3 mm/yr. Slip rate estimates for Fault Displacement Model 2 (0.64 km), range from 3.7 to 1.5 mm/yr with an average value of 2.6 mm/yr. The maximum potential slip rate of 5.9 mm/yr provided by the youngest estimate of the Qt-BC2 surfaces (age of drainages) appears unreasonably high when compared to estimated left-lateral slip rates for other fault segments along the TRSBLL (Figure 2), which range from 0.27 to 2.0 mm/yr (Figure 6). It should be noted that if the lower slip rate estimates for Model 2 are correct, then this provides additional evidence that the Qt-BC2 surfaces are closer to the age of 580 kya (Figure 21) as compared to 400 to 320 kya (Figure 20). These slip rate estimates can be compared to those determined for other TRSBLL faults to the west (offshore) to assist in determining which calculation parameters may be more accurate.

Numerous slip rate estimates have been determined for the Malibu Coast TRSBLL fault segment (Figure 6), which includes some relatively high slip rates. Left-lateral displacement values of 5 km (+8/-1 km) during the past 4 M.y. from Sorlien et al. (2006) for the Dume fault-Santa Monica Fault (offshore) suggest maximum and minimum slip rate values of 4.3 and 0.8 mm/yr. Their preferred long-term slip rate for the Dume-Santa Monica Fault (offshore) is 1.5 mm/yr estimated for the past 4 M.y. The average of the maximum and minimum values is approximately 2.6 mm/yr. These values also do not take into account the Malibu Coast Fault that Sorlien et al. (2006) indicate may have exhibited approximately 9 km of left-lateral slip during the past 4 M.y. However, they indicate that much of this left-lateral displacement may have resulted from clockwise rotation of the Santa Monica Mountains immediately north of the Malibu Coast Fault. The higher slip rate values suggested by Sorlien et al. (2006) suggest the possibility that the Santa Monica Boulevard Fault may have exhibited relatively high slip rates as well. The estimated relatively high Quaternary slip rate values for the Santa Monica Boulevard Fault-Potrero Canyon Fault System may have partitioned to the Malibu Coast and Dume Faults to the west, which collectively exhibit a left-lateral slip rate of 1.8 to 2.0 mm/yr (Figure 2). To the east, the blind and inactive Santa Monica Fault South and North (onshore) of Wright (1991) accommodated a component of left-lateral slip prior to its abandonment and initiation of slip on the Potrero Canyon and Santa Monica Boulevard Fault Zones. This analysis suggests that a slip rate in the range of 2.0 mm/yr to 1.5 mm/yr is reasonable for the Potrero Canyon-Santa Monica Boulevard Fault System.

The estimated slip rate of 1.5 mm/yr utilizing 0.64 km of left-lateral displacement (Model 2) and the oldest age for soil marker horizon A of ~580 kya (i.e. age of drainages; A2 on Figure 21) is within the range of published slip rates for most fault segments along the TRSBLL. This suggests that the age of the Qt-BC2 fan-terrace surfaces are likely close to the 580 kya age, which is significant in terms of evaluating local tectonic strain rates for uplift of the Cheviot Hills.

Total left-lateral strike-slip displacement across the Potrero Canyon-Santa Monica Boulevard Fault Zone System can be estimated utilizing a range of annual slip rate values of 2.7 to 1.6 mm/yr, and the total duration of time of fault activity. This calculation is complicated however because the Santa Monica Boulevard Fault Zone became inactive 200 kya. However, the Potrero Canyon Fault East has become active since that time, and it will be assumed it has accommodated the left-lateral displacement east of the Potrero Canyon Fault proper during the past 200 kya. The Potrero Canyon-Santa Monica Boulevard Fault System likely formed sometime between 1.0 and 0.9 Ma, which averages to 0.95 Ma. Hence, the total displacement for the Potrero Canyon-Santa Monica Fault Zone System (PC-SMB) based on slip rates of 2.7 and 1.6 mm/yr, and duration of faulting of 950,000 years are 2.6 and 1.4 km respectively.

Figure 20: Modified figure from KGS (2014) showing the estimated minimum ages of deposition of major stratigraphic units, development of the Qt-BC2 fan-terrace, development of the local drainages, and timing of activity on the Santa Monica Boulevard fault. Age ranges utilized to estimate fault slip rate and total displacement for the Santa Monica Boulevard Fault are shown. Slip rates determined from the relatively younger ages for the Qt-BC2 surfaces are significantly higher than those determined for other left-lateral fault systems along the TRSBLL, suggesting that the Qt-BC2 surfaces are indeed older that originally estimated by KGS (2014).

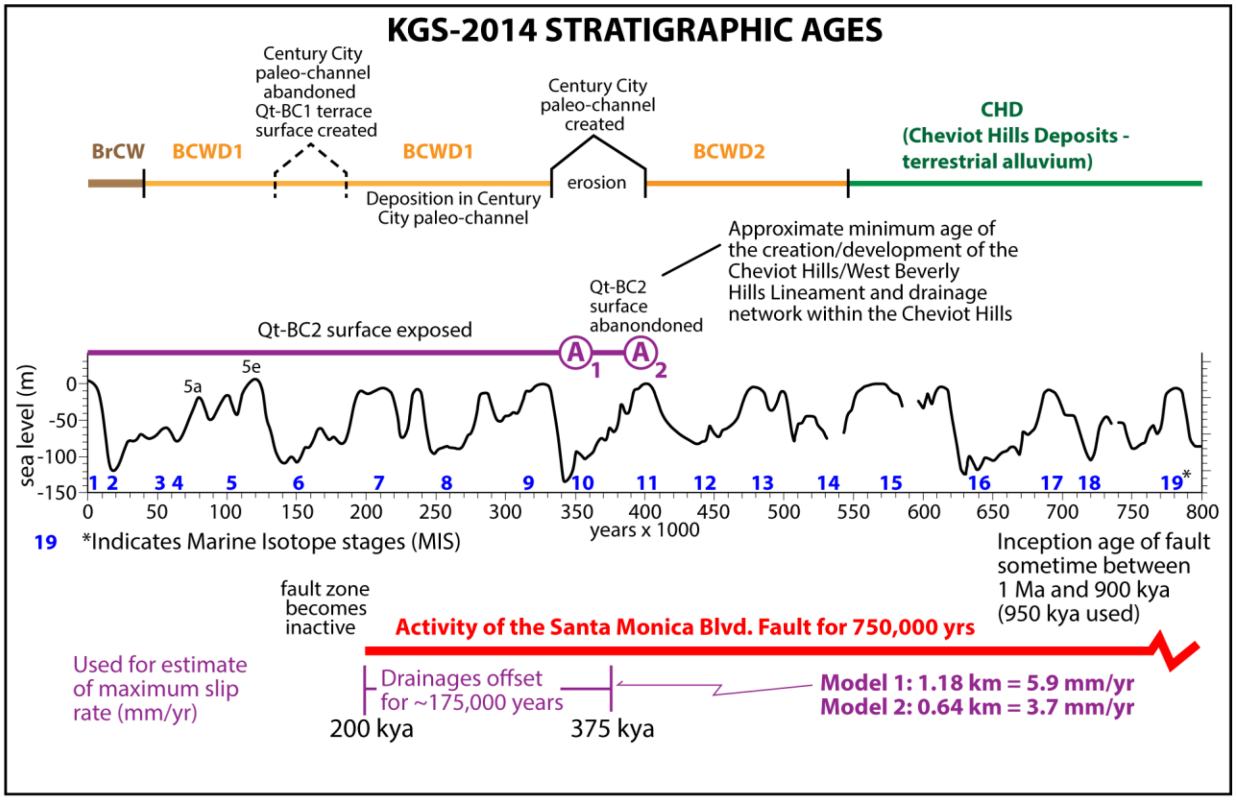


Figure 21: Alternate model for the estimated minimum age of deposition of major stratigraphic units utilizing soil cumulative ages for development of the BCWD1 and upper BCWD1 evaluated from Helms (2012) as shown on Figure 22. The age of development of the local drainages and timing of activity on the Santa Monica Boulevard Fault are also shown. Age ranges utilized to estimate fault slip rate and total displacement for the Santa Monica Boulevard Fault are shown.

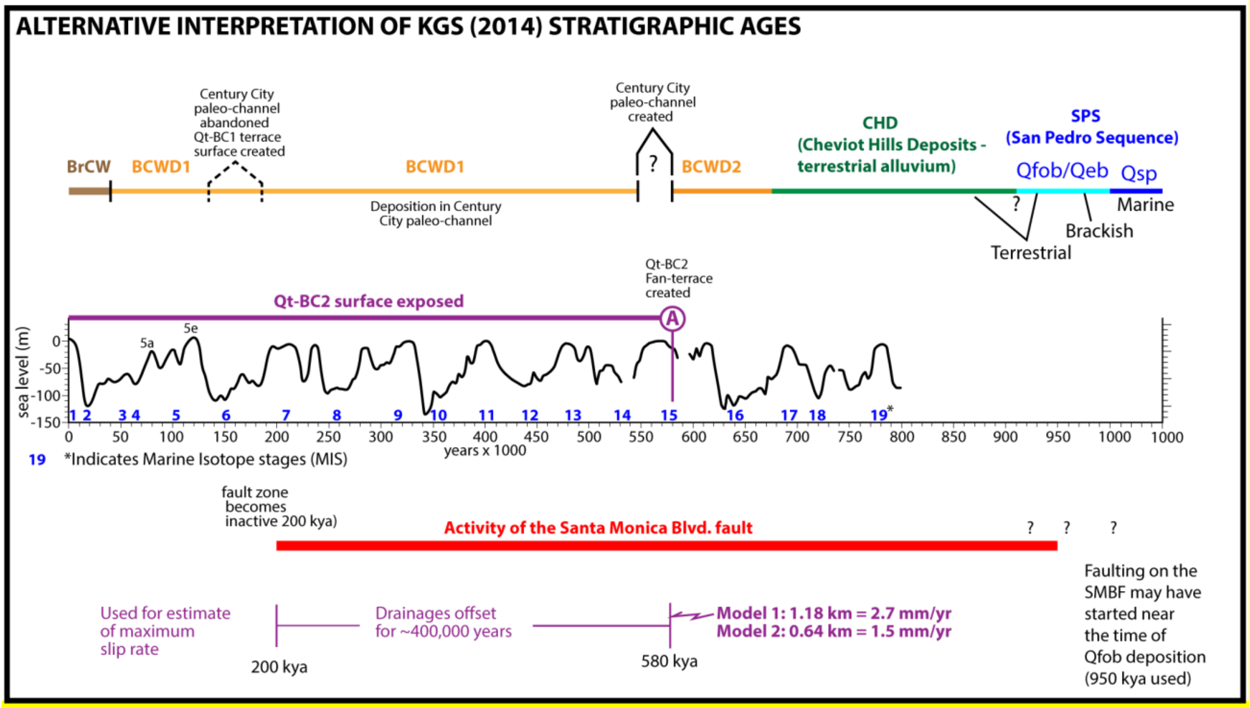
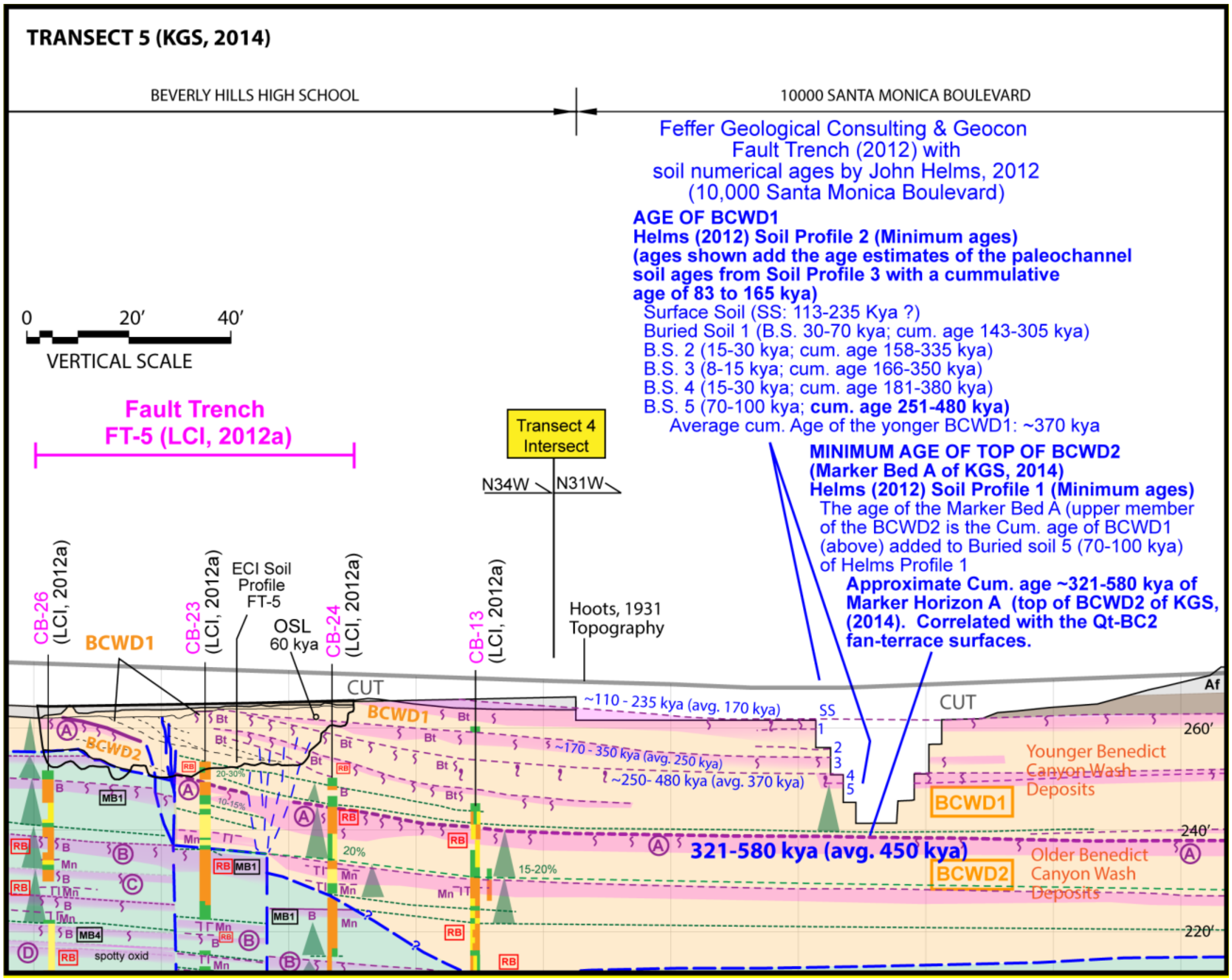


Figure 22: A portion of KGS (2014) cross section of Transect T5 showing the evaluated cumulative soil ages for the BCWD1 and upper dominant soil marker horizon A of the BCWD2 based on evaluation of soil Helms (2012).



4.5 Local tectonic and kinematic implications

The left-lateral slip rate and total fault displacement analysis of the Potrero Canyon-Santa Monica Boulevard Fault System provided a number of insights regarding the local tectonics. These insights include the effects of the restraining bend along the Potrero Canyon Fault Zone, strain rates of the north trending anticline in the southern Cheviot Hills, and long-term behavior of the Santa Monica Boulevard Fault - Potrero Canyon Fault System. These are discussed below.

4.5.1 Potrero Canyon Fault restraining bend – estimates of timing and magnitude of total vertical displacement

This analysis evaluates apparent vertical displacement associated with the local restraining bend along the Potrero Canyon Fault segment relative to the nearly pure left-lateral strike-slip motion along the Santa Monica Boulevard Fault. The Santa Monica Boulevard Fault connects with the Potrero Canyon Fault as a dominantly strike-slip fault near the Mormon Temple (Plate 3; KGS, 2011, 2012, 2014). Uplift due to the local restraining bend trend of the Potrero Canyon Fault Zone resulted in the development of the local scarps, which were first documented by Wright (1991) and Crook and Proctor (1992), and later geomorphically mapped by Dolan and Sieh (1992) as a series of left stepping en-echelon fault strands.

The magnitude of early to mid-Quaternary compressional strain associated with left-lateral Fault Displacement Models 1 and 2 (1.18 and 0.64 km respectively) is estimated by the "compression gap" shown on Figure 18 and Figure 19. These coincide with maximum vertical uplift of approximately 172 meters for Model 1, and 136 meters for Model 2 (width of the gap assuming all compression is expressed as vertical uplift). These values are consistent with estimates of total apparent vertical displacement (separation) of Quaternary sediments across the Potrero Canyon Fault provided by numerous publications. These include:

- Dolan and Pratt (1997) and Pratt et al. (1998) of 100 meters,
- Dolan et al. (2000a) of approximately 145 meters,
- Tsutsumi et al. (2001) of ~155 meters, and
- Catchings et al. (2008) of 120 meters.

These data indicate that the vertical displacement across the Potrero Canyon-Fault west of the Cheviot Hills may very well be attributed to restraining bend related uplift associated with a left-lateral fault system. The relatively shallow near surface dip of the "Santa Monica Fault" (Potrero Canyon fault in this study) observed by Dolan et al. (2000a) and Catchings et al. (2008) in the area of the Veterans Administration Hospital may be associated with a positive flower structure associated with a primarily strike-slip fault within a restraining bend (Plate 3 and Plate 4).

Estimates of apparent vertical displacement of the contact between the underlying Topanga Formation (middle Miocene) and overlying Pico Formation on Cross Sections B-B' and C-C' Tsutsumi et al. (2001; see Santa Monica Fault North Strand - Figure 34) across the Potrero Canyon Fault is approximately 180 meters. In addition, internal member contacts within the overlying Pico Formation (Pliocene) exhibit essentially identical apparent vertical displacements as that shown for Miocene age sediments. These displacement values are very similar to those determined for the base of the mid- to late Quaternary (M-L Quaternary) of 170 and 150 meters for cross sections B-B' and C-C' respectively (Figure 34).

Tsutsumi et al. (2001) indicates that their Santa Monica Fault North-Strand (Potrero Canyon Fault herein) did not initiate displacement (activity) until 0.9 Ma (see Figure 9 in Appendix A). Evaluation of cross sections of Tsutsumi et al. (2001) does indicate slightly less vertical apparent displacement of the base of the mid- to late Quaternary section (M-L Quaternary unit of Figure 34) verses older Miocene formational contacts of possibly 30 meters, which suggest the possibility that the Potrero Canyon Fault may have begun movement slightly prior to 0.9 Ma. It is permissible that the Potrero Canyon Fault developed during an erosional period (unconformity) in the area prior to deposition of the mid- to late Quaternary sediments of Tsutsumi et al. (2001). It should be pointed out that Dolan and Pratt (1997) suggest that the Santa Monica Fault (Potrero Canyon fault in this study) initiated movement 300,000 years ago if their 0.6 mm/yr minimum estimated slip rate for the faults characterized the entire history of the fault.

4.5.2 Tectonic timing, uplift rates, and development of the northwest trending anticline in the southern Cheviot Hills

KGS (2014) proposed that the north-northwest trending anticline in the southern Cheviot Hills (Figure 7) developed in response to compression associated with interaction of left-lateral motion on the Santa Monica (Potrero Canyon) and Santa Monica Boulevard Fault Zones and right-lateral strike-slip motion on the Newport-Inglewood Fault (Plate 3). These motions essentially compress the southern Cheviot Hills in a direction perpendicular to the strike of the Newport-Inglewood fault that acts as a local buttress. This model works as long as strands of the Newport-Inglewood Fault Zone extend up to the southern Cheviot Hills. In addition, a syncline occurs within, and/or east of the Newport-Inglewood Fault Zone that led to the development of the Beverly Hills Sub-Basin (Plate 3). This syncline is identified as a Holocene structure (Wright, 1991) with a fold axis parallel to the Newport-Inglewood Fault (Figure 37). An area of subsidence is identified in the modeled INSAR data shown on Figure 14 that is associated with the syncline. As discussed in KGS (2012 and 2014), uplift of the Cheviot Hills in concert with erosion from south flowing drainages like Benedict Canyon Wash via Moreno Creek was the dominant cause for the development of the southern portion of the West Beverly Hills Lineament (also see LCI, 2012a). Proposed herein however, is the possibility of a sympathetic syncline to the east that may have resulted in higher relative relief between the axis of the Cheviot Hills anticline and the region immediately east of the Cheviot Hills.

A minimum age for the initiation of uplift of the southern Cheviot Hills is approximated by the age of the Qt-BC2 preserved fan-terraces, which is 580 kya. Evaluation of stratigraphy in the Century City area indicates that the fold began to form sometime during deposition of the Cheviot Hills Deposits (CHD in Figure 12). Age dates for the CHD is lacking, but is certainly younger than the underlying San Pedro Formation estimated to be 1 million years old (upper members) and older than the overlying older Benedict Canyon Wash Deposits (BCWD2) estimated to be a minimum of 580 kya.

KGS (2014) estimated a range of maximum uplift rates of approximately 0.04 to 0.07 mm/yr for the anticline and concluded that it developed sometime after deposition of unit Qfob (Figure 12 and Figure 26). These uplift rates associated with development of the anticline were based on an age range of the Qt-BC2 surface of 400 to 200 kya. If the Qt-BC2 fan-terraces are older (i.e. 580 kya; Figure 21), this leads to even slower uplift rates. The anticline may exhibit approximately 12 meters of vertical uplift, resulting in an uplift rate of 0.021 mm/yr. In either case, the uplift rate of the anticline is fairly low.

4.5.3 Summary of Quaternary kinematics and activity of the Santa Monica Boulevard Fault, Potrero Canyon Fault, Potrero Canyon Fault East and Newport-Inglewood Fault

The Santa Monica Boulevard Fault became inactive approximately 200 kya. The Potrero Canyon Fault has remained active in addition to the newly developing Potrero Canyon Fault East extending through the southern Cheviot Hills. As indicated earlier, Dolan and Pratt (1997) suggest that the Santa Monica Fault (Potrero Canyon fault in this study) initiated movement 300,000 years ago if their 0.6 mm/yr minimum estimated slip rate characterized the entire history of the fault. This is consistent with findings in this report and Tsutsumi et al. (2001) that the Potrero Canyon Fault is youthful; however this study supports the initiation of the Potrero Canyon Fault consistent with that of Tsutsumi et al. (2001) of approximately 0.9 Ma. KGS (2014) indicated that the north-northwest trending anticline in the southern Cheviot Hills (Figure 7) developed in the middle to late Pleistocene, which approximately correlates with the time that the Santa Monica Boulevard Fault initiated movement, approximately 1.0 to 0.9 Ma. As discussed in the next section, the Newport-Inglewood Fault Zone migrated northward from the Baldwin Hills during the Pleistocene.

Inactivity on the Santa Monica Boulevard Fault during the past 200 kya suggests that left-lateral displacement during the past 200 kya is occurring on presumably approximately east-west trending fault or faults. Movement could be partitioned among several other area faults including the western San Vicente Fault and the Rancho Fault (Plate 3 and Plate 4). However, due to their short lateral extent, these faults seem incapable of accommodating all the left-lateral slip since the cessation of activity on the Santa Monica Boulevard Fault. The primary candidate is the proposed Potrero Canyon Fault East, which is simply an extension of the Potrero Canyon Fault eastward across the Cheviot Hills south of the SMBF (see Plate 4 and Figure 26).

These observations indicate that the kinematics of the region have been quite dynamic during the early to mid-Quaternary and continuing to the present day. Notable changes involve:

- Abandonment of the Santa Monica Fault North and South as oblique reverse left-lateral faults accommodating both compressional and left-lateral strike-slip deformation.
- Creation of the Potrero Canyon and Santa Monica Boulevard Fault Zones and associated left lateral movement.
- Compressional deformation moving north and south of the TRSBLL.
- Northward migration of the Newport-Inglewood Fault southeast of the Cheviot Hills (discussed in the next section).
- Development of the southern Cheviot Hills north-northwest trending anticline,
- Left-lateral displacement on the Potrero Canyon Fault and Santa Monica Boulevard Fault
- The Santa Monica Boulevard Fault, Western Hollywood Fault, and Cross Fault No. 1 (Fault Zone A) become inactive.
- Creation of the Potrero Canyon Fault East during the past several hundred thousand years, which subsequently “cut off” the northernmost strands of the Newport-Inglewood Fault Zone.
- The northern portion of the Cheviot Hills Anticline possibly becoming inactive; however, uplift in the southernmost Cheviot Hills continues.

5.0 THE NORTHERN EXTENT OF THE NEWPORT-INGLEWOOD FAULT

The Newport-Inglewood Fault (NIF) is an important tectonic component in the region of the Beverly Hills Unified School District (BHUSD). The Newport-Inglewood Fault Zone is active resulting in two notable Historical earthquakes. The first was in 1920, which is estimated to have been an M 4.9 occurring near the City of Inglewood and located approximately 3 km south of the Baldwin Hills (Taber, 1920; Barrows, 1974). The second was the M 6.4, 1933 Long Beach Earthquake that occurred in the Newport Beach-Long Beach area. Surface rupture was not observed during this event, however abundant surface fractures occurred and widespread ground shaking damage was documented.

The active Newport-Inglewood Fault is a northwest trending right-lateral strike-slip fault considered part of the Peninsular Ranges (PR) tectonic-geomorphic province (Figure 1). The Newport-Inglewood Fault is clearly identified in the Baldwin Hills uplift area immediately south of Ballona Gap (Figure 6 and Figure 19; Plate 6) where it has been placed in State of California Fault-Rupture Hazard Zone (Bryant and Hart, 2007). Smaller microseisimicity earthquakes frequently occur along the fault zone and near the study area. Mapping and activity level of the Newport-Inglewood Fault south of the Baldwin Hills is supported by a variety of data and scientific consensus.

There is no such consensus north of the Baldwin Hills where numerous locations for the northward extension of the Newport-Inglewood Fault NIF within and particularly north of Ballona Gap have been proposed. However, the Century City Fault Investigation (Parsons, 2011), which triggered this investigation, concluded that the West Beverly Hills Lineament was in fact the northern extension of the Newport-Inglewood Fault, and that the entire system should be presumed active. This report disputes those conclusions as well as KGS (2012, 2013, and 2014) and LCI (2012a, 2012b, and 2012c), plus attendant CGS reviews of those LCI reports. It is the conclusion of this report that the escarpment associated with West Beverly Hills Lineament is not a "fault scarp" in any way, and instead developed associated via erosion along Moreno Creek in combination with local tectonics that varies north and south of the Santa Monica Boulevard Fault Zone (see Section 5.0). However, it is the conclusion of this report that the Newport-Inglewood Fault does extend well north of the Baldwin Hills but within and east of the southeastern Cheviot Hills. However, it is also the conclusion of this report that the activity of the Newport-Inglewood Fault ends at the proposed Potrero Canyon Fault East, south of the Beverly Hills high school. These conclusions are based on the evaluation of numerous sources including:

- Evaluation of the oil well boring data provided in published reports (Erickson and Spaulding, 1975; Tsutsumi et al., 2001).

- Topographic profile along Ballona Creek through Ballona Gap (Moran, 1986).
- Correlation of near surface boggy areas and artesian wells from an early 1900's groundwater study (Mendenhal, 1905).
- Interpretations of geomorphology and geology by early mappers of the area (Hoots, 1931)
- Evaluation of ground water barrier in the San Pedro Formation (Poland et al., 1959).
- Evaluation of faults within the boundary of the east and west Beverly Hills Oil Fields that have a strike similar to the Newport-Inglewood Fault Zone, and appear to displace Pleistocene sediments based on a groundwater barrier (Erickson and Spaulding, 1975).
- Evaluation of oil well data that identified the Newport-Inglewood Fault at a depth of 2.2 km in the northeastern Ballona Gap (Tsutsumi, et al., 2001).
- Evaluation of LiDAR imagery provided by the California Geological Survey.
- Evaluation of local seismicity data (ECI, personal communication) and by Hauksson et al. (2002).
- Evaluation of red-flagged and yellow-flagged structures associated with the 1994 Northridge Earthquake.
- Evaluation of changes in local stress directions from 2.5 Ma, 0.8 Ma and 0.58 Ma (interpretation of deformation structures provided by Hummon, 1994, Hummon et al., 1994, Wright (1991) and KGS (2014, and current study).
- Fault, stratigraphic, and structural studies in the Century City area (Parsons, 2011; LCI, 2012abc; Geocon, 2014; KGS, 2014) and published geologic maps (CGS, USGS).

The conclusion supported by the data interpreted in this report is that multiple strands of the Newport-Inglewood Fault extend north of Ballona Gap to the southern BHUSD; but the exact location and activity of these fault strands remains unknown because of the lack of fault investigations in this area. This paper also concludes that the West Beverly Hills Lineament was formed by multiple non-tectonic forces, is not an active fault zone, and is not an extension of the Newport-Inglewood Fault.

5.1 Published evidence for the location of the Newport-Inglewood Fault Zone north of the Baldwin Hills

Numerous locations for the northward extension of the Newport-Inglewood Fault within and north of Ballona Gap have been proposed. There has been a lack of surface rupture hazard fault investigations in this area forcing researchers to rely on more indirect sources of data. These data are compiled and collectively evaluated below.

Relatively older publications often attributed uplift in the Cheviot Hills to result from the northward continuation of the Newport-Inglewood Fault east of the Cheviot Hills (Hoots, 1931; Wright, 1991). Wright (1991) indicates that early workers in the region suggested that the Newport-Inglewood Fault extended along the western side of the region of artesian wells shown by Mendenhal (1905; Plate 3), well to the east of the Cheviot Hills.

Poland et al. (1959) proposed that the Newport-Inglewood Fault extended into the southeastern Cheviot Hills based on offset San Pedro sands and an associated groundwater barrier (Plate 6). Based on well data, Poland et al. (1959) interpreted the Newport-Inglewood Fault across Ballona Gap within sediments underlying un-faulted late Pleistocene gravels (the 50-foot gravels) (Plate 6 and Plate 7). Moran (1986) evaluated the 50-foot gravels in the southeastern portion of Ballona Gap estimating an age of approximately 15 kya and 18 kya at the top and bottom of the 50-foot gravels in a fining upward sequence. This data suggests that the northern Newport-Inglewood Fault (Baldwin Hills to Cheviot Hills) has not ruptured the surface since the latest Pleistocene. However, the Moran (1986) study occurred east of the dominant northwest trending fault strand of the Newport-Inglewood Fault in the Baldwin Hills, and the Poland et al. (1959) study did not have sufficient resolution to evaluate whether or not the 50-gravels may have exhibited small scale offsets. Poland et al. (1959) interprets the base of the San Pedro Formation across their dominant strand of the Newport-Inglewood Fault as exhibiting between 110 to 75 meters of apparent down to the east vertical separation (Plate 6 and Plate 7; Figure 25). This is a significant vertical (dip-slip) apparent separation across a dominantly strike-slip fault considering that the local San Pedro Formation ceased deposition approximately 1 Ma.

Erickson and Spaulding (1975) proposed that the West and East Beverly Hills Oil Fields are structurally separated by strands of the Newport-Inglewood Fault (Figure 23). Wright (1991) made the same interpretation. Their findings are based on the identification of faults in the oil-bearing strata of the East and West Beverly Hills Oil Fields in correlation with near surface groundwater barriers in Pleistocene sediments. Erickson and Spaulding (1975) indicate that the West Pico Fault No. 4 likely represents an eastern strand of the Newport-Inglewood Fault that lies east of the southeastern Cheviot Hills

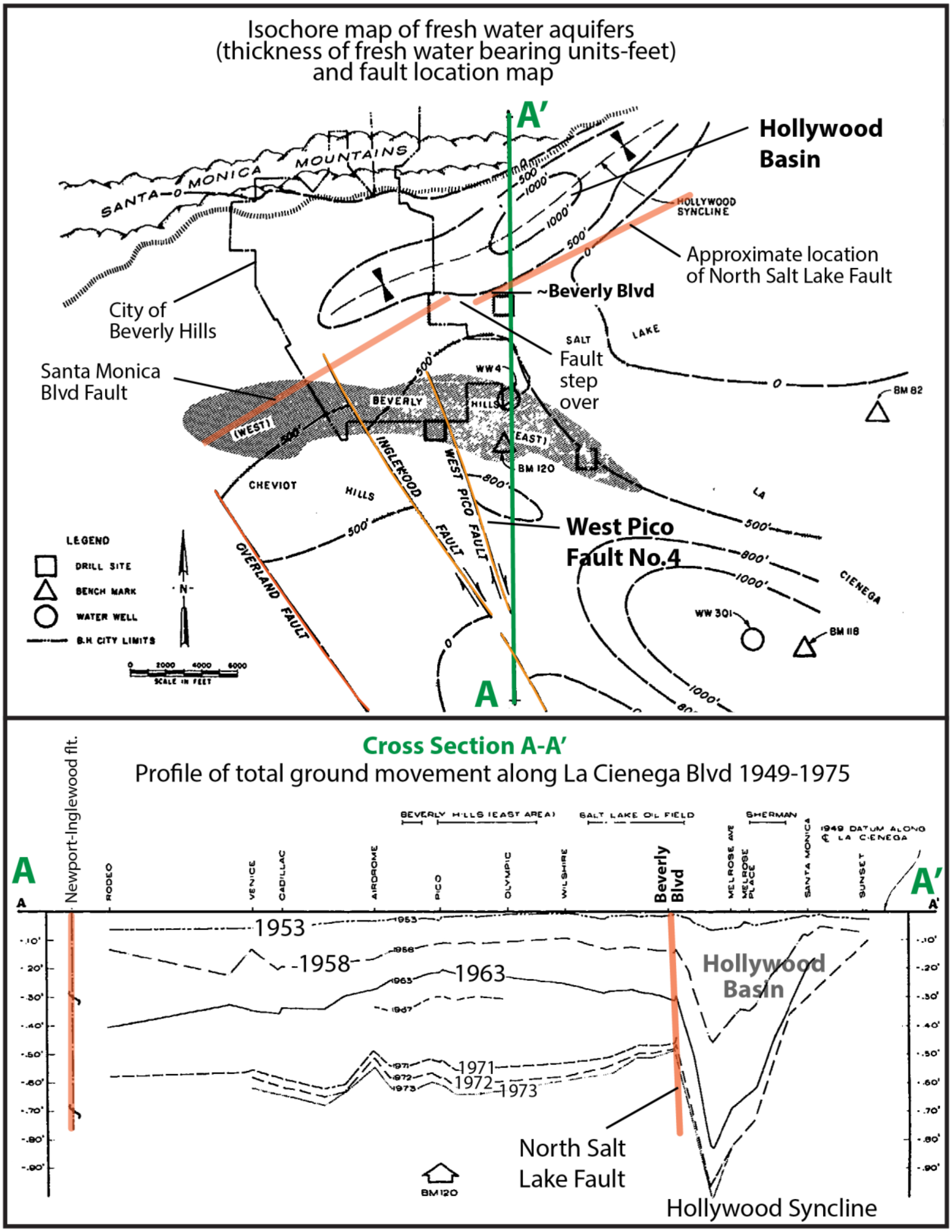
(Figure 23; Plate 3 and Plate 4). They identify the West Pico Fault No. 4 at depths greater than 3000 feet within the Beverly Hills Oil Field that occurs in the southern region of the BHUSD. Erickson and Spaulding (1975) identify another northwest trending right-lateral strike slip fault west of the West Pico Fault No. 4 that they refer to as the Newport-Inglewood Fault. They show this fault extending through the southeastern Cheviot Hills very close to the location shown by Wright (1991; Figure 23). Erickson and Spaulding (1975) show the West Pico Fault No. 4 extending into the southern region of the BHUSD, however, their groundwater barrier data utilized to identify the near surface location of this fault is located approximately 3000 feet south of the southern border of the BHUSD. They may have extrapolated their groundwater data from the south where no deep structure data was presented to correlate with their identification of the West Pico Fault No. 4 to the north. This correlation is not reasonable based on these data alone.

Moran (1986) evaluated a topographic relief profile through Ballona Gap that extended many miles to the east and west of the Ballona Gap region. Their analysis showed a break in slope from a relatively flat surface immediately east of the Newport-Inglewood Fault, to a slightly west dipping surface west of the Newport-Inglewood Fault. Moran (1986) suggests that the anomalous flattening of gradient upstream of the Newport-Inglewood Fault indicates obstruction of flow at that point due to tectonic uplift and increased deposition inland.

Wright (1991) indicates that a northwest trending anticline in the Baldwin Hills began to develop with movement of the Newport-Inglewood Fault at depth in the mid-Pliocene. The axis of the fold was subsequently offset 1200 meters right-laterally by the Newport-Inglewood Fault in the latest Pliocene to Pleistocene (Wright 1991; Hummon 1994). Wright (1991) also indicates that the Newport-Inglewood Fault has migrated northwestward during the Quaternary and shows the Newport-Inglewood Fault extending into the southeastern Cheviot Hills (Plate 3). In this region, he indicates that movement of the Newport-Inglewood Fault has led to folding within, and east of, the Cheviot Hills. For example, he interpreted a Holocene age syncline with a strike parallel to, and east of, the Newport-Inglewood Fault, in the region of the Beverly Hills sub-basin east of the Cheviot Hills (compare Figure 37 with Figure 14). The location of the Newport-Inglewood Fault by Wright (1991) is essentially identical to that of Poland et al. (1959; Plate 6).

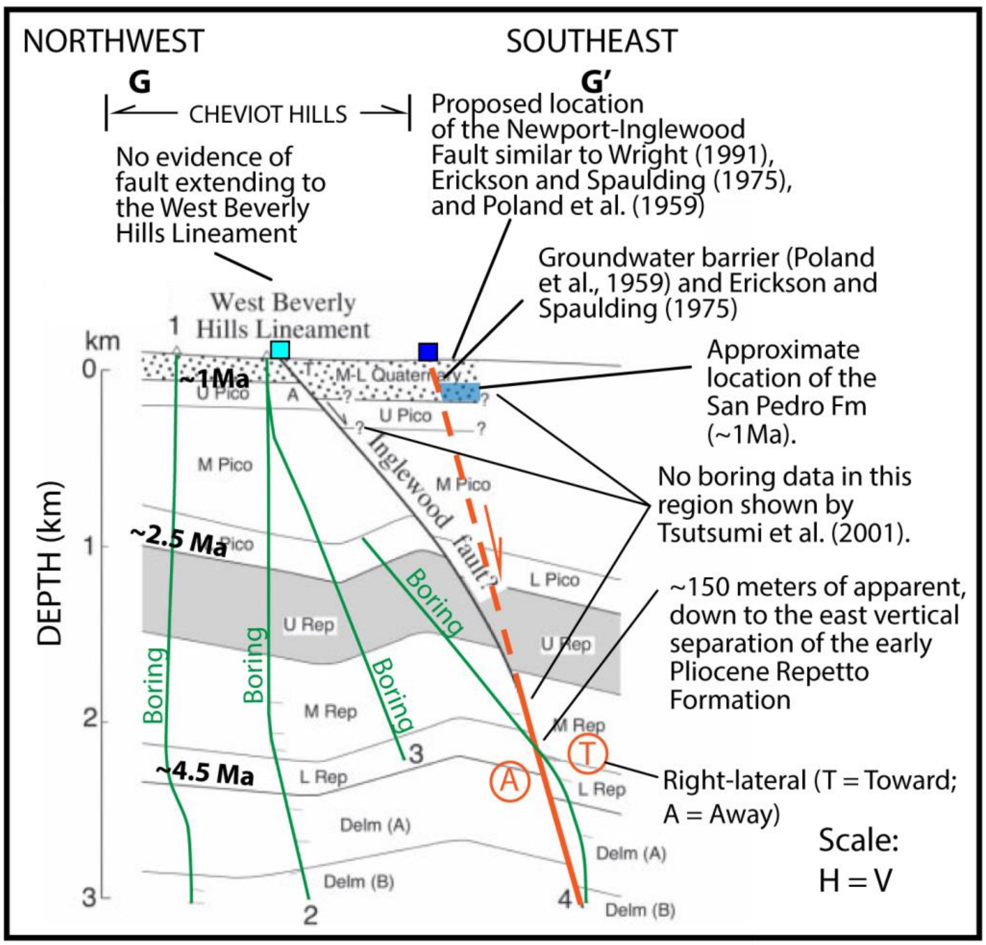
Tsutsumi et al. (2001) identified the Newport-Inglewood Fault in the southeastern Cheviot Hills-northern Ballona Gap area in oil well data at a depth of approximately 2.2 km on their cross section G-G' (Figure 24, Figure 25 and Plate 3). Above the depth where they identify the Newport-Inglewood Fault, they bend it towards the west to reach the surface near the West Beverly Hills Lineament (Figure 25; Plate 3); however they do not indicate any well data to support that westward bend (Figure 24). If the Tsutsumi et al. (2001) fault at depth is projected more vertically, as illustrated here in Figure 24, then it is in close agreement with the location of the Newport-Inglewood Fault of others (Poland et al., 1959, Erickson and Spaulding (western splay), 1975, and Wright, 1991). The depth structure contour map of the Cheviot Hills Oil Field (CDOG, 1992), shows no northwest striking faults in the southeastern Cheviot Hills Oil Field vertically below the West Beverly Hills Lineament. It is more likely that the WBHL identification as the Newport-Inglewood Fault by Dolan et al. (1997) served as the surface connection for Tsutsumi et al.'s (2001) interpretation to bend the Newport-Inglewood Fault westward. The Dolan et al. interpretation has been demonstrated to be incorrect; the same factors reject Tsutsumi et al.'s westerly bending of the Newport-Inglewood Fault's surface projection. .

Figure 23: Modified isochore map (i.e. same thickness) of fresh water aquifers, the location of northern Newport-Inglewood Fault, the East and West Beverly Hills Oil fields, and cross section A-A' from Erickson and Spaulding (1975).


Isochore map of fresh water aquifers
(thickness of fresh water bearing units-feet)
and fault location map
A'
Hollywood Basin
HOLLYWOOD SYNCLINE
Approximate location of North Salt Lake Fault
~Beverly Blvd
City of Beverly Hills
Santa Monica Blvd Fault
SANTA MONICA MOUNTAINS
SALT LAKE
Fault step over
BEVERLY HILLS
(WEST)
(EAST)
WW4
BM 120
BM 82
CHEVIOT HILLS
INGLEWOOD FAULT
WEST PICO FAULT
OVERLAND FAULT
West Pico Fault No.4
LA CIENEGA
WW 301
BM 118
LEGEND
DRILL SITE
BENCH MARK
WATER WELL
B.H. CITY LIMITS
N
SCALE IN FEET
A
Cross Section A-A'
Profile of total ground movement along La Cienega Blvd 1949-1975
Newport-Inglewood flt.
RODEO
VENICE
CADILLAC
AIRDROME
PICO
OLYMPIC
WILSHIRE
Beverly Blvd
MELROSE AVE
MELROSE PLACE
SANTA MONICA
SUNSET
BEVERLY HILLS (EAST AREA)
SALT LAKE OIL FIELD
SHERMAN
1949 DATUM ALONG LA CIENEGA
1953
1958
1963
1967
1971
1972
1973
Hollywood Basin
North Salt Lake Fault
Hollywood Syncline
BM120

At a depth of 2.2 km, Tsutsumi et al. (2001) identified 150 meters of down to the east apparent dip-slip separation of early Pliocene sediments (Repetto Formation) across the Newport-Inglewood Fault in the northern Ballona Gap area (Figure 24). The magnitude of the vertical separation of these Pliocene sediments is larger than those identified by Poland et al. (1959; 110 to 75 m) for the contact between the overlying ~1 Ma San Pedro Formation and underlying upper Pico Formation (Figure 25). However, Pliocene age sediments in the Baldwin Hills exhibit a higher magnitude of folding than the younger San Pedro Formation, which could account for the large variation in apparent vertical separation by the strike-slip Newport-Inglewood Fault. Across this fault strand, the elevation of Cheviot Hills is lower on the east side by ~70 feet (~21 meters), which is consistent with east side down for this fault strand identified by Tsutsumi et al. (2001) and Poland et al. (1959).

Figure 24: Modified cross section G-G' from Tsutsumi et al. (2001) showing alternative interpretation for the surface projection of the Newport-Inglewood Fault in the northern Ballona Gap (see Plate 3 for map locations; dark blue surface projection also shown on Figure 25).



Toward the southeast, within the Baldwin Hills, Poland et al. (1959) point out the main strand of the Newport-Inglewood Fault Zone exhibits down to the west apparent vertical separation (Figure 25; also see Wright, 1991). Changes of apparent vertical separation across strike-slip faults are common, for example, in areas where the sediments are tilted and exhibit local restraining and releasing bends. The local down to the west separation across the Newport-Inglewood Fault in the Baldwin Hills (east strand), may be associated with secondary faulting to the west that created a local graben in the northern Baldwin Hills (Central Graben in Figure 25). Wright (1991) indicates that the local graben did not result from stretching of the anticlinal crest, but most probably to the right-lateral separation of the two halves of the pre-existing anticline.

Dolan and Sieh (1992) proposed that the eastern edge of the Cheviot Hills, which represents a trend nearly parallel to the Newport-Inglewood Fault, be called the West Beverly Hills Lineament (WBHL) concluding that the lineament most likely resulted from the Newport-Inglewood Fault in close proximity to the edge of the hills and extending through the antecedent river gap in the southeastern Cheviot Hills (Figure 25, see D2).

The California Geological Survey (CGS) and the United States Geological Survey (USGS) both published fault maps that also interpreted the Newport-Inglewood Fault along the West Beverly Hills Lineament; however, the maps were published without any direct evidence that the Newport-Inglewood Fault actually exists there (Yerkes and Campbell, 2005; Bryant and Hart, 2005). Parsons (2011) performed a fault investigation in the Century City area and interpreted a northwest trending fault zone in very close proximity to where the CGS and USGS had shown their West Beverly Hills Lineament-Newport-Inglewood Fault. However, LCI (2012a, 2012b), based on extensive trenching perpendicular to and across the West Beverly Hills Lineament, demonstrated that faults previously identified by the CGS, USGS, and Parsons (2011) do not exist since at least San Pedro Formation time. KGS (2012; 2014) interpreted some northwest trending faults (Fault Zone H, Figure 11) that may be associated with the Newport-Inglewood Fault but project further east of where the CGS, USGS and Parsons (2011) identified their fault zone. KGS also identified Fault Zone H as becoming inactive during deposition of the Benedict Canyon Wash Deposits young (BCWD1). Geocon (2014) evaluated the same faults associated with Fault Zone H, and determined that if they exist, they are inactive as they were not observed to offset sediments at the bottom of their Fault Trench 1 estimated to be a minimum of 40 to 27 kya.

5.2 Geomorphic evaluation of LiDAR Data

The California Geological Survey (CGS) provided KGS with a LiDAR image of the Cheviot Hills-Baldwin Hills area that allows for a geomorphic evaluation of possible scarps associated with the Newport-Inglewood Fault Zone (Figure 25, Diagram B). The original and unmodified CGS LiDAR image (Diagram B), shows the location of a series of en-echelon mapped strands of the Newport-Inglewood Fault extending into Ballona Gap that are currently bounded by Fault-Rupture Hazard Zones by the State of California (Bryant and Hart, 2007). The CGS also interpreted 3 general areas in the southeastern Cheviot Hills where strands of the NIF Zone may occur, which are labeled A, B and C (Figure 25, Diagram B).

Figure 25: Proposed possible location of fault strands associated with the Newport-Inglewood Fault into the southeastern Cheviot Hills (CHse). Modified from base map provided by the California Geological Survey (LiDAR data).

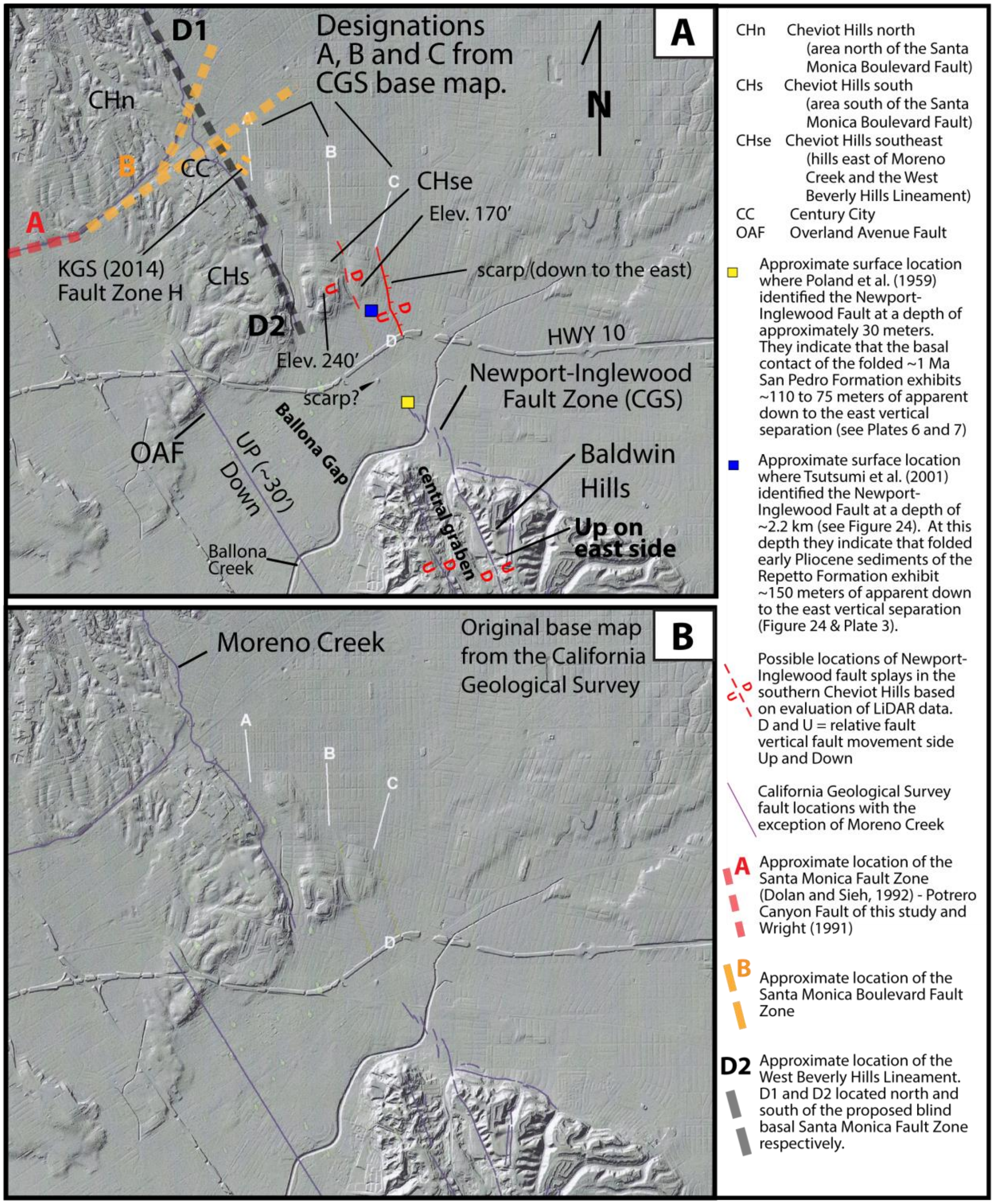


Diagram A of Figure 25 is modified to show interpreted geomorphic features and structures on the CGS LiDAR image. Three possible fault-related topographic features were identified on Figure 25 (Diagram A). The first is a small knob in the central area of Ballona Gap, however, this feature is not linear, and likely represents a small man built mound. The second geomorphic feature that may be fault related is the notch, or swale, within the southeastern Cheviot Hills. This feature correlates well in terms of location with the proposed location of the Newport-Inglewood Fault of Poland et al. (1959) and Wright (1991). The third geomorphic feature possibly attributed to the Newport-Inglewood Fault is a subtle rise in slope toward the west, trending N39W, located in the southeastern most Cheviot Hills and extends into the northeastern Ballona Gap alluvial plain. This feature aligns with the southeastern edge of the Cheviot Hills, and is in close proximity to the location of the West Pico Fault No. 4 of Erickson and Spaulding (1975). This is the strongest "fault scarp" feature identified in the LIDAR data as it is linear, trends approximately parallel with the Newport-Inglewood Fault Zone, and likely occurs within latest Pleistocene to Holocene-age alluvial sediments.

The east-side down, apparent dip-slip (vertical) separation across the Newport-Inglewood Fault Zone identified in Ballona Gap is consistent with the southeastern Cheviot Hills occurring to the west. In addition, the east-side down across the western strand of the Newport-Inglewood Fault identified at depth in Ballona Gap is consistent with the east-side down across a swale within the southeastern Cheviot Hills (Figure 25, also see Figure 18).

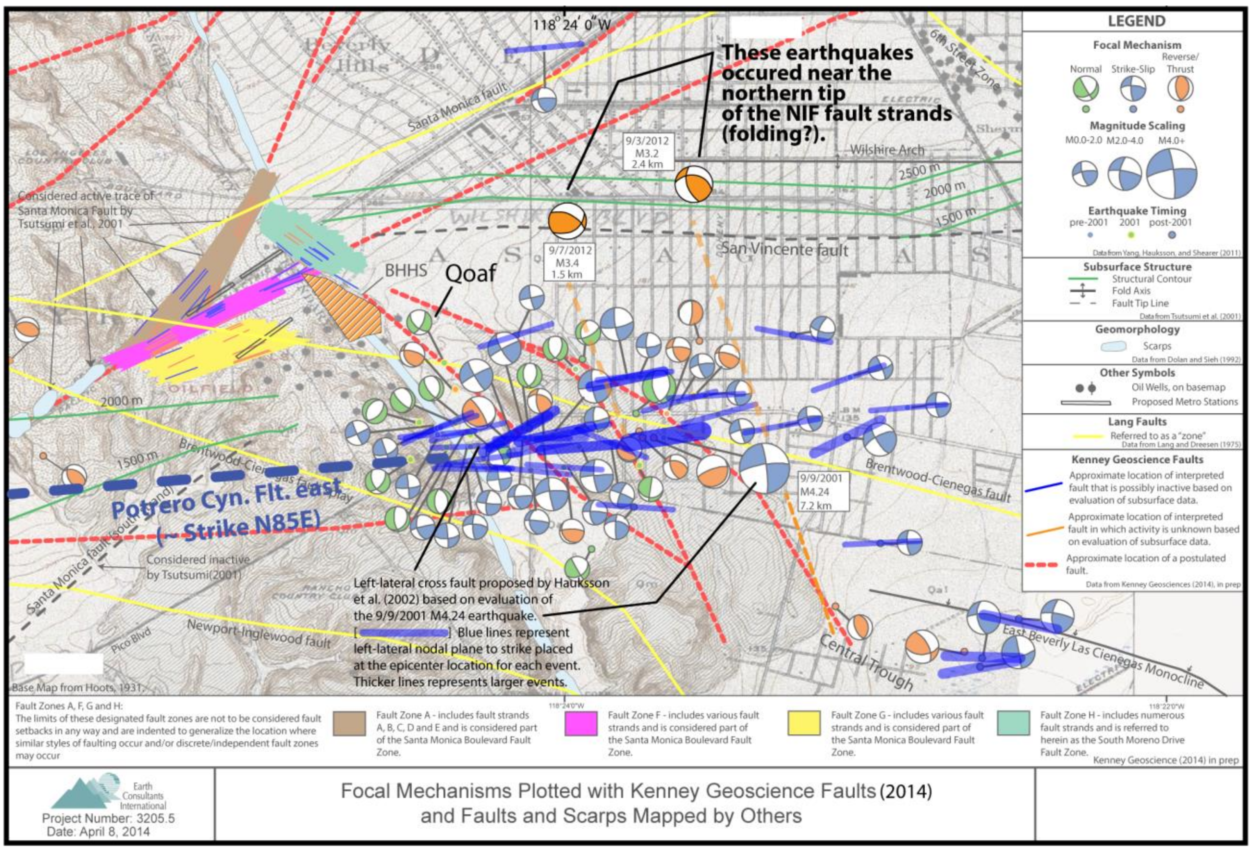
5.3 Evaluation of historical seismicity

Recent seismicity suggests that the Newport-Inglewood Fault exists in the southeastern Cheviot Hills. Hauksson (1987) identified a diffuse zone of seismicity associated with the Newport-Inglewood Fault Zone that extended north of the Baldwin Hills and southeast of the Cheviot Hills. Hauksson (1987) identified one earthquake in this region from 1985 (Plate 3) that he considered possibly associated with the northern extent of the Newport-Inglewood Fault Zone.

Earthquake focal mechanism data compiled by Earth Consultants International (Figure 25) shows an approximate east-west trending event cluster in the southeastern Cheviot Hills. This cluster occurs in the general region of the boundary between the West and East Beverly Hills Oil Fields, southeastern Cheviot Hills. On September 9, 2001, a M 4.2 earthquake occurred at a depth of 6 km (Hauksson et al, 2002), with an epicenter just slightly east of the Newport-Inglewood Fault strand proposed by Wright (1991). This event exhibits a north-northwest trending right-lateral nodal plane consistent with the trend and style of slip of the Newport-Inglewood Fault (Figure 26; Hauksson et al., 2002). However, the event resides within an east-west trending cluster of earthquakes, locally relocated by Hauksson et al. (2002), that trends east-west, nearly parallel with the left-lateral nodal plane for the September 9, 2001 event. Based on this observation, Hauksson et al. (2002) suggests that the September 9, 2001 main shock event occurred on an east-west trending left-lateral fault associated with a small step-over in the Newport-Inglewood Fault Zone (Figure 26; Plate 3). The general trend of the cross faults, shown as the blue line on Figure 25, are parallel to Pico Boulevard and occur along a generally east-west trending saddle in the Cheviot Hills.

It is also possible that the east-west trend of the seismicity cluster may be the development of a new dominantly left-lateral fault zone within the TRSBLL. If this seismicity trend is extended westward, it connects near the location of the intersection of the Potrero Canyon Fault and the Santa Monica Boulevard Fault Zone near the Mormon Temple (Plate 3). This is significant because the Potrero Canyon Fault is still considered active (Dolan et al., 2000a), however the Santa Monica Boulevard Fault has been demonstrated to be inactive (LCI, 2012a; Geocon, 2013). This raises the question as to where left-lateral displacement may be occurring along the TRSBLL in the region of the Cheviot Hills. This proposed “new” fault is the Potrero Canyon Fault East, and may accommodate the left-lateral slip that is no longer accommodated by the Santa Monica Boulevard Fault Zone for the past ~200 kya.

Figure 26: Modified earthquake focal mechanisms and fault map of the southeastern Cheviot Hills area. Figure shows approximate location of proposed left-lateral cross fault to the Newport-Inglewood Fault proposed by Hauksson et al. (2002, thick blue line), which is postulated herein to be the eastern portion of the approximately east-west trending, dominantly left-lateral Potrero Canyon Fault east (dashed blue line). Base figure provided by Earth Consultants International, Inc. Most of the earthquakes shown occurred as a swarm in 2001 with the largest event being the M4.24 occurring on September 9, 2001. Most of these earthquakes occur at a depth of 6 to 8 km, hence, that is the depth where the Potrero Canyon Fault east is shown in the area of the earthquake swarm. Note that some faults shown from previous KGS reports and published reports have changed in terms of their location and that numerous published fault locations shown are not necessarily agreed upon in this study.



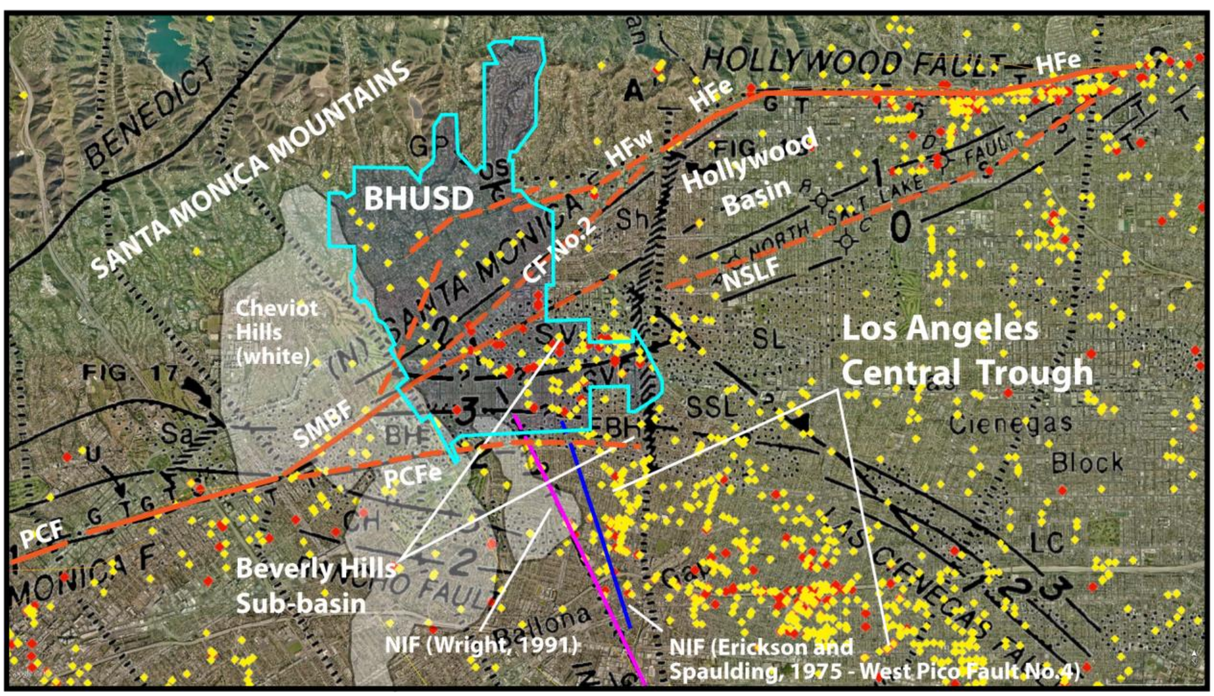
5.4 Red- and Yellow-tagged structures in the BHUSD region from the 1994 Northridge Earthquake – Evidence regarding the location of the northern Newport-Inglewood Fault

The 1994, M 6.7 Northridge Earthquake (Hauksson et al., 1995) caused considerable damage in the BHUSD region (Trifunac and Todorovska, 1997). Numerous red-flagged buildings considered unsafe for entry or continued usage occurred within the southern

BHUSD. Abundant yellow-tagged minor damage but habitable structures were also identified. The pattern of red- and yellow-tagged structures provides an insight regarding areas that are relatively more susceptible to amplified ground shaking. This issue is discussed later in the report.

The density of tagged structures decreases dramatically westward along a northwest trending line that is consistent with the location of the West Pico Fault No. 4 (Newport-Inglewood Fault) of Erickson and Spaulding (1975; blue line Figure 27). Farther to the west, there is a more subtle decrease in tagged structures across the Newport-Inglewood Fault as shown by Poland et al. (1959) and Wright (1991; purple line in Figure 27).

Figure 27: Approximate locations of red-flagged and yellow-flagged structures in the BHUSD region identified after the 1994 Northridge Earthquake. Note the concentration of red-flagged structures above the approximate east-west trending San Vicente Fault (SV, dark black line) in the southern BHUSD. A relatively high number of red- and yellow-flagged structures occurred in the region south of the Santa Monica Boulevard Fault (SMBF) and east of the Newport-Inglewood Fault. This region correlates with the Beverly Hills sub-basin where Wright (1991) shows a Holocene age northwest trending syncline (Figure 39), and modeled InSAR data shows an area of subsidence (Figure 14). The dramatic decrease of flagged structures toward the west occurs along a northwest trending line parallel to, and in close proximity to, the mapped location of the Newport-Inglewood Fault,(NIF) suggesting that the Newport-Inglewood Fault resides in this region. CF No.2 – Cross Fault No. 2; HFw – Hollywood Fault west; HFe – Hollywood Fault east; NSLF – North Salt Lake Fault; PCF – Potrero Canyon Fault; PCFe – Potrero Canyon Fault east; SMBF – Santa Monica Boulevard Fault.



North of Ballona Gap, the decrease in tagged structure density decreases substantially westward across the proposed location of the West Pico Fault No.4, which extends east and southeast of the Cheviot Hills (white shaded area on Figure 27). In the northernmost region of the West Pico Fault No. 4, the fault is overlain by a relatively planar alluvial surface and not bounding the eastern edge of the Cheviot Hills. Hence, the location of tagged structures associated with the 1994 Northridge Earthquake supports the proposal that a strand of the Newport-Inglewood Fault Zone (West Pico Fault No. 4) occurs east of the Cheviot Hills. It is interesting to note that where West Pico Fault No. 4 enters the BHUSD, the density of tagged structures is similar on both sides of the fault. This suggests that if the fault extends this far north, it is dying out or extending to deeper depths.

There is a clustering of yellow- and red-flagged structures north and south of the left-lateral Potrero Canyon Fault East (Figure 27). The near surface (upper couple thousand feet) Beverly Hills Sub-basin located south of the Santa Monica Boulevard Fault and north of the proposed Potrero Canyon Fault East may be trapping seismic waves from regional major earthquakes causing increased local ground shaking conditions.

5.5 Change in tectonic strain directions during the Quaternary – suggests Newport-Inglewood Fault migrated north since 2.5 Ma

The orientation of fold axis and their age of development indicate local tectonic stress directions during a particular period of time. If the right-lateral strike-slip Newport-Inglewood Fault migrated northward from the Baldwin Hills during the Pleistocene as indicated by Wright (1991), then local tectonic stress directions would change over time and be reflected in shifting local fold axis orientations. This concept was explored by comparing structure contour maps of sedimentary formations over the past 2.5 million years, namely, structure contour maps of 2.5 and ~1.0 million years old (Ma), and evaluation of the deformed fan-terraces surfaces in the Cheviot Hills that are ~580 to 400 kya.

Hummon (1994) created a detailed structure contour map of the 2.5 million year old contact between the Pico and Repetto formations (Plate 5). The map exhibits numerous fold axis that trend approximately N75W in the region immediately northwest of the Baldwin Hills (thick gray lines in Plate 5). The west-northwest tectonic trend is also consistent with those identified by Lang and Dreessen (1975) in the area within Miocene age sediments. The WNW fold axis indicates that tectonic compressional stress directions were oriented approximately north-south (NNE to SSW).

A structure contour map of 0.8 to 1 million year old marine gravels (Hummon, 1994; Hummon et al., 1994) exhibits fold axis within the Baldwin Hills and toward the northwest along strike with the Newport-Inglewood Fault that trend approximately N30W, locally very similar to structure contours of water bearing gravels within the ~1 Ma San Pedro Formation from Poland et al. (1959; Plate 6). These two studies were likely mapping either the same unit or member of the same formation (i.e. San Pedro Formation) as both show a northwest trending gentle anticline extending from the Baldwin Hills to the Cheviot Hills. Wright (1991) also identifies a northwest trending, east dipping monocline that extends from the southern to the northern Cheviot Hills.

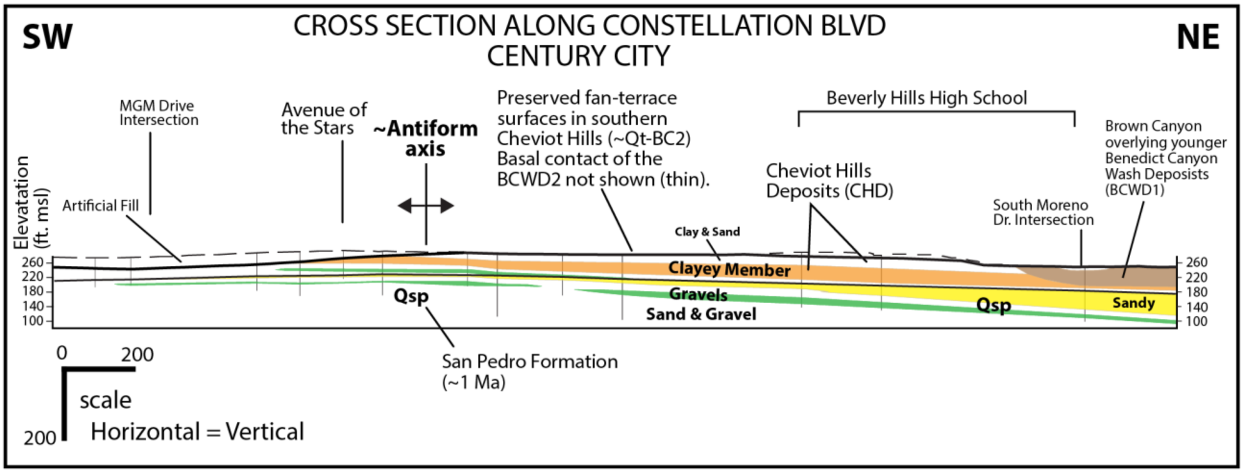
KGS (2012 & 2014) identified a gentle north-northwest trending anticline within ~580 kya (Qt-BC2 of Figure 7) fan-terraces in the southern Cheviot Hills. The fold also deformed marine terraces of unknown age in the southern Cheviot Hills (Figure 7). As observed in the Constellation Boulevard cross section (Figure 28), the San Pedro Formation and overlying “Clayey Member”, which is Cheviot Hills Deposits (CHD), are deformed about equally. This suggests that uplift associated with the development of the anticline did not begin until after deposition of the Cheviot Hills Deposits as shown in Figure 28. However, the uppermost members of the Cheviot Hills Deposits in the Century City area consist primarily of sandy clay members, that are finely bedded, many of which exhibit rhythmic “varve” type bedding (Parsons, 2011; KGS, 2012, 2014). This type of unit suggests that it was deposited in a region of low relief, and not associated with alluvial fans. Hence, the Cheviot Hills Deposits were likely deposited prior to local uplift of the Cheviot Hills. Subsequent to deposition of the older Benedict Canyon Wash Deposits (BCWD2), erosion into the Cheviot Hills Deposits occurred. The Qt-BC2 preserved fan-terraces are deformed slightly less than the underlying “Clayey Member” of the Cheviot Hills Deposits (Figure 28). The Qt-BC2 fan-terrace surface and associated soil (Marker Horizon A, Figure 22) developed in the upper most member of the older Benedict Canyon Wash Deposits (BCWD2). Hence, the gentle north-northwest trending anticline in the southern Cheviot Hills likely formed sometime during deposition of the BCWD2 and/or abandonment of the Qt-BC2 surface.

The anticline is therefore a tectonically recent structure having developed since the mid-Quaternary and may or may not remain active through the Holocene due to the recent development of the Potrero Canyon Fault East. Alternatively, if the Potrero Canyon Fault East exhibits a restraining bend orientation, then the anticline and its syncline pair (Hollywood Sub-basin) may remain active since the latest Pleistocene. Although improved age data on the anticline is needed, these structures provide insights regarding the local stress directions in the area to indicate that stress orientations have changed in the southern Cheviot Hills since the early Quaternary. The anticline developed due to east-west compression associated with left-lateral movement on the Potrero Canyon-Santa Monica Boulevard Fault System causing rocks south of these faults to buttress up against the Newport-Inglewood Fault (Plate 3). Stress buttressing resulting in strain across strike-slip faults is common in the upper most crust (Kenney, 1999, 2008), and even at very shallow depths of hundreds of feet (Kenney, 2007; KGS, 2013). Development of the north trending anticline in the southern Cheviot Hills may have migrated northward, hence, initiating in the southern Cheviot Hills, as the Newport-Inglewood Fault Zone migrated north of Ballona Gap. This is supported by the higher relief of the southern Cheviot Hills relative to the central Cheviot Hills (Figure 29).

The results shown on Plate 5 and discussed above for the north-northwest trending anticline in the southern Cheviot Hills indicate a shift in strain orientations (fold axis rotations) that reflects a change in tectonic stress occurred approximately 2.5 and 1.0 Ma in the Cheviot Hills near the region of the northern projection of the Newport-Inglewood Fault Zone north of Ballona Gap. Deformation occurring prior to 2.5 Ma was characterized by approximately north-south compression, and that trend changed to be approximately parallel to the Newport-Inglewood Fault at ~1 Ma particularly north of the Baldwin Hills and within the southern Cheviot Hills. Most of the oil field structures, which are generally deeper than 3000 feet, indicate approximately only north-south compressional strain. However, since approximately 1 Ma, the fold axis in the region of the Cheviot Hills exhibit approximately north-south to north-northwest trending fold axis suggesting an east-west oriented compression. These types of structures are common along the Newport-Inglewood Fault, including in the Baldwin Hills, indicating that the Newport-Inglewood Fault likely had migrated northward from Ballona Gap within the past ~1 Ma.

However, it remains unclear whether or not compressional structures remain active north of the Potrero Canyon Fault East since ~200 kya. Collectively, the data suggest that the Newport-Inglewood Fault had migrated as far north as the Santa Monica Boulevard Fault Zone during the early Quaternary. However, these northern fault strands of the Newport-Inglewood Fault Zone became inactive when they were cut off due to the development of the east-west trending Potrero Canyon Fault East during the past several hundred thousand years.

Figure 28: Cross section approximately along Constellation Boulevard modified from KGS (2012) showing the approximately north-northwest trending Quaternary antiformal fold in the southern Cheviot Hills. Location of cross section shown on Figure 11.



5.6 Development of the West Beverly Hills Lineament

The higher relief of the Cheviot Hills in association with a relatively planar alluvial fan surface to the east has long been proposed to be associated with the presence of the Newport-Inglewood Fault extending to latitudes of the southern Cheviot Hills (Hoots, 1931; Grant and Sheppard, 1939; Poland et al., 1959; Hill, 1971; Yeats, 1973). Dolan and Sieh (1992) and Dolan et al. (1997) proposed the West Beverly Hills Lineament as a northwest trending, eastward sloping tectonic geomorphic feature occurring along the west side of Moreno Creek from the base of the Santa Monica Mountains to the southern Cheviot Hills (Figure 29), and labeled it as a northward extension of the Newport-Inglewood fault. A fault investigation by Parsons (2011) proposed that numerous strand of the West Beverly Hills Lineament – Newport-Inglewood Fault Zone were identified, determined to be active, and that extended through the Beverly Hills High School property and west to the BHUSD office building.

These findings led to numerous fault investigations to determine whether or not these faults exist (LCI, 2012a, 2012b, 2012c, 2015, 2016; MTA-Parsons, 2012a, 2012b; CGS, 2012, 2016; Feffer and Geocon, 2012; Geocon, 2014). In addition, fault evaluations were conducted to re-evaluate the Parsons (2011) findings utilizing their data and all other available data at the time (KGS, 2012; 2013, 2014). The West Beverly Hills Lineament confusion regarding various hypothesis of the existence of potential faulting, and inconsistencies regarding the presentation of postulated faults by various agencies and companies, led to a peer review journal publication discussing the complexities of the entire geologic professional process (Gath et al., 2013).

It is clear that public entities such as the MTA, USGS, and CGS have supported the hypothesis that a northwest trending fault zone occurs along the West Beverly Hills Lineament, although no faults had ever been positively identified associated with the development of the lineament, even to this day. The only study to identify possible faults associated with the development of the West Beverly Hills Lineament (i.e. faults strike approximately parallel to the West Beverly Hills Lineament) was KGS (2014). In this study, early Pleistocene units (~1 Ma San Pedro Formation and immediately overlying sediments Qeb and Qfob, see Figure 12) were interpreted as displaced by minor faults that trended north-northwest. This fault zone was referred to as Fault Zone H (Figure 11). However, it should be pointed out all fault strands interpreted in Fault Zone H have never been physically observed as they were inferred from continuous core boring and CPT data, and that if they are faults, and based on that same data, they became inactive by the at least the mid- to late Pleistocene ~200 kya, around the same time as cessation of activity on the Santa Monica Boulevard Fault Zone.

The West Beverly Hills Lineament is discussed in this section of the report regarding the Newport-Inglewood Fault simply because of the large number of publications that associate a causative link between them. However, as discussed in this section, while the Newport-Inglewood Fault is assumed to play a role in the development of the southern West Beverly Hills Lineament, it was not present along the northern segment of the West Beverly Hills Lineament. The role played by the Newport-Inglewood Fault in the development of the southern West Beverly Hills Lineament was indirect: the southern West Beverly Hills Lineament was not formed by near surface faulting, but instead due to associated tectonic folding (uplift and subsidence), later defined by erosion and deposition processes of Moreno Creek.

The N30W trend of the West Beverly Hills Lineament is approximately parallel with, but shifted 1.3 to 0.8 km west of the northward projection of the Newport-Inglewood Fault Zone strands, suggesting a causative relationship (Figure 29). However, the Quaternary tectonics along the West Beverly Hills Lineament are modeled as different north and south of the Santa Monica Boulevard Fault Zone, which defines the northern and southern Cheviot Hills, and are discussed separately. Moreno Creek, which is fed primarily from Benedict Canyon in the southern Santa Monica Mountains, has a watershed of approximately 8.6 square kilometers (3.3 square miles), and flows directly along the eastern side of the WBHL. However, it is important to realize that the same older alluvial (and marine) deposits occur east of Moreno Creek as well, extending into the western Hollywood Basin, indicating that the Cheviot Hills geologically occur east of Moreno Creak. In addition, Moreno Creek is “antecedent” in the northern West Beverly Hills Lineament area along a small section where it incises into older alluvial deposits of

Benedict Canyon Wash younger sediments (BCWD1; Figure 29). This relationship of older alluvial deposits on either side of the apex of the fan where Moreno Creek exits the Santa Monica Mountains is very similar to stream apex locations west of the West Beverly Hills Lineament essentially to the coast. This indicates that uplift of the Cheviot Hills proper was not necessary to assist in producing the upper most portions of the northern West Beverly Hills Lineament near the base of the Santa Monica Mountains and northwestern Hollywood Basin. Toward the east of the northern West Beverly Hills Lineament, a planar alluvial fan apron occurs in the western Hollywood Basin (Figure 29) and understanding how this planer alluvial fan apron formed is critical to the understanding of the development of the northern West Beverly Hills lineaments. This is discussed later in this section.

Moreno Creek also played a dominant role in the development of the southern West Beverly Hills Lineament. In this area, the West Beverly Lineament is generally identified along Moreno Creek. However, Moreno Creek has clearly eroded “through” the southern Cheviot Hills resulting in a set of small hills east of the West Beverly Hills Lineament referred herein as the southeastern Cheviot Hills (Figure 29). This condition would not have occurred unless the erosion potential of Moreno Creek into the moderately consolidated terrestrial and marine Pleistocene sediments of the southern Cheviot Hills was sufficient to outpace the uplift rate of the hills themselves. Hence the dominant southern West Beverly Hills Lineament formation factors were the erosion and depositional processes of Moreno Creek into the Cheviot Hills. The cause of the uplift of the southern Cheviot Hills in the first place is discussed later in this section.

5.6.1 Geomorphology of Moreno Creek along the eastern Cheviot Hills

The local relief between Moreno Creek and the adjacent hills varies considerably along the length of the West Beverly Hills Lineament. Along the northern West Beverly Hills Lineament, the relief gradually decreases from the north at ~50 feet near the fan apex, to 25 feet in the area of the Santa Monica Boulevard Fault Zone (Figure 29). Along the southern Western Beverly Hills Lineament section, the opposite relief variation occurs where the relief decreases northward from ~100 feet in the southernmost Cheviot Hills, to 25 feet near the Santa Monica Boulevard Fault (Figure 29). Hence, the lowest relief area is at the boundary between the north and south West Beverly Hills Lineament along the Santa Monica Boulevard Fault.

The low relief between the hills and the Moreno Creek drainage along the Santa Monica Fault is partly due to down faulting in the region of the Santa Monica Boulevard Fault and Cross Fault No. 1 (KGS, 2012; 2014). In addition, as discussed in the geomorphic evaluation section of this report, the southern Cheviot Hills exhibit a relatively horizontal upper fan-terrace surface along the axis of the north-northwest trending anticline that intersects the Santa Monica Boulevard Fault, and a southward sloping degraded "alluvial fan" system north of the Santa Monica Boulevard Fault (Figure 7), resulting in a slope inflection point between the southern and northern Cheviot Hills as shown on Figure 8. This suggests that different geological processes likely led to the local relief observed along Moreno Creek in the northern vs. southern Cheviot Hills. The highest relief area is in the southernmost Cheviot Hills suggesting that this region has experienced a relatively higher magnitude of uplift than the hills to the north. The relief of approximately 100 feet from the stream elevation of Moreno Creek where it flows between the southern and southeastern Cheviot Hills is higher in magnitude than any other local relief to the west. This indicates that this region has been uplifted since the early to middle Quaternary, with the age based on eroded terrestrial Cheviot Hills Deposits in the southern Cheviot Hills.

Along the northern West Beverly Hills Lineament, the local relief between Moreno Creek and the Cheviot Hills is equal if not less than that observed for other drainages incised into older alluvial deposits from the Cheviot Hills to the coast. For example, local relief along Brown Canyon Wash and Stope Canyon and the adjacent top of the northern Cheviot Hills is approximately 35 and 55 feet respectively (Figure 29). The magnitude of local relief between drainages and older alluvial abandoned surfaces is similar all the way to the Pacific Ocean. This indicates that what sets the northern West Beverly Hills Lineament geomorphology apart from that observed to the west is the paucity of abandoned and degraded older alluvial deposits to the east of Moreno Creek, with the exception of the older alluvial fan "apex" deposits shown on Figure 29. Therefore, the key to understanding the northern West Beverly Hills Lineament is understanding why older alluvial deposits do not occur east of Moreno Creek, south of the older alluvial fan "apex" deposits in the western Hollywood Basin (Figure 29). This issue is discussed later in this section.

5.6.2 The West Beverly Hills Lineament development and left-lateral offset across the Santa Monica Boulevard Fault Zone

The West Beverly Hills Lineament is typically discussed as a continuous, northwest trending feature that follows Moreno Creek. However, the dominantly left-lateral Santa Monica Boulevard Fault System, and the fault becoming inactive ~200 kya have not been considered in this model. This report provides evidence of 1.18 to 0.64 km (average of ~ 1 km) of left-lateral displacement on the Potrero Canyon-Santa Monica Boulevard Fault System (Figure 18 and Figure 19). Once restored, the northern West Beverly Hills Lineament aligns with the outside edge of the Cheviot Hills (Figures 18 and 19, Stream G). With left-lateral motion restored on the Potrero Canyon-Santa Monica

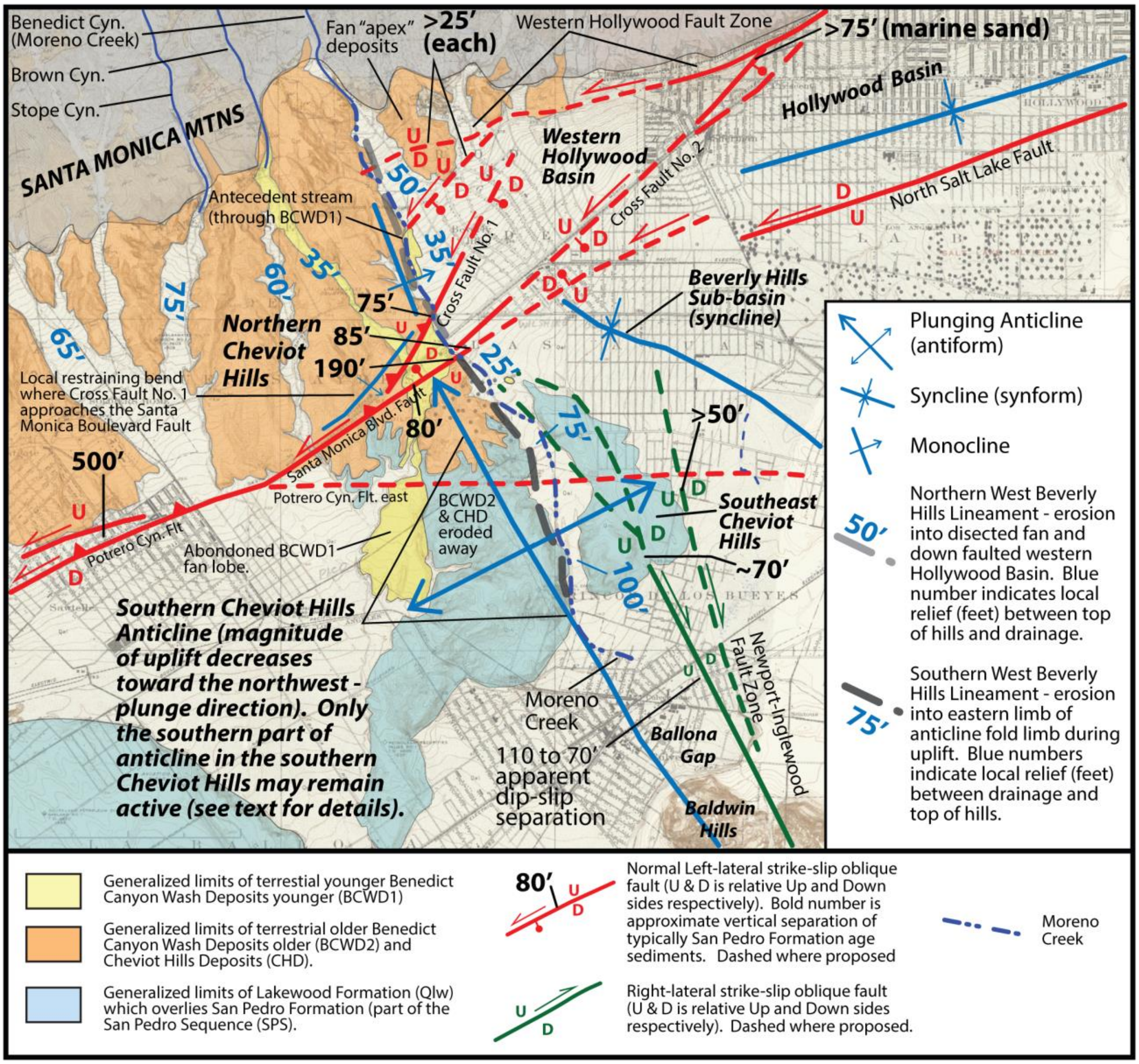
Boulevard Fault, the southern portion of the West Beverly Hills Lineament would have received drainage flow from Moreno Creek (Benedict Canyon) and from Brown Wash. Moreno Creek may have flowed along the southeastern most edge of the southeastern Cheviot Hills during early stages of development of the West Beverly Hills Lineament. Once left-lateral motion ceased on the Santa Monica Boulevard Fault ~200 kya, Moreno Creek was able to continue its episodic cycle of eroding and depositing along the eastern edge of the West Beverly Hills Lineament, which provided sufficient time to increase its linearity. In addition, the southern West Beverly Hills Lineament could have developed associated with erosion and flow from Brown Canyon Wash during earlier stages of development when some left-lateral slip is restored across the Santa Monica Boulevard Fault (see Figure 18 and Figure 19).

5.6.3 Tectonic factors that assisted in the development of the West Beverly Hills Lineament

Local folding (uplift and subsidence) and faulting, in combination with erosion and deposition, are necessary for the development of the northern and southern West Beverly Hills Lineament. As pointed out by Dolan et al. (1997), different tectonic mechanisms likely led to the development of the West Beverly Hills Lineament north of the Santa Monica Boulevard Fault (SMBF, northern Cheviot Hills; their Santa Monica Fault), verses south of the Santa Monica Boulevard Fault (southern Cheviot Hills). Dolan et al. (1997) proposed that the northern West Beverly Hills Lineament formed via an east dipping normal fault associated with extension along a left step between the Hollywood and Santa Monica Fault Zones. They however did not prefer this model because as they pointed out, the West Beverly Hills Lineament continued to the southern Cheviot Hills and they apparently preferred a single tectonic cause for the formation of the West Beverly Hills Lineament. They instead proposed an alternative model suggesting that the West Beverly Hills Lineament is formed by a series of left-stepping, en echelon right-lateral fault segments that make up the northern Newport-Inglewood Fault Zone. Dolan et al. (1997) also proposed that movement on the deep Compton Thrust may also play a role to assist in uplift of the region west of the Newport-Inglewood Fault.

In the following subsections, it is proposed that left-step cross faults in the western Hollywood Basin were necessary for the development of the northern West Beverly Hills Lineament, and that tectonic folding associated with the Newport-Inglewood Fault Zone migrating to latitudes of the southern Cheviot Hills were required for the development of the southern West Beverly Hills Lineament.

Figure 29: Structures associated with the development of the northern and southern West Beverly Hills Lineament (WBHL) segments that occurred primarily between approximately 1 to 0.2 Ma. The WBHL is proposed to have formed since the dynamic tectonic transition that occurred in the region approximately 1 Ma. The location of the Potrero Canyon Fault East is projected from depth to the surface along a steeply north dipping fault plane at depths of 3 to 8 km; it is not proposed to reach the surface along this trend as it is believed to be blind.



5.6.4 Development of the northern West Beverly Hills Lineament and western Hollywood Basin

The northern Cheviot Hills, defined as the region north of Santa Monica Boulevard and the Santa Monica Boulevard Fault Zone, exhibit dissected older fan contours (Figure 7) and dissected older alluvium of the Benedict Canyon Wash Deposits (BCWD2) and underlying Cheviot Hills Deposits (CHD; Figure 12, Figure 29). The local relief of the hills as measured from the difference in elevation of the local Moreno Wash and the adjacent Cheviot Hills ranges from 25 feet near the central region of the Cheviot Hills, to 50 near the apex fan area (Figure 29). Hence, the northern Cheviot Hills are a relatively subdued geomorphic feature.

The elevated alluvial fan sediments in the northern Cheviot Hills were derived from Stope, Brown and Benedict canyons (Figure 29). The preserved fan-terrace surfaces in the northern Cheviot Hills are estimated to be 580 to 400 kya (with the preferred age of 580 kya) and represent the uppermost member of the BCWD2 and identified as Qt-BC2 fan-terrace surfaces. This age is certainly a minimum for sediments close to the mountain front that in all likelihood are older but yet to be dated. Hence, incision by local drainages in the northern Cheviot Hills began at least ~600 kya.

Erosion patterns by Brown and Stope canyons through the central region of the northern Cheviot Hills are fairly linear, similar to Moreno Creek. They had sufficient stream power to erode through the Cheviot Hills in a similar manner as Moreno Creek had sufficient stream power to erode along the eastern edge of the Cheviot Hills thereby forming the West Beverly Hills Lineament. Also the magnitude of stream inset relief of Stope, Brown and Benedict (Moreno Creek) washes are similar, ranging from 50 feet along Moreno Creek, to 75 feet along Stope Canyon wash (Figure 29). This strongly suggests that the Cheviot Hills have not been uplifted independently compared to the alluvial fan areas west of the Cheviot Hills. This in turn indicates that the land east of the northern West Beverly Hills Lineament has dropped down tectonically, specifically, the region south of the fan "apex" deposits at the foot of the Santa Monica Mountains and east of the West Beverly Hills Lineament and east of the northern West Beverly Hills Lineament in the western Hollywood Basin.

A series of fault related scarps identified by Dolan and Sieh (1992) immediately east of the West Beverly Hills Lineament and in the northwest corner of the Hollywood Basin, the western Hollywood Fault occur in older alluvium. These scarps are identified in the fan "apex" area shown on Figure 29. The outcrops of older alluvium are likely close in age with the older Benedict Canyon Wash Deposits (BCWD2) and are essentially an eastward continuation of the northern Cheviot Hills sediments across the northern West Beverly Hills Lineament (Figure 29).

The geomorphology of the fan “apex” scarps exhibit a minimum of 25 feet down to the south for each of two faults in this area (Figure 29). Some of the scarps along the western Hollywood Fault are identified in alluvial sediments younger than BCWD2 when compared to mapping conducted by Hoots (1931). This suggests that the western Hollywood Fault Zone remained active after cessation of BCWD2 deposition and abandonment of the Qt-BC2 fan terraces and likely during or even since deposition of the younger Benedict Canyon Wash Deposits (BCWD1; Figure 29). This is consistent with fault investigations in the City of West Hollywood that determined that strands of the western Hollywood Fault Zone west of Cross Fault No. 2 had ruptured sediments up to approximately 120,000 years ago, but no active faults have been identified along this segment of the western Hollywood Fault Zone (Plate 4).

Additional faults are proposed to be part of the Western Hollywood Fault Zone, which include Cross Faults No. 1 and No. 2 (Figure 29; Plate 4). Cross Fault No. 1 (Fault Zone A in Figure 11) exhibits 75 feet down to the southeast of the ~1 Ma old San Pedro Formation in the Cheviot Hills (KGS, 2014; LCI, 2015). Cross Fault No. 2, which is proposed to connect with Fault No. 1 along the Hollywood Fault (Hernandez and Treiman, 2014), exhibits a minimum of 75 feet down to the southeast of a marine sand estimated to be 900 to 400 kya. This fault was determined to be active (WLA, 2004 – see Hernandez and Treiman, 2004) with its last major event occurring between 10 to 8.5 kya. Earlier, Earth Consultants International (1999) (see Hernandez and Treiman, 2014) had conducted a fault investigation down slope from the WLA (2004) site and concluded that the fault had not displaced Holocene age sediments. Hernandez and Treiman (2014) suggest however, that ECI correlated contacts that are not clearly continuous and some, albeit minor, Holocene offset could not be precluded because of the divergent WLA findings.

Cumulative apparent down to the southeast vertical separation across the step over faults in the western Hollywood Basin is a minimum of 200 feet (Figure 29; 50’ fan “apex” faults + 75’ Cross Fault No.1 + 75’ Cross Fault No.2). This value is sufficient to produce the observed relief between the northern Cheviot Hills and the western Hollywood Basin (Figure 29). This is shown on Figure 29 that indicates a relief from the top of the local Cheviot Hills to the current drainage ranges from only 55 to 35 feet (blue numbers) in the northern Cheviot Hills. Preserved topography from the down to the southeast faulting remains preserved in the fan “apex” region, and in the eastern Cheviot Hills immediately north of the Santa Monica Boulevard Fault and south of Cross Fault No. 1 where BCWD1 are exposed (Figure 29).

Movement across the step over faults was oblique left-lateral normal; however, it also led to some compression due to a restraining bend between the intersection of the southwestern end of Cross Fault No. 1 and the Santa Monica Boulevard Fault (Figure 29). In this area, tilting occurred north of the Santa Monica Boulevard Fault west of its intersection with Cross Fault No. 1 and in the region of the southwestern most portion of Cross Fault No. 1. This is observed in Transects 1 and 3 (Figure 12)

Another structural feature may also have been involved in the development of the northern West Beverly Hills Lineament. This includes a northwest trending monocline in the eastern Cheviot Hills that strikes approximately parallel with the West Beverly Hills Lineament (Figure 29). The monocline was identified by Wright (1991) and also observed in subsurface mapping of likely San Pedro Formation age deposits by Poland et al. (1959; Plate 6), Hummon et al. (1994; Plate 5) and KGS (2014). Fault and stratigraphic studies in the eastern Cheviot Hills immediately north of the Santa Monica Boulevard Fault Zone identified an approximate 3-degree eastward dip of the San Pedro Formation and overlying deposits (KGS, 2012; KGS, 2014; LCI, 2015). A similar dip in San Pedro Formation age sediments is also identified south of the Santa Monica Boulevard Fault (LCI, 2012a) and is the eastern limb of an anticline discussed in the next section. This monocline structure may simply have resulted from down-faulting associated with the cross faults in the western Hollywood Basin. However, Wright (1991) proposed that folding occurred in the Cheviot Hills area as a mechanism to absorb movement of the northern Newport-Inglewood Fault.

In summary, the northern West Beverly Hills Lineament developed as a result of erosion by Moreno Creek in combination with faulting in the western Hollywood Basin that dropped the basin sediments downward relative to the areas northwest of the faults. A left-step connecting the western Hollywood Fault Zone and the Santa Monica Boulevard Fault (SMBF) Zone occurring between ~1 and 0.2 Ma (Figure 29) played an important role. This is the period of time when the Santa Monica Boulevard Fault and western Hollywood Fault Zones were active. The general concept of this model was first proposed by Dolan et al. (1997). However, Dolan presumed that a normal fault occurred near and essentially parallel to the base of the West Beverly Hills Lineament. Note that this model of the development of the northern West Beverly Hills Lineament did not require any involvement from the Newport-Inglewood Fault Zone, nor involve any approximately north-south trending fault. The approximate north-south of the northern West Beverly Hills lineament is a direct result of erosion primarily associated with Moreno Creek emanating from Benedict Canyon.

5.6.5 Development of the southern West Beverly Hills Lineament

Most of the southern Cheviot Hills expose marine deposits (Hoots, 1931; Figure 29) are not well documented in terms of age and regional formational correlations. The most recent geologic maps from Yerkes (1997), and Yerkes and Campbell (2005) show only older alluvial deposits (terrestrial) exposed in the southern Cheviot Hills. This mapping is inconsistent with recent investigations. Rodda (1957) documents the marine late Pleistocene Medill Sand overly the early Pleistocene marine Timms Point Silt in the southern most Cheviot Hills (Figure 31). Rodda (1957) correlates the Timms Point Silt with the San Pedro Formation, which is consistent with Parsons (2011), (LCI, 2012a) and KGS (2014) stratigraphy in the Century City area within the central Cheviot Hills (Figure 12). The Lakewood Formation, a term utilized by Parsons (2011) and adopted by KGS (2012, 2014) for marine dominantly sandy sediments (near shore) deposited immediately on top of the San Pedro Formation may correlate with the late Pleistocene Medill Sand of Rodda (1957). However, the Lakewood Formation in the Century City area is clearly older than late Pleistocene and resides at higher elevations. The mapping with Rodda (1957) is consistent with mapped marine deposits in the southern Cheviot Hills by Hoots (1931). The point here is that the geomorphology and geologic history of the southern Cheviot Hills have very little to do with alluvial fan processes other than that alluvial fan deposits were eroded from the southern Cheviot Hills during early to late Quaternary uplift (Figure 29).

The southern part of the West Beverly Hills Lineament developed as the southern Cheviot Hills were elevated by uplift associated with a northwest trending and plunging anticline (Figure 7, Figure 29; KGS, 2012, 2014). The anticlinal structure (Poland et al., 1959 and Hummon et al., 1994) extends from the Santa Monica Boulevard Fault in the central Cheviot Hills to the Baldwin Hills and lies entirely west of the Newport-Inglewood Fault Zone (Figure 7; Plate 3, Plate 5 and Plate 6). Based on a geomorphic evaluation by KGS (2011), the northwest trending anticline was identified in the southern Cheviot Hills and suggested that it likely did not extend north of the Santa Monica Boulevard Fault (Figure 29).

The fold is believed to have begun forming in the Century City area sometime during later stages of deposition of the Cheviot Hills Deposits (CHD The BCWD2 and Cheviot Hills Deposits are both completely eroded away from the southern Cheviot Hills, indicating the area continued to be uplifted after deposition of BCWD2 (Figure 29). By the time of deposition of the younger Benedict Canyon Wash Deposits (BCWD1), the southern Cheviot Hills were already uplifted sufficiently to provide topographic control for local drainages (Figure 29). Upper members of the BCWD1 are defined as a minimum of 40 kya in the Century City area (KGS, 2014) and based on soil profile stratigraphic ages may have begun deposition sometime between 480 and 250 kya (Figure 22). The abandoned fan lobe of BCWD1 along the southwestern flank of the Cheviot Hills is likely over a hundred thousand of years old as it represents an early member of the unit (Figure 18 and Figure 19).

The magnitude of uplift due to development of the northwest trending anticline in the southern Cheviot Hills decreases toward the north indicating that the development of the fold may have migrated northward. Evidence for this includes: the fold plunges toward the north (Figure 7), elevations in the southern Cheviot Hills do not decrease very much along the fold axis, however the minimum depth of incision of Moreno Creek into the Cheviot Hills along the West Beverly Hills Lineament decreases from 100 feet in the south to 25 feet in the north (Figure 29).

The northwest trending anticline in the southern Cheviot Hills resulted from ~east-west compression due to left-lateral motion on the Potrero Canyon-Santa Monica Boulevard Fault System between ~1 to 0.2 Ma buttressed by the northern strands of the Newport-Inglewood Fault to the east (Plate 3). Since ~-0.2 Ma, The Santa Monica Boulevard Fault Zone became inactive, and the approximately east-west trending Potrero Canyon Fault East began its development along pre-existing fault and fold structures along the southern limits of the Beverly Hills Oil Field and along the location of the Las Cienegas Fault Zone. This fault is considered active, however its westward extension to the eastern end of the Potrero Canyon Fault is unknown and would require further study.

An interpretation of the INSAR data shown on Figure 14 (location labeled “Ua”) suggests that the anticline is active south of the Potrero Canyon Fault East. It is uncertain if the fold is active north of the Potrero Canyon Fault East. It is possible that the northern portion of the fold remained active after the development of the Potrero Canyon Fault East but the mechanism for its development changed. For example, the fold could have continued developing once the Potrero Canyon Fault East developed associated with the restraining bend orientation of the Potrero Canyon Fault East along the TRSBLL.

The Beverly Hills Sub-basin is associated with a northwest trending syncline occurring near the northern limits of the Newport-Inglewood Fault Zone. The eastern limb of the southern Cheviot Hills northwest trending anticline extends across the West Beverly Hills Lineament and southeastern Cheviot Hills (Figure 25) to the syncline axis of the Beverly Hills Sub-basin. Hence, the anticline and syncline are a fold pair proposed to be associated with compressional forces along the right-lateral strike-slip Newport-Inglewood Fault Zone.

Uplift rates for the anticline are estimated to be a minimum of 0.021 mm/yr (see text for details). Although the fold growth rate may have changed over time, this rate is sufficiently slow to allow for Moreno Creek to erode vertically into the moderately indurated marine sediments during uplift. The eastern limb of the anticline extends across the southern West Beverly Hills Lineament, hence, as the fold developed, Moreno Creek simply eroded into the uplifting sediments resulting in a fairly linear drainage.

In summary, the development of the southern West Beverly Hills Lineament reflected a combination of slow uplift of the local Cheviot Hills and concurrent erosion by Moreno Creek into the older uplifted sediments. This produced an antecedent stream flow of Moreno Creek through the southern Cheviot Hills to the west and the southeastern Cheviot Hills to the east. This model for the development of the southern West Beverly Hills Lineament does not require a strand of the Newport-Inglewood Fault Zone extending within the region of the antecedent Moreno Creek in the Cheviot Hills as is shown by published geologic maps, Dolan and Sieh (1992) and Tsutsumi et al. (2001).

In addition, the model does not require that strands of the Newport-Inglewood Fault Zone reach the surface along the entire length of the southern Cheviot Hills because the model only requires that uplift and subsidence associated with folding was needed to produce the erosional geomorphology and not surface fault rupture. In other words, as documented in the Baldwin Hills (Wright, 1991), transpressional folding occurred in the Baldwin Hills prior to the development of the Newport-Inglewood Fault strands rupturing near surface sediments. A similar geologic history is proposed for the southern, southeastern, and eastern parts of the Cheviot Hills. If the Newport-Inglewood Fault Zone does rupture to the surface north of Ballona Gap, it likely does in the southeastern nose of the Cheviot Hills based on a weak fault scarp interpreted from the LiDAR image (Figure 25), but there is no evidence of surface rupture north of the southeastern Cheviot Hills.

5.7 Estimate of the age of the northern Newport-Inglewood Fault Zone

Wright (1991) indicates that the Newport-Inglewood Fault in the Baldwin Hills exhibits approximately 1200 meters of right-lateral displacement since the latest Pliocene. This measurement can be utilized to grossly approximate the age of activity on the Newport-Inglewood Fault locally. Similar faults have 1 to 3 meter displacements per earthquake. If each earthquake on the Newport-Inglewood Fault exhibited 1 to 3 meters of right-lateral displacement, that would require 1200 to 400 total earthquakes to generate the 1200 meters of displacement. Assuming a recurrence interval of 1.2 to 3.0 thousand years, results in a range of ages for the inception of the Newport-Inglewood Fault from 0.5 to 3.6 million years.

But, because the Baldwin Hills are near the presumed termination region of the active portion of the Newport-Inglewood Fault Zone, it is reasonable to conclude that the magnitude of right-lateral displacement per event is closer to 1 m than 3 m. At 1 meter average displacement, 1200 meters of total right-lateral displacement, and recurrence intervals of 1.2 kya and 3.0 kya results in an age for the northern Newport-Inglewood Fault Zone of 1.4 to 3.6 million years respectively. This range of ages of the inception of near surface faulting along the northern Newport-Inglewood Fault is consistent with Wright (1991) latest Pliocene age estimate.

5.8 Summary of findings for the Newport-Inglewood Fault Zone

Numerous lines of evidence indicate that the Newport-Inglewood Fault Zone extended north of the Baldwin Hills to close proximity or within the southern regions of the Beverly Hills Unified School District. This northern portion of the Newport-Inglewood Fault Zone developed during the latest Pliocene to early Quaternary (early Pleistocene) as new fault strands migrated northward (Wright, 1991).

Published maps extending back to the early 1900′s provide evidence that the Newport-Inglewood Fault Zone extends through the Ballona Gap toward the northwest along a similar strike as the Newport-Inglewood Fault within the Baldwin Hills. These data also indicate that the Newport-Inglewood Fault Zone splays into numerous strands some of which cut through the southeastern Cheviot Hills and along the southeastern most margin of the hills to possibly reach the southern BHUSD. However, it was only during the past 30 years that geologic maps began showing a strand of the Newport-Inglewood Fault along the southern West Beverly Hills Lineament in the region of Moreno Creek.

Faults presumed to be the Newport-Inglewood Fault are documented to displace ~1 Ma, water bearing gravels (Pleistocene sediments; Poland et al., 1959; Erickson and Spaulding, 1975) approximately 60-90 meters vertically within Ballona Gap and east of the Cheviot Hills (Plate 7). However, there is no evidence of Holocene activity of the Newport-Inglewood fault north of Ballona Gap. In fact, there is no direct evidence that deposits younger than the San Pedro have been displaced north of Ballona Gap. Although it is well established that the Newport-Inglewood Fault is active south of the Baldwin Hills, the only evidence of fault activity north of the Baldwin Hills is the evaluation of historical seismicity attributed to the Newport-Inglewood Fault Zone (Hauksson, 1987; Hauksson et al., 2002).

Evaluation of well data indicates that apparent vertical displacement across the Newport-Inglewood Fault Zone in the central and northern Ballona Gap area is substantial, and similar in magnitude to values identified in the Baldwin Hills. The apparent offset of the San Pedro in Ballona Gap indicates that the Newport-Inglewood Fault Zone extends north of the southern Cheviot Hills, but how far remains unknown. Apparent vertical separation down to the east observed at depth in Ballona Gap is consistent with down to the east topography across a possible fault related scarp in the southeastern Cheviot Hills (Figure 25). Based on evaluation of LiDAR imagery, possible fault scarps were identified, and in particular, a possible scarp has been interpreted in alluvial deposits in the southeastern Cheviot Hills and northeast corner of Ballona Gap. The trend and location of the scarp identified on the LiDAR image aligns very closely with the West Pico Fault No. 4 of Erickson and Spaulding (1975). The northwest termination of the identified scarp also connects with the southeastern most edge of the Cheviot Hills (Figure 25).

In the region northwest of the Baldwin Hills along strike with the Newport-Inglewood Fault, changes in fold axis trends during the Quaternary suggest a northward migration of the Newport-Inglewood Fault Zone to the southern Cheviot Hills. Fold structures in the region of the southern Cheviot Hills that developed in the 2.5 million year old contact between the overlying Pico Formation and underlying Repetto Formation show a clockwise rotation of approximately 40 degrees from west-northwest, to northwest. These data are consistent with the northward migration of the Newport-Inglewood Fault from the Baldwin Hills to the BHUSD region since the latest Pliocene. The development of the early to late Quaternary-age, northwest trending anticline in the southern Cheviot Hills, and the Beverly Hills Sub-basin syncline also suggest that the Newport-Inglewood Fault extended north of Ballona Gap.

Local seismicity in the region of the proposed northern limits of the Newport-Inglewood Fault Zone east of the Cheviot Hills was evaluated as evidence of right-lateral faulting (Hauksson, 1987). However, as discussed earlier, the seismic cluster in the region of the M 4.4 2001 earthquake more strongly supports that a left-lateral fault zone (Potrero Canyon Fault East) transects the southern Cheviot Hills referred to herein as the (Figure 26; Hauksson et al., 2002).

Density of identified red- and yellow-tagged structures in the BHUSD region associated with the 1994 Northridge Earthquake decrease dramatically across the Newport-Inglewood Fault as mapped by Erickson and Spaulding (1975) West Pico Fault No. 4, and to a lesser degree the location of the "western" strand of the Newport-Inglewood Fault of Wright (1991; see Figure 27). The pattern of tagged structures provides supportive evidence that the West Pico Fault No. 4 occurs in close proximity to where Erickson and Spaulding (1975) mapped it. However, in the northernmost portion of the West Pico Fault No. 4, tagged structures continue across the fault suggesting that it may not extend as far north as originally proposed. It is possible that the West Pico Fault No. 4 also extended as far north as the southern Beverly Hills Unified School District, but this strand also became inactive once the east-west trending, dominantly left-lateral Potrero Canyon Fault East developed (Figure 26; Figure 27; Plate 4).

Quaternary tectonics in the region of the BHUSD has clearly undergone significant changes during the Quaternary, and particularly at the time of approximately 1 Ma and subsequently around 0.2 Ma. As discussed in this report, it was around 1 Ma that the blind, left-lateral reverse Santa Monica Fault North and South faults became inactive and the dominantly left-lateral Potrero Canyon Fault and Santa Monica Boulevard Fault Zones were created. Then, approximately 200 kya (0.2 Ma), the dominantly left-lateral east-west trending faults zones along the Transverse Ranges Southern Boundary Fault System "Left-Lateral" (TRSBLL) in the region of the Cheviot Hills and Hollywood Basin became inactive. These fault zones include the Santa Monica Boulevard, the western Hollywood, the western portion of Cross Fault No. 1, Cross Fault No. 2, and possibly the North Salt Lake Fault.

Near the time of cessation of activity of these local fault zones within the TRSBLL, a new approximately east-west trending, left-lateral strike-slip fault zone began to develop within the southern Cheviot Hills, the Potrero Canyon Fault East (Figure 26, Figure 27 and Plate 4). The Potrero Canyon Fault East developed along pre-existing east-west trending structures (faults and tilted sediments) within the Santa Monica Fault South of Wright (1991) and numerous faults shown by Tsutsumi et al. (2001). Hence, the Potrero Canyon Fault East developed along existing structural zones of weakness in the upper crust and in a similar fashion as the mechanism for the development of the Santa Monica Boulevard Fault and Potrero Canyon Fault discussed in this report (Figure 32 and Figure 34). In other words, the entire Potrero Canyon Fault System developed along structures closely associated with the Santa Monica Fault South of Wright (1991), which he proposes may have extended across the eastern Cheviot Hills. This model predicts that northern fault strands of the Newport-Inglewood Fault Zone occurring north of the Potrero Canyon Fault east (Plate 4) would be inactive as they are essentially cut off.

The model predicts that the Beverly Hills Sub-basin may in part develop as a consequence of a pull-apart left-step between the active eastern Hollywood Fault Zone (and North Salt Lake Fault?) and the Potrero Canyon Fault East. As discussed earlier, it cannot be ruled out that the northwest trending anticline in the southern Cheviot Hills may remain active if the orientation of the Potrero Canyon Fault East has a restraining bend trend relative to pure left-lateral slip along this segment of the TRSBLL. It is interesting to note that Wright (1991) shows a northwest-west trending Holocene anticline in the southwestern Cheviot Hills that could have resulted from transpression along the proposed Potrero Canyon Fault East (Figure 37).

During the late Pliocene to early Pleistocene, compressional deformation had already began to be accommodated to the north and south of the Santa Monica Fault North and South, and this was likely accelerated approximately 1 Ma when these faults became inactive. Compressional deformation migrated northward to the Camarillo Fold and Thrust Belt in the central Western Transverse Ranges during the past approximately 200 kya (Region B of Figure 5) and to faults to the south underlying Santa Monica-Culver City (i.e. Culver City Fault) and various faults east of the Newport-Inglewood Fault in the northern Los Angeles Basin.

These tectonic changes are introduced here because they likely had an effect on the activity of the northern Newport-Inglewood Fault. It is possible that the Newport-Inglewood Fault migrated northward to within the southern regions of the BHUSD during the early Pleistocene when oblique reverse left-lateral deformation was focused along the TRSB (Santa Monica Fault North and South), but became inactive once compressional deformation associated with the southern boundary of the Western Transverse Ranges fully migrated to the north and south of the TRSBLL. In other words, it is possible that the Newport-Inglewood Fault Zone migrated northward close to the Santa Monica Boulevard Fault (i.e. Fault Zone H in Figure 11), but then abandoned these strands soon after cessation of activity on the Santa Monica Boulevard Fault and creation of the Potrero Canyon Fault East. These issues are discussed in more detail in Sections 6.0 and 9.0.

6.0 CREATION OF THE SANTA MONICA BOULEVARD AND POTRERO CANYON FAULT ZONES - DRAMATIC TECTONIC CHANGES DURING THE QUATERNARY

This section provides evidence of the age of creation, style of motion, and complexities in the literature of the "Santa Monica Fault Zone", which extends from the Pacific Ocean to the western Hollywood Basin. This evaluation has large ramifications for any seismic hazard evaluation of the region. This is because some faults within this zone are shown to be inactive, others are active, some previously unknown active faults exist, and the style of displacement of the faults remains controversial in published literature. One of the primary reasons for the confusion regarding the "Santa Monica Fault" zone is that this east-west trending tectonic zone exhibited normal extensional faulting in the Miocene, and then compressional oblique reverse left-lateral deformation in the Pliocene to early Pleistocene, evolving to nearly pure left-lateral slip ~1 Ma, and several strands becoming inactive at ~200 ka.

6.1 The Santa Monica Fault Zone – Inactive, blind, oblique reverse left-lateral faults

There is considerable confusion regarding what is the Santa Monica Fault, where does it exist, what type of fault is it, is it active, etc. Much of this confusion stems from the fact that the name "Santa Monica Fault" has been applied to essentially two parallel, but very different fault zones.

There are older, inactive, blind, oblique reverse left-lateral faults that reside parallel to, and south of the Potrero Canyon Fault and the Santa Monica Boulevard Fault, which are referred to as the Santa Monica Fault South and Santa Monica Fault North by Wright (1991) (Figure 32). The Santa Monica Fault South of Wright (1991) and Tsutsumi et al. (2001) occur below, and project south of the currently mapped location of the Santa Monica Fault of Dolan and Sieh (1992) in the region of the Pacific Ocean coastline, and the Mormon Temple (Plate 4). Toward the east, the Santa Monica Fault North of Wright (1991) is a blind, inactive, oblique reverse left-lateral fault that occurs south of the Dolan and Sieh (1992) mapped location of their Santa Monica Fault in the Cheviot Hills.

The Potrero Canyon Fault and the Santa Monica Boulevard Faults are typically referred to collectively as the Santa Monica Fault Zone in the literature (Crook and Proctor, 1992; Dolan and Sieh, 1992; Dolan et al., 2000a; Plesch et al., 2007; Catchings et al, 2008). However, it is clear that the Potrero Canyon and Santa Monica Boulevard Fault Zones are distinct, at least in the near surface, from the deeper, blind Santa Monica Fault North and South of Wright (1991). This study attempted to understand the relationship of the blind, older inactive oblique faults (Santa Monica Fault North and South), and the younger faults that rupture to the surface (Potrero Canyon and Santa Monica Boulevard faults) as understanding this relationship is critical for evaluating local and regional seismic hazards. The question arises regarding which of these faults is the "Santa Monica Fault"? Do both exist? Are both fault zones active, or is one active and the other not? A detailed review and analysis of data and findings from Wright (1991) and Tsutsumi et al. (2001) has led to the proposal of an entire new kinematic history of the "Santa Monica Fault Zone" from the Pacific Ocean to the Cheviot Hills (Century City – BHUSD) region.

Wright (1991) was insightful in that he referred to the "Santa Monica Fault" that has been shown to rupture to the surface west of the Mormon Temple near the VA Hospital as the Potrero Canyon Fault (Plate 4). This allowed Wright (1991) to only use the name Santa Monica Fault for those that were inactive, blind, oblique reverse left-lateral. These include his Santa Monica Fault North and South as shown on Figure 32. Unfortunately, no recent publications since Wright have adopted his nomenclature of the Potrero Canyon Fault for the surface-rupturing westernmost strand of the Santa Monica Fault Zone (Plate 4). This may be due to the fact that there is a fault that has been identified for years in Potrero Canyon at the coast that remains controversial whether or not it is even a fault or if it is a landslide structure (Plate 4). The name Potrero Canyon Fault is adopted here for the fault strand that extends from the coast to the Mormon Temple in the western Cheviot Hills throughout this report, although, it is not required to connect with the fault identified along the coast in Potrero Canyon. It remains unknown exactly where the western end of the Potrero Canyon Fault occurs as it approaches the coast.

Wright (1991), did not fully evaluate the relationship of the Santa Monica Fault South with that of his Potrero Canyon Fault, which he simply shows as two different fault zones. Wright (1991) also shows his Santa Monica Fault North in the central Cheviot Hills and western Hollywood Basin as an inactive, blind oblique fault and did not identify a shallower fault analogous to the Potrero Canyon Fault to the east. Wright (1991) was unaware of the surface-rupturing strand of the "Santa Monica Fault" in the Cheviot Hills, which in this report is the Santa Monica Boulevard Fault, mapped by Dolan and Sieh (1992) and Tsutsumi et al. (2001).

In contrast, Tsutsumi et al. (2001) did identify Wright's (1991) Potrero Canyon Fault, but confusingly labeled it the Santa Monica Fault North. Tsutsumi et al. (2001) also identified Wright's Santa Monica Fault South, and referred to this fault as the Santa Monica Fault South (S Strand). Toward the east, Tsutsumi et al. (2001) did identify a shallow fault that has now been confirmed to exist along the location of the proposed scarps of Dolan and Sieh (1992). This fault is referred to herein as the Santa Monica Boulevard Fault. However, Tsutsumi et al. (2001), and nearly all other workers refer to this fault as the Santa Monica Fault even though Wright (1991) shows the Santa Monica Fault North occurring at depth.

One of the motivations of this study was to provide a consistent nomenclature to assist in clearing up the names of the various faults. All of this can be achieved by maintaining the name Potrero Canyon Fault as defined by Wright (1991), and labeling the near surface fault in the Cheviot Hills the Santa Monica Boulevard Fault as done by KGS (2012, 2014). The use of the Potrero Canyon Fault and Santa Monica Boulevard Fault labels will allow for the name Santa Monica Fault to only be used for the blind, inactive, oblique reverse faults that were active during the late Pliocene to early Pleistocene. These faults are shown on Plate 4. Utilizing the new names for the various faults will greatly assist in discussing the style, age, location, and tectonic history of the area.

6.2 Creation of the Santa Monica Boulevard and Potrero Canyon Fault Zones

Wright (1991) provided an insightful evaluation of the “Santa Monica Fault” between the Pacific Ocean to the Cheviot Hills in the sense that he decided to call the surface expression fault along the “Santa Monica Fault” System the Potrero Canyon Fault. In other words, he reserved the name Santa Monica Fault for the blind, inactive, oblique reverse left-lateral Santa Monica Fault South. The Potrero Canyon Fault of Wright (1991) exhibits a nearly identical development history as the Santa Monica Boulevard Fault.

The Santa Monica Faults South and North of Wright (1991) changed from oblique, reverse left-lateral fault zones to dominantly left-lateral during the early Pleistocene (~1 Ma). At this time, the Santa Monica Boulevard and Potrero Canyon fault zones were created to accommodate the dominantly left-lateral motion above the blind Santa Monica Fault South and North at depths less than 1 km (Figure 30). At the same time, the “tip” of the Santa Monica Fault South and North of Wright (1991), became inactive, while the portion of the faults below their intersection with the Potrero Canyon and Santa Monica Boulevard Fault zones remained active, but transitioned into dominantly left-lateral strike-slip faults (Figure 30, Figure 31). The Potrero Canyon Fault may have simply cut through the Santa Monica Fault South to connect with an older Miocene normal fault as shown on Figure 34.

There are numerous lines of evidence to support the concept that the Potrero Canyon and Santa Monica Boulevard fault zones deserve their own name designation:

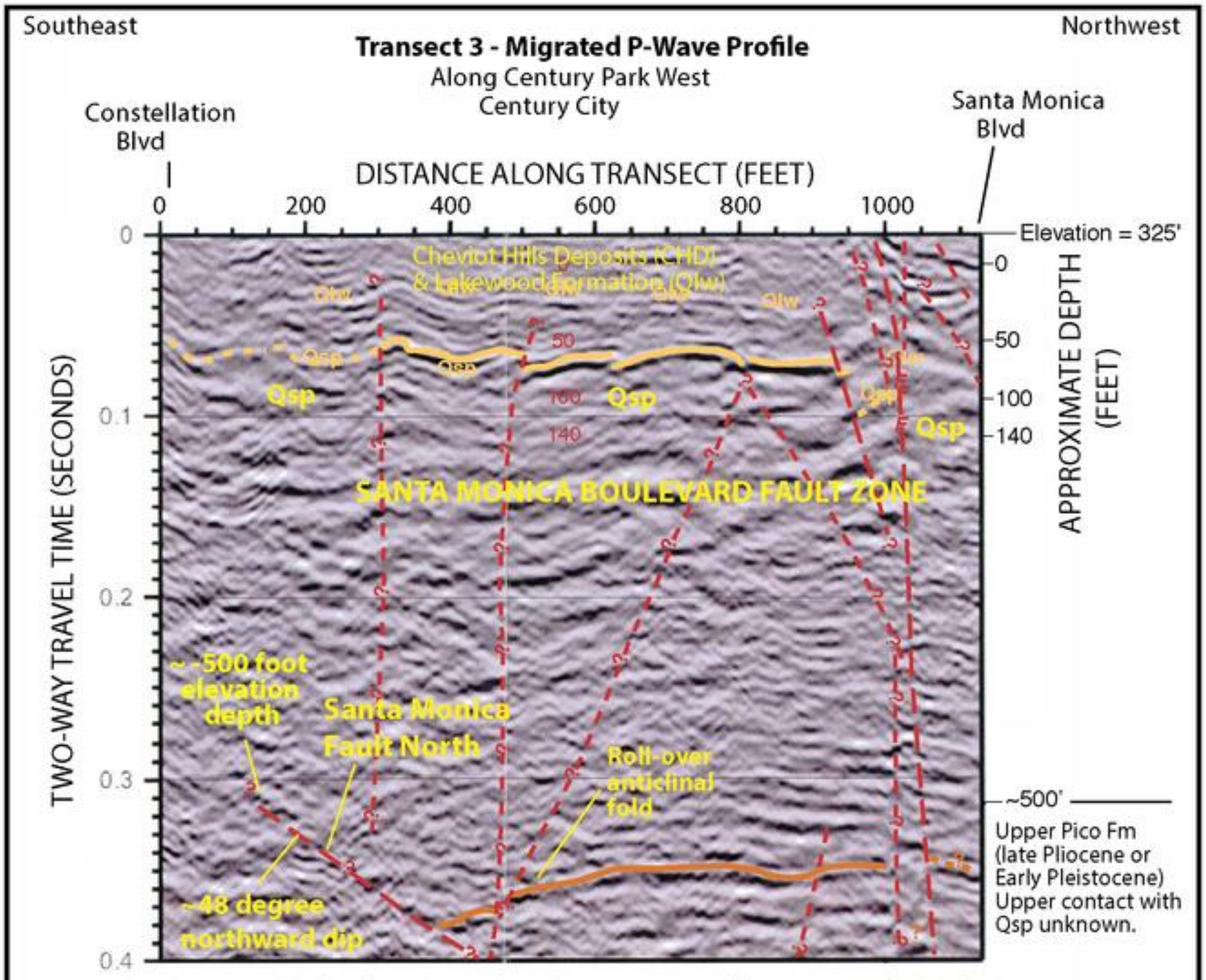
- Both have ruptured to the surface during the Quaternary.
- The Potrero Canyon Fault is a left-lateral strike slip fault that was created only about 1 Ma (0.9 Ma, Tsutsumi et al., 2001) and remains active today.
- The Potrero Canyon Fault is active and extends to the surface or near surface in contrast to the blind, inactive Santa Monica Fault South at depth.
- The Santa Monica Boulevard Fault is a distinct fault in the near surface in that it connects with the older and inactive Santa Monica Fault North of Wright (1991) at a depth of ~0.6 km. Hence, at least in the near surface, they are two different faults zones.
- The Santa Monica Boulevard Fault is a dominantly strike-slip fault (KGS, 2011, 2012, 2014) and not a reverse fault in contrast to the typical description of the Santa Monica Fault North as an oblique reverse left-lateral fault zone.
- The Santa Monica Boulevard Fault is geologically very youthful; having only formed about 1 million years ago (Ma) and also ruptured to the surface until ~200 kya when it became inactive.

Dr. Mark Legg was requested to perform a secondary review (analysis) of a north-south trending seismic reflection line conducted by Parsons (2011; Figure 11). Dr. Legg's (personal communication; Figure 30) analysis indicated that a fold structure is likely associated with a reverse fault with an upper termination depth of approximately 500 feet deep, and that the fault dips approximately 48 degrees to the north (Figure 30). The fold occurs in Pliocene to early Pleistocene upper Pico Formation, which underlies the San Pedro Formation (Qsp). Fault Zone F, (i.e. Santa Monica Boulevard Fault Zone, Figure 11), connects with the Santa Monica Fault North at a depth of approximately 0.6 to 1 km, which is consistent with the depth location of the Santa Monica Fault North of Wright (1991; Figure 31; Plates 4a and 4b).

The Santa Monica Boulevard Fault connects at depth with the Santa Monica Fault North toward the northeast along the southern boundary of the western Hollywood Basin (Figure 13), where it terminates near the northwestern edge of the Salt Lake Oil Field (Figure 14, Figure 15, Figure 16, and Figure 32). This model predicts that Cross Fault No. 2 (Plate 3) connects with the Santa Monica Fault North as well but at progressively deeper depths toward the northeast (Figure 32). However, Cross Fault No. 2 may also connect with the Santa Monica Fault North of Wright (1991) as well.

Evidence that the Santa Monica Boulevard Fault was formed about 1 Ma comes from a number of sources. The ~1 Ma San Pedro Formation (Qsp) is offset approximately equal amounts, at least in terms of apparent dip-slip separation as immediately overlying sediments Qfob and Qeb (Figure 12). The magnitude of apparent dip-slip separation across the Santa Monica Boulevard Fault is essentially equal for the contact between the base of the Quaternary and upper Pico, and the upper Pico and Middle Pico as evaluated on Cross Section D-D′ of Tsutsumi et al. (2001; Figure 33). This indicates that the fault was young, and created sometime during latest Pliocene to early Quaternary. As discussed in Section 4.0, the left-lateral strike slip displacement and slip rate analysis of the Santa Monica Boulevard-Potrero Canyon Fault System, the Santa Monica Boulevard Fault could not have been active much more than approximately 1 Ma because if it had, it would have accumulated more vertical apparent separation across the Potrero Canyon Fault due to its restraining bend orientation. And lastly, the Tsutsumi et al. (2001) determined that the Potrero Canyon Fault developed approximately 0.9 Ma, and its geologic history of development is intrinsically connected to that of the Santa Monica Boulevard Fault.

Figure 30: Modified and re-interpreted Seismic Transect Line 3 from Parson (2011) in Century City along Century Park West. Location of the transect line shown on Figure 11 and Cross Section C-C' (Figure 31)



Seismic profile data from Parsons (2011). Interpretation of the seismic profile data by Legg Geophysical Inc. (2012b). Approximate depth and dip of potential blind reverse Santa Monica Fault provided by M. Legg (2012, personal communication)

Figure 31: Generalized geologic Cross Section C-C' through the Cheviot Hills. Location of the Cross Section C-C' shown on Figure 7.

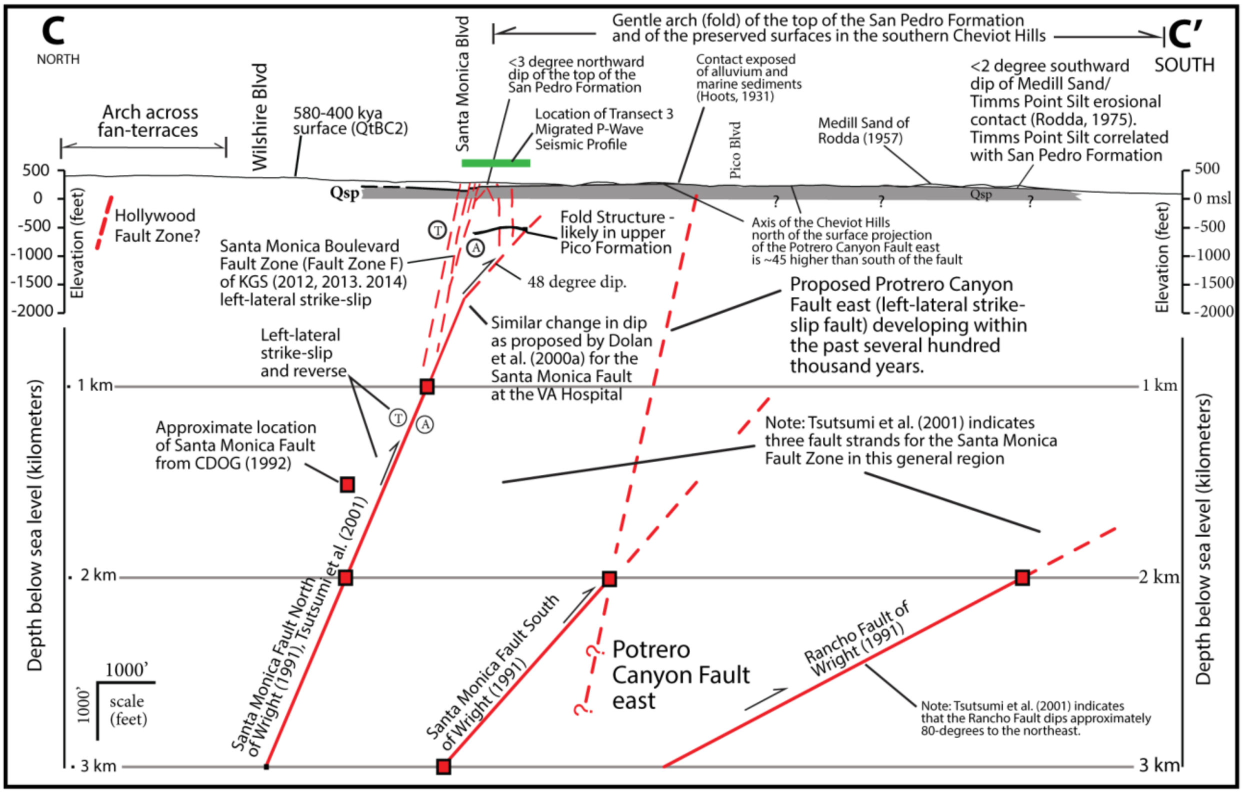
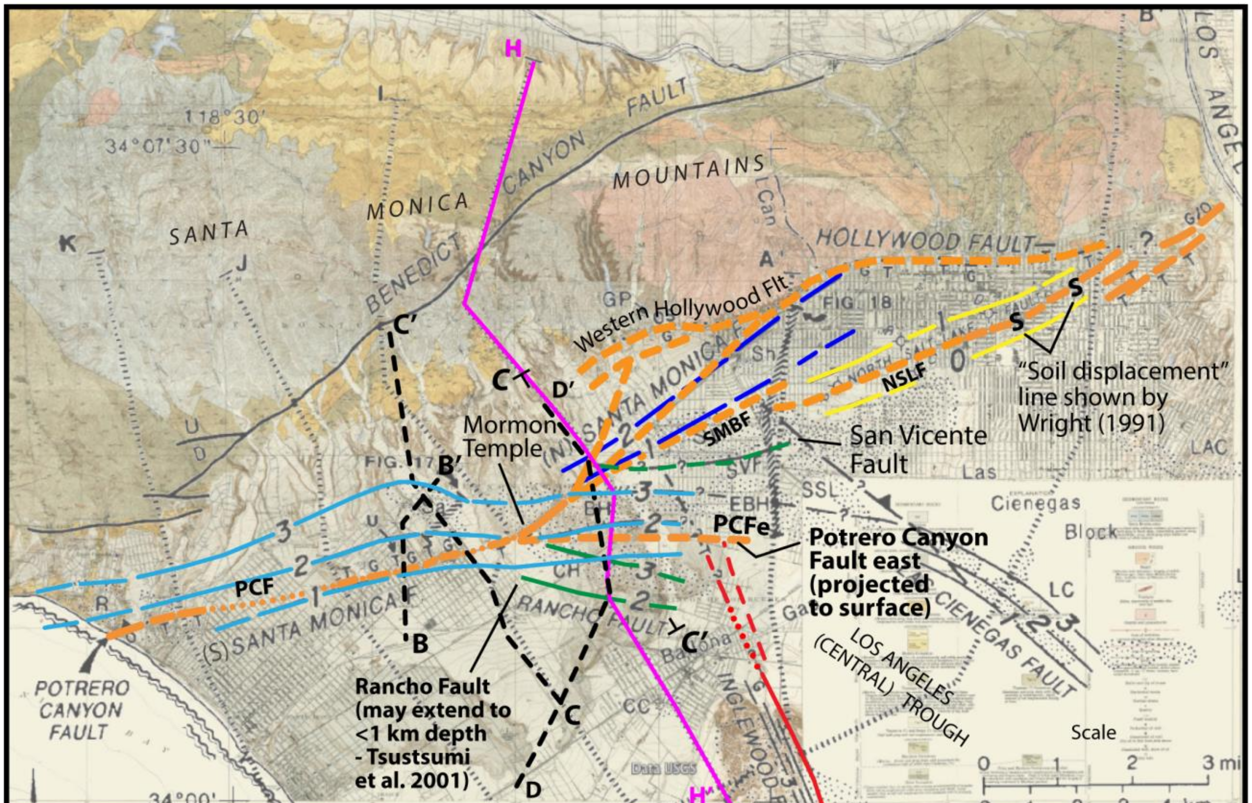


Figure 32: Geologic and subsurface structure map of the northwestern Los Angeles basin showing fault structure contours from Figure 19 of Wright (1991), location of the Potrero Canyon-Santa Monica Boulevard-North Salt Lake-Hollywood Fault Zones. The location Tsutsumi et al. (2001) Cross Sections B, C and D are shown.



Fault locations at the surface and at depth from Wright (1991) over geologic map from Hoots (1931).

Map showing major faults in the northwestern Los Angeles basin. Fault-plane contours on the Inglewood, Las Cienegas, North Salt Lake, Rancho and Santa Monica Faults (north and south) are from Wright, (1991). Contour interval: 1 km. Evidence of the surface traces of the Hollywood and Potrero Canyon faults and the northern extension of the Inglewood fault includes outcrop data (O), topography (T), and geotechnical data (G) from trenches and borings, plus soil contacts (**S**) and oil seepages (OS). Oil field abbreviations: Beverly Hills (BH), Cheviot Hills (CH), Culver City (CC), East Beverly Hills (EBH), Inglewood (I), Las Cienegas (LC), Los Angeles City (LAC), Los Angeles Downtown (LAD), Salt Lake (SL), San Vicente (SV), Sawtelle (Sa), Sherman (Sh), South Salt Lake (SSL, Venice Beach (VB), Riveriera (R). Potrero Canyon Fault (**PCF**), Potrero Canyon Fault east (**PCFe**), Santa Monica Boulevard Fault (**SMBF**), North Salt Lak Fault (**NSLF**)

Approximate location of fault proposed to have exhibited primarily left-lateral motion since the early Quaternary. Most of these faults utilized older faults (shown as blue and yellow structure contours).

Right-lateral strike-slip fault (Newport-Inglewood fault), dotted where concealed.

C ≺ ≻ C′ Approximate location of Cross Section C-C′ through the Cheviot Hills. Cross section shown on Figure 31. Location also shown on Figure7.

Subsurface structure contours of faults from Wright (1991). Santa Monica Fault South - light blue; Santa Monica Fault North - dark blue; Rancho Fault - dark green; North Salt Lake Fault - yellow structure contours. Shallowest depth shown represents the approximate shallowest depth that the fault extends below the surface. Above that depth the fault is blind, and caused folding of overlying sediments.

H —— H′ Wright (1991) cross section H-H′

D′ - - - - D Tsutsumi et al. (2001) cross sections B-B′, C-C′ and D-D′

Figure 33: Modified Cross Sections D-D' of Tsutsumi et al. (2001), and H-H' of Wright (1991). The locations of the cross sections shown on Figure 32.

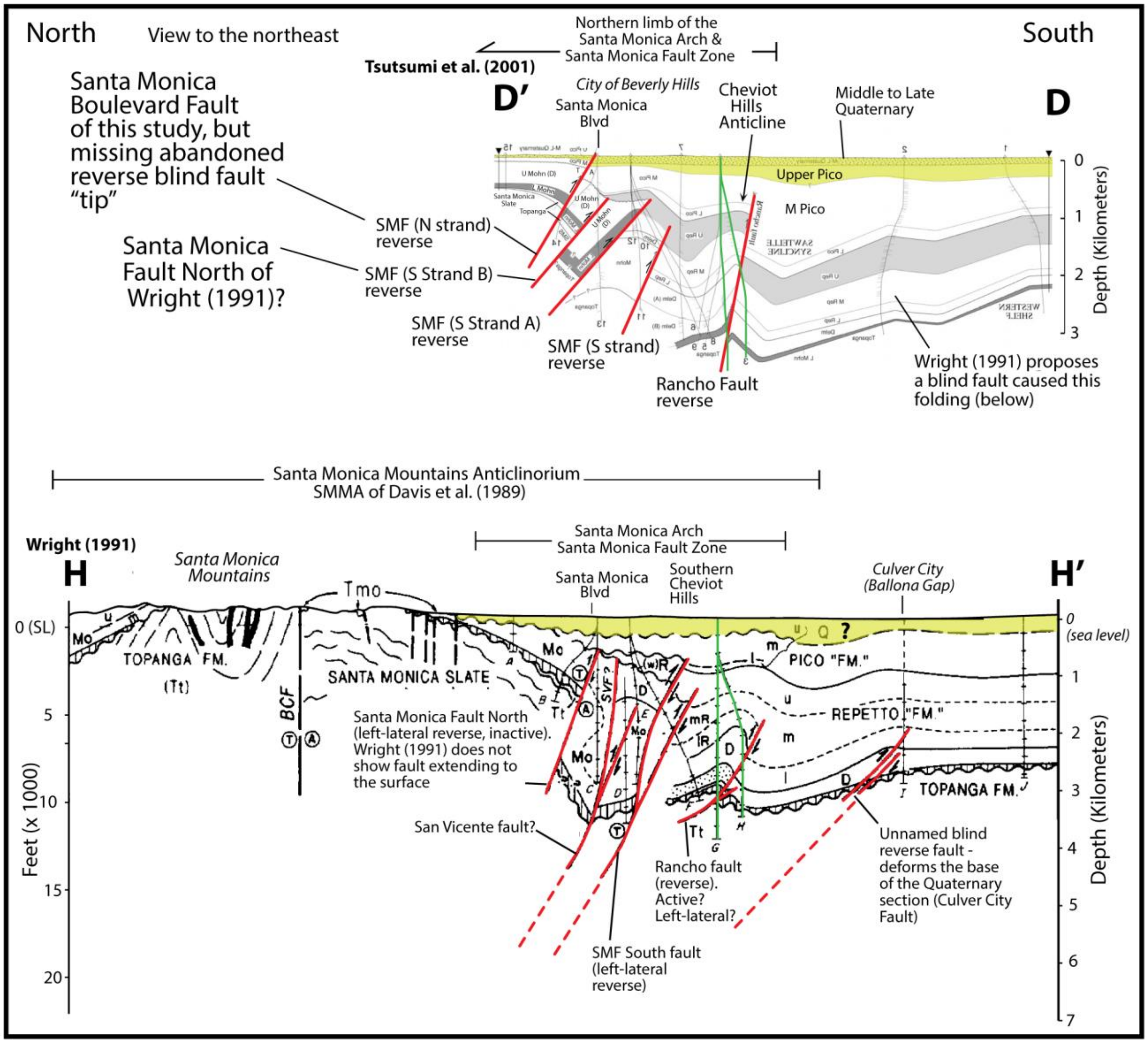
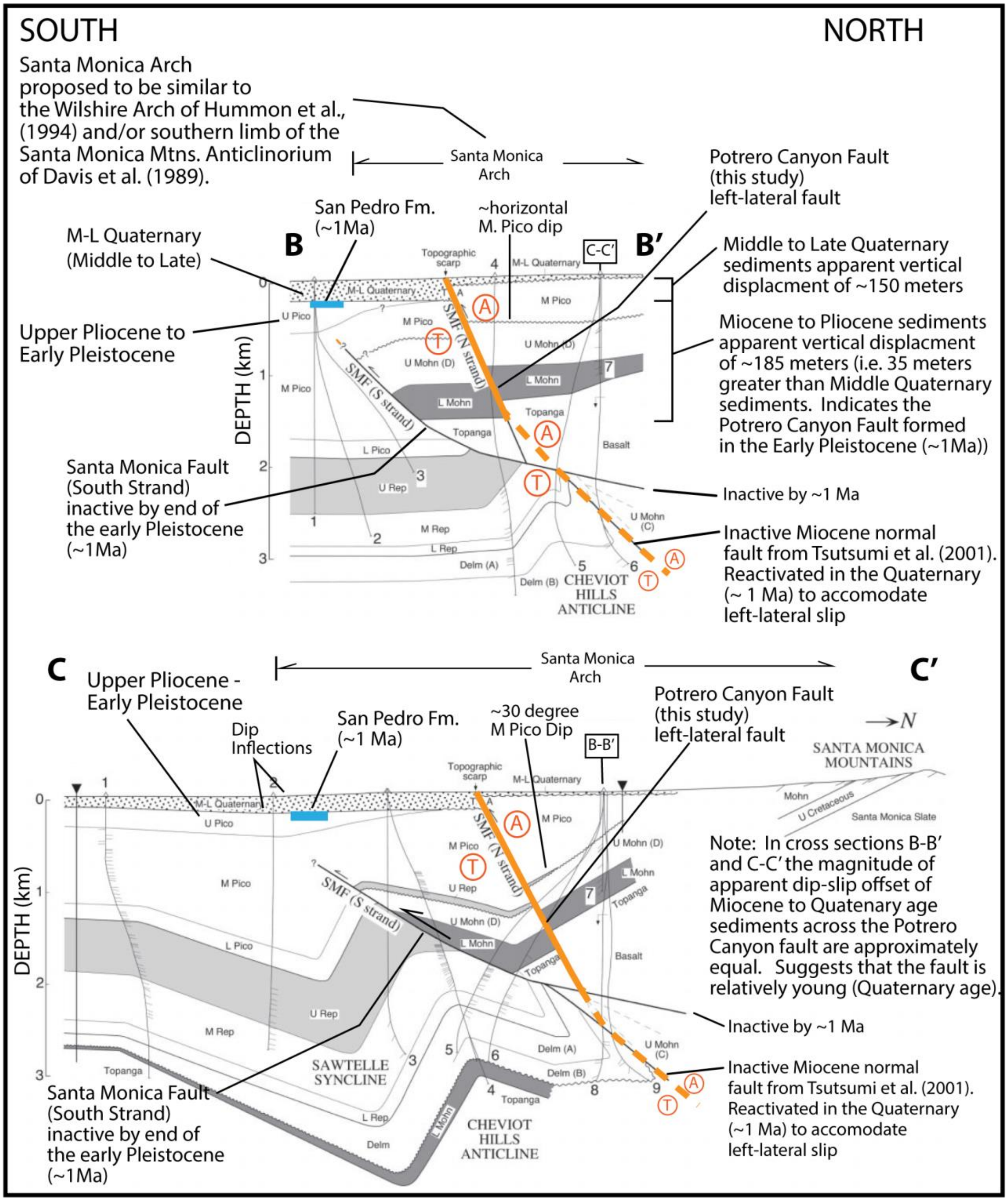


Figure 34: Modified Cross Sections B-B' and C-C' of Tsutsumi et al. (2001) showing the approximate limits of the Santa Monica Arch, and model for the depth structure of the Potrero Canyon Fault. Location of Cross Section of B-B′ and C-C′ are shown on Figure 32.



6.3 Extending the model to the Hollywood and North Salt Lake Fault Zones

Unfortunately, there is very little oil well, deep structure data at the west end of the North Salt Lake Fault based on a review of Tsutsumi et al. (2001) and Hummon (1994). However Tsutsumi et al. (2001) suggests that the North Salt Lake Fault may extend all the way to the eastern Cheviot Hills. This report does interpret that North Salt Lake Fault extends westerly and steps over onto the Santa Monica Boulevard Fault through the Cheviot Hills.

It is proposed that toward the east, a relatively young, relatively shallow, steeply north dipping fault was created in the early to mid-Pleistocene that connects with the original North Salt Lake Fault at a depth of approximate 0.5 to 1 km (Figure 32). This relationship is observed by the orange "S" (Soil) line of Figure 32 that resides directly above the ~0.5 km depth of the North Salt Lake Fault. The "S" soil of Figure 32 is where Wright (1991) found data suggesting that near surface soil contacts were displaced by the North Salt Lake Fault. Wright (1991) also shows the depth structure contours of the North Salt Lake Fault extending farther to the south of the offset soil contact line. This relationship indicates that the older North Salt Lake Fault was reactivated or changed its style of displacement from normal left-lateral, to dominantly left-lateral in the early Pleistocene. During this transition a new fault developed in the upper 0.5 to 1 km that dipped more steeply than the North Salt Lake Fault at deeper depths.

Proposing left-lateral slip on the North Salt Lake Fault during the early to mid-Pleistocene indicates that the left-lateral slip rate and total left-lateral displacement across the Hollywood Fault Zone to the north would be diminished by a proportional amount and Hollywood Fault Zone would not need to accommodate all the estimated left-lateral slip displacement along this TRSBLL segment (Figure 6).

6.4 Summary of the Santa Monica Boulevard – Potrero Canyon Left-Lateral Tectonic Model and creation of the Potrero Canyon Fault east

The Potrero Canyon Fault and the Santa Monica Boulevard Fault are youthful, having only formed ~1 Ma in response to a local change in tectonics where the older Santa Monica Fault Zone began to accommodate dominantly left-lateral strike-slip faulting and abandoned a strong reverse (compressional) sense of movement. The Potrero Canyon Fault connects with the Santa Monica Fault South of Wright (1991) at a depth of approximately 1 km (Figure 32). The Santa Monica Boulevard Fault connects at depth with the Santa Monica Fault North of Wright (1991). The bend from the N75E Potrero Canyon Fault to the N55E Santa Monica Boulevard Fault occurs near the Mormon Temple. This location coincides with a similar turn in strike where the Santa Monica Fault South and Santa Monica Fault North connect under the Mormon Temple identified by Wright (1991; Figure 32). This bend between the Potrero Canyon and Santa Monica Boulevard Faults produced a restraining bend orientation along the Potrero Canyon Fault whereas the Santa Monica Boulevard Fault exhibited nearly pure left-lateral strike-slip displacement (KGS, 2011, 2012, 2014).

More recently, the Santa Monica Boulevard Fault Zone became inactive approximately 200 kya and its strain was transferred southerly onto a newly-developed Potrero Canyon Fault East, extending from the eastern end of the Potrero Canyon Fault, through and east of the southern Cheviot Hills (Plate 4, Figure 26, and Figure 32). The Potrero Canyon Fault East occurs along deformational structures created along the blind, north-dipping Santa Monica Fault South of Wright (1991; Figure 31 and Figure 32). These structures occur along the southern boundary of the Beverly Hills Oil Field and may connect with the northwestern end of the Las Cienegas Fault farther east. Wright (1991) proposed that his Santa Monica Fault South may connect with the Las Cienegas Fault but there was insufficient data to substantiate the physical connection. These pre-existing structures, which include nearly vertical dipping, east-west trending sedimentary bedding, and older faults acted as a strain guide for the newly developing Potrero Canyon Fault East.

Collectively, the North Salt Lake Fault, Santa Monica Boulevard Fault and the Potrero Canyon Fault represent a relatively continuous left-lateral strike-slip fault system that initiated dominantly left-lateral slip activity in the early Pleistocene. The Hollywood Fault likely also changed in tectonic style approximately 1 million years ago similar to the Santa Monica Fault South and Santa Monica Fault North to the west. The Hollywood Fault had reverse left-lateral strike-slip oblique motion up to the early Pleistocene, and switched to dominantly left-lateral motion since that time. For the Hollywood Fault, the model predicts that older oblique reverse left-lateral faults occur at depth and are inactive, and that these older faults project south of the current mapped trace of the Hollywood Fault. Furthermore, the model predicts that younger late Pleistocene strands of the Hollywood Fault exhibit dominantly left-lateral displacement, dip very steeply northward, and extend to the near-surface.

7.0 COMPRESSIONAL TECTONICS IN THE SANTA MONICA-BEACH CITIES REGION

This section provides a review and analysis of published and unpublished reports and data that led to the identification of two new thrust ramp faults in the Beach Cities Region. The Beach Cities Region is defined as west of the Newport-Inglewood Fault, south of the Dume-Santa Monica, Potrero Canyon and Santa Monica Boulevard Fault Zones and north of Palos Verdes (Figure 35). Upon review of the existing literature regarding faulting in the Beach Cities Region, it became clear that no active reverse thrust ramp faults have been identified. However, the regional Compton-Baldwin Hills Detachment Fault is proposed to occur underlying the entire Beach Cities Region (Shaw and Suppe, 1996; Sorlien et al., 2013a). This fault occurs at a depth of 10 km beneath the Newport-Inglewood Fault, and shallows to a depth of 5 km beneath the Palos Verdes Fault in Santa Monica Bay (Plate 1, Plate 2; Figure 38). Motion across this fault zone based on its presumed gentle northeastward dip would raise the entire coastline, and it may not be a coincidence that the shoreline itself parallels the strike of the Compton-Baldwin Hills Detachment Fault at depth. Motion on this fault may explain why the area west of the northern Newport-Inglewood Fault is geomorphically higher (deeply incised into older alluvial fans) than regions to the east.

However, no active thrust ramp faults which ramp up from the regional shallow dipping detachment fault (Compton-Baldwin Hills Detachment) have been identified in the Beach Cities region. In contrast, numerous active thrust ramp faults have been identified east of the Newport-Inglewood Fault Zone (Figure 38). This raised the obvious question regarding whether or not blind thrust ramp faults occur west of the Newport-Inglewood Fault Zone in the Beach Cities region in a similar fashion as they occur to the east in the northern Los Angeles Basin.

The results of this analysis include:

- The only published presumed active compressional fault in the Beach Cities Region is the deep, blind, and shallow northeastward gently dipping Compton-Baldwin Hills Detachment Fault.
- No active reverse thrust ramp faults are currently identified in the literature in the Beach Cities Region to emanate upwards from the Compton-Baldwin Hills Detachment Fault; which raises the question regarding where active compressional deformation may be occurring in this region.
- Identification of the proposed Culver City Fault, which is a blind reverse thrust ramp fault, tending approximately east-west from the City of Santa Monica to the western Baldwin Hills, and extends to depths of 2 to 3 km below the surface.

- The Culver City Fault may be responsible for the Holocene deformation in the northern Beach Cities Region identified by Wright (1991); which suggests that the fault may be active.
- Identification of the Proposed Dume Fault East, which is a blind reverse thrust ramp fault, that connects with the Dume Fault south of the Point Dume, and curves towards the southeast where it reaches the coastline near Playa Del Rey, and extends to depths of 2 km below the surface.
- The Dume Fault east clearly deforms 1 Ma sediments in Santa Monica Bay, and 2.5 Ma sediments onshore, but activity during the past 1 Ma remains uncertain.

7.1 Compressional deformation in the Beach Cities Region

As discussed in this report, essentially no compressional deformation is occurring along the Transverse Ranges Southern Boundary Fault System "Left-Lateral". It was shown that the Santa Monica Fault South of Wright (1991; Figure 32, Figure 33) experienced reverse left-lateral displacement in the Pliocene to early Pleistocene (Wright, 1991; Tsutsumi et al., 2001), but became inactive by the end of the early to mid-Pleistocene. Similarly, the Santa Monica Fault North of Wright (1991) in in the Cheviot Hills (Century City) also experienced reverse left-lateral displacement in the Pliocene but was not active during the Quaternary (Figure 33 Cross Section H-H'). If compressional deformation is no longer occurring along these fault zones, other faults must be actively absorbing compressional deformation in this region.

The steeply, north dipping Rancho Fault occurs in the southwestern Cheviot Hills (Figure 33). Wright (1991) indicates that this fault displaces lower Pliocene sediments (Repetto Formation), and may deform overlying sediments as young as Quaternary (Figure 33, Cross Section H-H'). Wright (1991) also shows a Holocene anticlinal fold that may be associated with the Rancho Fault (Figure 37) suggesting that the Rancho Fault may be active as a blind reverse fault. In contrast, Tsutsumi et al. (2001) shows the Rancho Fault as displacing middle Pico Formation that is late Pliocene to early Pleistocene, but only folding overlying upper Pico Formation that is early Pleistocene (Figure 33, Cross Section D-D'). Tsutsumi et al. (2001) show essentially un-deformed mid to late Quaternary sediments overlying the surface projection of the Rancho Fault (Figure 33 Section D-D') suggesting that the fault is inactive. Tsutsumi et al. (2001) also suggest that the Rancho Fault accommodated strike-slip deformation in the Quaternary due to its steep dip of approximately 80 degrees to the north. The Rancho Fault is laterally fairly short, and would not be sufficient to accommodate compressional stress across the entire Beach Cities Region nor accommodate all of the left-lateral motion required for this segment of the TRSBLL. However, the Rancho Fault should be considered potentially active and it may be accommodating a component of local shortening since the late Pleistocene

Davis et al. (1989) proposed that the "lower" Elysian Park Thrust extends from the San Andreas Fault in the north to at least Palos Verdes, which implies that the detachment (décollement) fault exists under Santa Monica (also see Davis and Namson, 1994; Namson and Davis, 1988). In the Santa Monica area, Cross Section No.9 by Davis and Namson (http://www.davisnamson.com/downloads/index.htm), extends NE-SW across the Potrero Canyon-Santa Monica Fault South to the Pacific Ocean and shows their Elysian Park Thrust System (ramp) connecting directly to the Santa Monica Fault (Appendix A). This suggests that reverse faulting compressional deformation is not occurring south of the Santa Monica Fault South of Wright (1991) and Tsutsumi et al. (2001). It appears that a pattern of uplift-folding and associated erosion of a large volume of upper crust is occurring along the region of the Santa Monica Fault South similar to the pattern proposed by Hummon et al. (1994) for the Wilshire Arch of east of the Newport-Inglewood Fault. This region is referred herein as the Santa Monica Arch (Figure 33 and Figure 34), but Dolan et al. (2000a) indicates that folding of upper crust in this region appears to not deform middle to late Quaternary sediments, suggesting that this folding is no longer active.

A few active (Holocene) compressional structures have been identified in the Beach Cities region. Wright (1991) identified a monocline-syncline pair (Figure 35, Figure 36, and Figure 37) that trend NEE-SWW, essentially parallel but south of the Santa Monica Fault South (Figure 38). Wright (1991) also identifies an antiformal structure that appears associated with the underlying blind Rancho Fault in the southwestern Cheviot Hills (Figure 36); however, that folding may be associated with the Potrero Canyon Fault East due to its restraining bend orientation for a left-lateral fault. Shaw and Suppe (1996) identify the Compton—Baldwin Hills Detachment Fault that underlies the entire Beach Cities Region (Plate 2). This fault may be the same fault interpreted by Geiser and Seeber (2008) based on their evaluation of historical seismicity. The Southern California Earthquake Center (SCEC) Community Fault Model (CFM) 4.0 has the Compton-Baldwin Hills Detachment Fault approximately 10 km under the Baldwin Hills (Plesch et al., 2007; yellow dashed line of Figure 38, Plate 1 and Plate 2).

Sorlien et al. (2013a) incorporate the Compton-Baldwin Hills Detachment Fault in the Playa Del Rey Region, shown on Cross Section A-A'-A" (Figure 38). Sorlien et al (2013a) interpret the shallow part of a Miocene low-angle normal fault beneath the base of the offshore San Pedro Escarpment to align with the Compton ramp in 3D beneath the eastern part of Santa Monica Bay (Figure 38). They proposed thrust or oblique thrust movement on this fault produced the Pliocene-Quaternary northwestern Palos

Verdes anticline, northwest of the Palos Verdes Peninsula. Estimated slip rates for the Compton Thrust are 1.1 to 1.6 mm/yr (Sorlien et al., 2013) and 1.4 mm/yr (Shaw and Suppe, 1996). The Compton-Baldwin Hills-Lower Elysian Park Detachment Fault System with associated overlaying thrust fault ramps is very structurally similar to structures identified in the Himalayan mountain ranges in India (Hauck et al., 1998; Caldwell et al., 2013; Morell et al., 2015).

Davis et al. (1989) suggest that detachment fault may occur below the Compton-Baldwin Hills Detachment Fault of Shaw and Suppe (1996; cross sections are compared in Figure 3 of Sorlien et al., 2013a). This deeper inferred thrust ramp is more consistent with the deeper structural level of Sorlien et al. (2013a) Catalina Island detachment, possibly connecting with the Lower Elysian Park Detachment Fault (green dashed faults in Figure 38 and Plate 1). It should be noted that the thrust ramps are inferred based on fault-related fold models and not imaged by seismic reflection beneath Los Angeles, although a mid-crustal reflection beneath the San Gabriel Mountains has been proposed to be part of the deep thrust system (Fuis et al., 2001). The tip of the SW-directed tectonic wedge of Shaw and Suppe (1996) is near the coastline near the Palos Verdes Hills and thus not far enough southwest to explain the 700 m-high San Pedro bathymetric escarpment and associated southwest limb of the Palos Verdes anticlinorium. Within this report, it is presumed that the Elysian Park Detachment Fault connects with the Compton-Baldwin Hills Detachment Fault at a depth of approximately 10 km beneath the northern Newport-Inglewood Fault, and then the Compton-Baldwin Hills Detachment Fault extends under Santa Monica Bay where it reaches a depth of 5 km beneath the Palos Verdes Fault. No other deeper detachment faults occur below the Compton-Baldwin Hills Detachment Fault in the Beach Cities Region.

Another possible source of Holocene (active) compressional deformation would be upper crust warping (mass folding) not associated with discrete faults, occurring in a similar process as that proposed by Davis et al. (1989) east of the Cheviot Hills. It is possible that the uplift associated with the folding assisted in the development of the Santa Monica Arch (Figure 33 and Figure 36) and the Holocene age east-west trending synclinal fold identified by Wright (1991). However, it seems reasonable that a thrust ramp fault would likely occur at depth to assist in accommodating the surface uplift and upper crustal folding; that fault may have been identified by Wright (1991), but not identified as such. This is discussed in the following section regarding the Culver City Fault.

The findings in this section suggest that either only minor mid to late Quaternary compressional shortening is occurring in the Beach Cities Region, or that some compressional structures have not yet been identified. Alternatively, upper crustal rocks in this region may simply be moving as a coherent block over shallow dipping relatively deep detachment faults (i.e. the Compton-Baldwin Hills Detachment Fault) thus moving the locus of compressional shortening offshore to the southeast. A pattern of deep detachment faults occur beneath the northern Los Angeles Basin, associated with numerous thrust ramps that extend upwards from the detachment faults (i.e. Puente Hills Thrust, Upper Elysian Park Fault, Wilshire Fault, etc.). It seems much more likely that a similar pattern of thrust ramp faults occur in the Beach Cities Region.

A correlation of both offshore and onshore structural studies was conducted to investigate the existence of unrecognized thrust ramps. This approach was possible because there is considerable deep structure data in the offshore region that does not exist on shore and these data have not yet been fully correlated in the literature.

Figure 35: Tentative subsurface structure map of the Playa Del Rey region (white area). Depth structure of faults shown in black and cyan cross section lines H, I, J and K are from Wright (1991). The approximate location of an active syncline from Wright (1991; Figure 37) is shown trending northeast through the City of Santa Monica to the Ballona Gap. The interpreted location of an antiformal structure involving bedrock and a possible thrust ramp is identified.

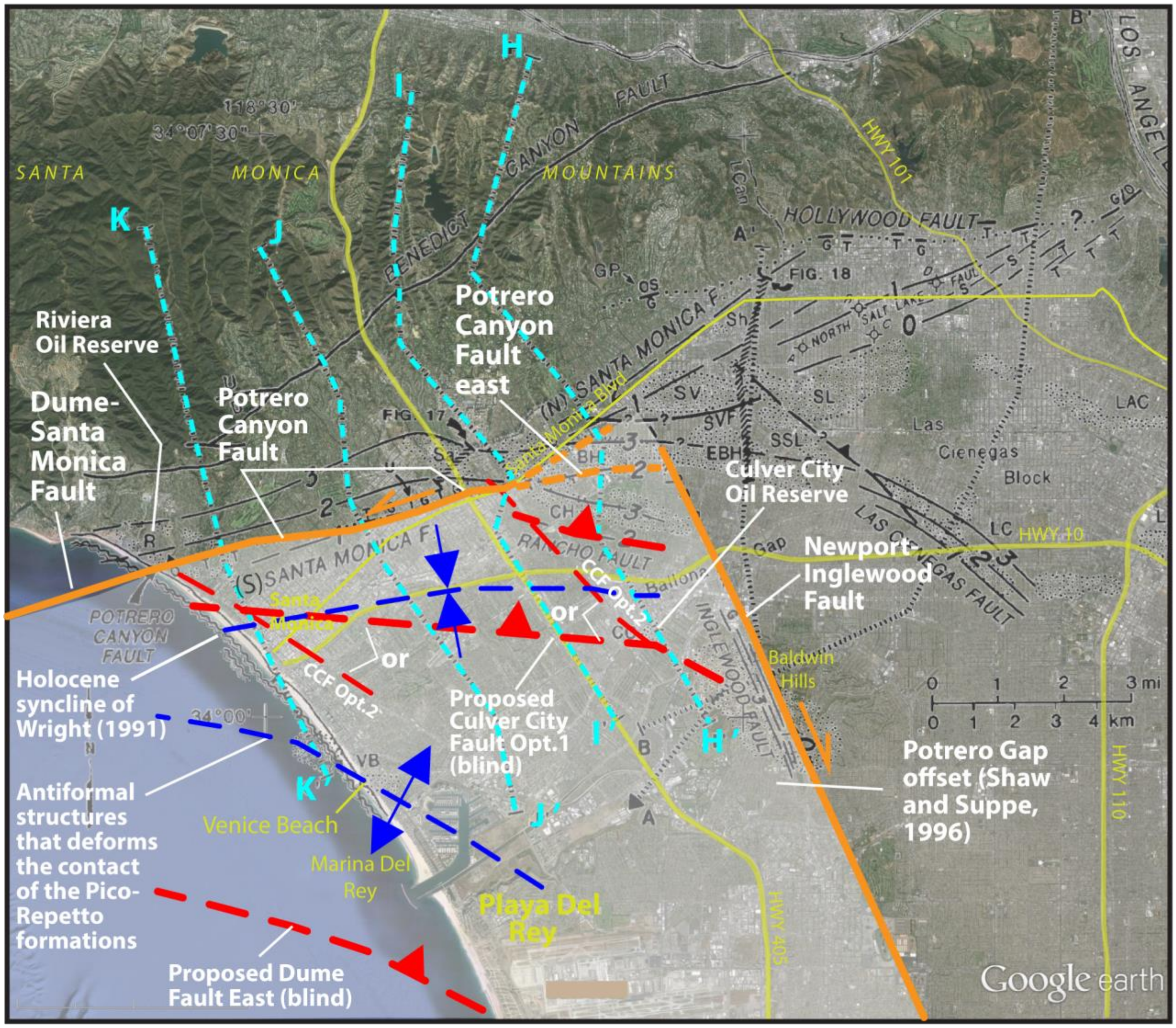


Figure 36: Modified Cross Sections H-H′ through K-K′ of Wright (1991) showing approximate Holocene syncline fold axis (blue) from Wright (1991; see Figure 37), the proposed Culver City Fault (thrust ramp), left-lateral strike-slip faults associated with the TRSBLL (orange), the Compton-Baldwin Detachment Fault and the proposed Dume Fault East Thrust Ramp Fault.

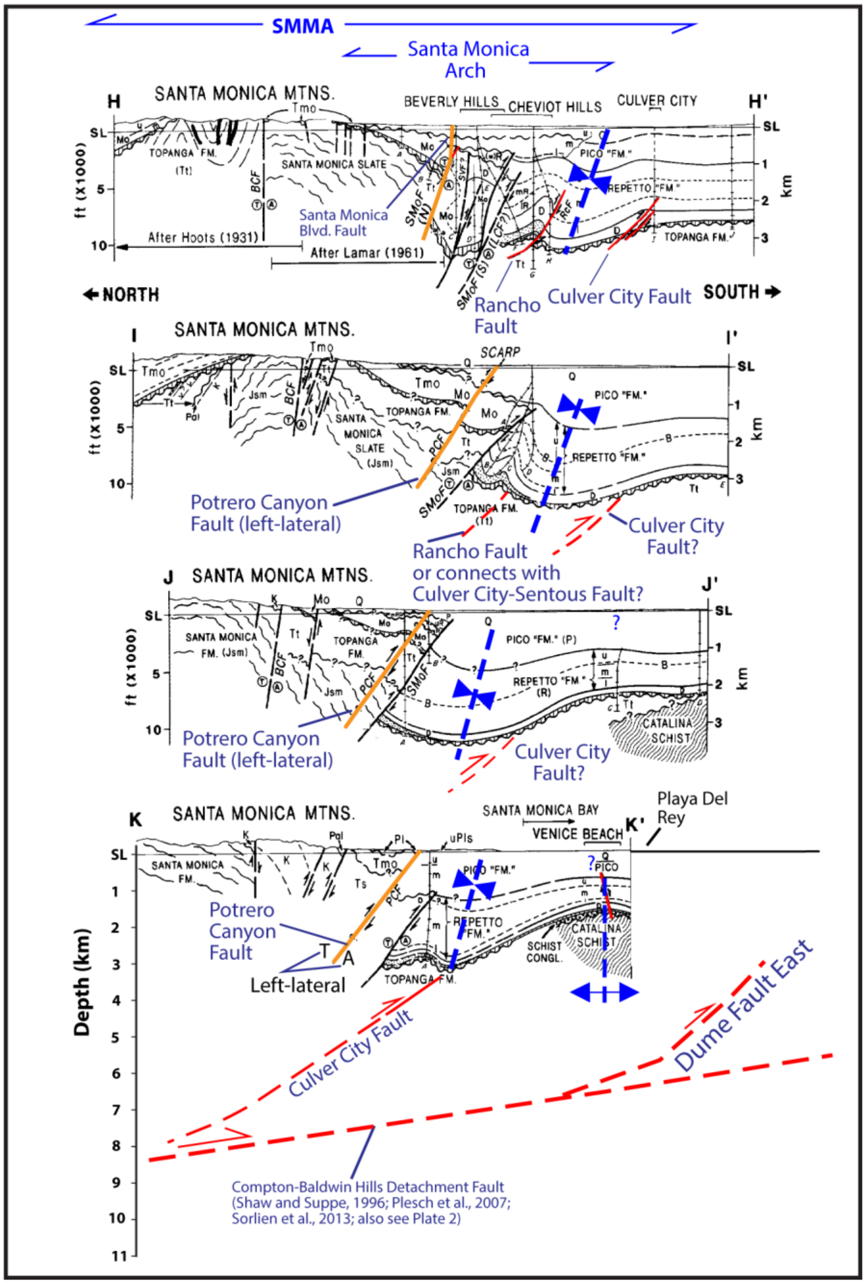
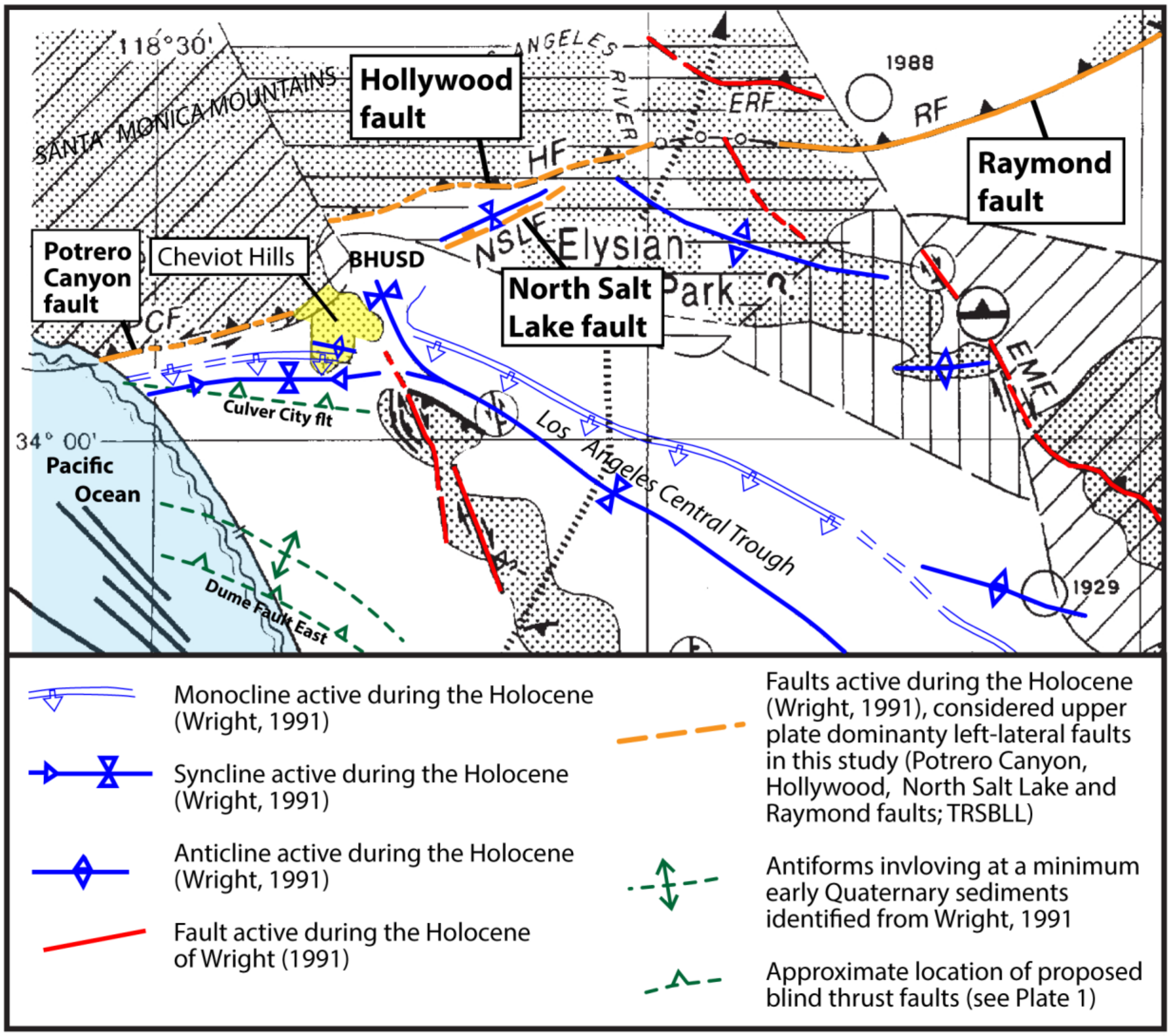


Figure 37: Modified from Wright (1991) showing Holocene deformation of the Los Angeles basin and vicinity. Wright (1991) indicates that the Potrero Canyon Fault (PCF) is a left-lateral reverse active fault and that to the south an active monocline and syncline have developed parallel to the PCF. Additional structures are located south of the active syncline including an interpreted antiform and thrust ramp.



7.2 Correlating offshore compressional deformation to the Santa Monica-Beach Cities Region

An analysis of offshore faulting along the Santa Cruz Island and Dume-Malibu Coast Fault Segments along TRSB (Figure 6) provided insights regarding styles and ages of faulting along onshore fault segments in the Beach Cities Region. In addition, it provided insights regarding potentially new thrust ramp faults that emanate upwards from regional detachment faults not yet discovered. To date, no published compressional active faults occur in this region with the exception of the deep, northward shallow dipping Compton-Baldwin Hills Detachment Fault (Plate 1; Plate 2 and Figure 38).

Numerous subsurface structural studies evaluating relatively deep detachment (décollement reverse) faults have been conducted along the Transverse Ranges Southern Boundary System (TRSB) from the Channel Islands to Santa Monica Bay. Shaw and Suppe (1994) identify the Deep Channel Islands Thrust that ramps upwards from a depth of approximately 17 km near the Santa Barbara coast, to 7 km immediately south of Santa Cruz Island. However, the fault was proposed primarily from balanced cross sections that do not provide a unique or “single” solution. A structural study from the Channel Islands by Seeber and Sorlien (2000) provide findings consistent with Davis et al. (1989) that the Santa Monica Mountains Anticlinorium was produced by folding above a mid-crustal thrust fault system (Figure 5). Seeber and Sorlien (2000) extend the thrust ramp south of the Channel Islands, which projects the fault south of the Santa Monica Mountains, and presumably under the City of Santa Monica. The relationship of this proposed fault and that of the Compton-Baldwin Hills Detachment Fault is unknown. Pinter et al. (2003) model uplift of the Channel Islands over a deep thrust that extends south of the Channel Islands they refer to as the Channel Islands Thrust. This is appears to be the same fault as the Deep Channel Islands Thrust of Shaw and Suppe (1994). Pinter et al. (2003) suggest that similar thrust faults occur under the Santa Monica Mountains to the east in the City of Santa Monica allowing for the development of the Santa Monica Mountains Anticlinorium (folding). It is difficult to reconcile all of these studies and determine whether they are truly identifying new faults that are distinct, or possibly identifying the same faults and attaching different names to them. Regardless, what these studies have in common is the identification of thrust faults in the vicinity of the TRSB some of which extend south of the TRSBLL.

Sorlien et al. (2006) identify the Santa Monica Bay Thrust Fault as a basal fault for their dominantly left-lateral hanging wall Dume and Malibu Coast Faults (also see Fisher, et al., 2005b; Plate 1 and Plate 2). Their model indicates that strain partitioning is occurring along the TRSB where the Transverse Ranges Southern Boundary System "left-lateral" (TRSBLL) system represent hanging wall dominantly left-lateral faults, and the tectonic shortening is dominantly accommodated by deeper basal thrust detachment faults and thrust ramps that extend south of the TRSBLL. The relationship at depth at the intersection of the dominantly left-lateral faults and underlying thrust or detachment faults remains unknown and is a very important question to answer for understanding regional tectonics along the TRSB. For example, although the "hanging wall" left-lateral faults are active (i.e. the Dume Fault), it is unclear whether or not the basal Santa Monica Bay Thrust Fault is active.

Alternatively, left-lateral slip across the TRSBLL may be associated with motion transferred through the entire lithosphere from the upper mantle, whereas the local detachment faults and thrust ramps may be associated with strain confined within the shallower middle to upper crust. This model indicates that it may be difficult for detachment faults to extend across the TRSBLL. In other words, that different regional detachment faults may occur but are distinct north and south of the TRSBLL. In this model, the Santa Monica Bay Thrust Fault would likely not extend under the TRSBLL as shown in Plate 2. Obviously, many questions remain.

Historical seismicity also suggests that active nearly north-south contraction, presumably associated with the Western Transverse Ranges, is occurring south of the western TRSBLL. Hauksson and Saldivar (1989) evaluated historical seismicity in Santa Monica Bay and determined that this region is experiencing N13E directed contraction that is associated with the southern Western Transverse Ranges. Geiser and Seeber (2008) evaluated seismicity in the region of Santa Monica Bay and onshore (i.e. Beach Cities Region) and determined that a deep (~12 to 17 km) décollement fault (detachment) occurs in this region. This may be the same fault as the Santa Monica Bay Thrust Fault shown.

As discussed earlier, Shaw and Suppe (1996) extend the active Compton-Baldwin Hills Detachment Fault ramp (Leon et al., 2009) into eastern Santa Monica Bay at a depth of approximately 5 km under the Palos Verdes Fault (Figure 39; Plate 1). Sorlien et al. (2013a) extend the Compton-Baldwin Detachment Fault to the southeast, under the Palos Verdes fault to reach near surface depths along the San Pedro Bay Escarpment Fault and the southeastern end of the Santa Monica Bay Detachment Fault (Figure 39). This is shown in cross section A-A'-A" of Sorlien et al. (2013a) and shown on Figure 39. These reports provide strong evidence that the Compton-Baldwin Hills Detachment Fault exists, occurs across the entire Beach Cities Region, and that the fault extends into seismogenic upper crustal depths (i.e. 10 to 5 km) that are capable of producing large magnitude earthquakes. It is reasonable to presume that a regional, shallow dipping, detachment fault occurs in the Beach Cities Region; the question now is whether or not active thrust ramp faults emanate upwards from the Compton-Baldwin Hills Detachment Fault.

7.3 The Culver City Fault Thrust Ramp

An evaluation of offshore and onshore data was conducted to assess the possible existence of previously unidentified thrust ramps in the Beach Cities Region that may connect at depth with the Compton-Baldwin Hills Detachment Fault (Figure 38). Wright (1991) produced a series of north-south trending cross sections in the northern Beach Cities Region (Figure 35 and Figure 36 - Cross Sections H-H′ through K-K′). These cross sections are based on oil well data that extend to depths of 3 to 2 km (Figure 36). These are the same data utilized by Tsutsumi et al. (2001) to produce Cross Sections B-B′ and C-C′ shown in Figure 34. Thrust ramps that terminate at depths deeper than 3 km may not have been readily recognized from the oil well data, however, overlying folds associated with movement on thrust ramps deeper than approximately 3 km may suggest their presence.

Wright (1991) identifies a couple of late Quaternary structures that could be associated with a deep thrust ramp fault that extends from the western Baldwin Hills to the coast. These include a Holocene age, approximately east-west trending syncline, extending from Ballona Gap to the City of Santa Monica (Figure 35, Figure 36, and Figure 37). This fold could be associated with upper crust shortening that is buttressed by the subsurface high of Catalina Schist to the south (Figure 36), that may have assisted in mass folding as proposed by Davis (1989) for the region east of the Newport-Inglewood Fault leading to the development of the Santa Monica Arch (Figure 33 and Figure 34).

A similar pattern could be occurring in the Beach Cities Region. Wright (1991) identifies a fault that was provided no name in his study under Culver City that terminates at a depth of approximately 2 km (Figure 36, Cross Section H-H’). He shows folding above this fault occurring in Quaternary sediments, however, the ground surface appears un-deformed. This fault may connect with the Sentous reverse fault zone identified along the western side of the Baldwin Hills (Plate 4), offsetting Pliocene sediments as shown on Plate 4 (Yeats, 1973; Wright, 1987; Yeats and Verdugo, 2010; Plate 4).

Farther to the west near the coast, along Cross Section K to K’ (Figure 35 and Figure 36), relatively tight folding below Wright’s (1991) Santa Monica Fault South suggests that a thrust ramp fault occurs at depth below that of the cross section. This folding is associated with the Riviera Oil Field (Figure 35). It is proposed that a blind thrust ramp fault extending from cross section H-H’ to K-K’ of Figure 36 occurs that had previously not been identified. This east-west trending blind thrust ramp fault is referred to herein as the Culver City Fault (Plate 4; Figures 35, Figure 36, Figure 37 and Figure 38). Wright's cross sections I-I' and J-J' do not show the tight folding or faulting revealed in other sections, however there is a paucity of oil well data in these areas and the lack of folding may be more a reflection of gaps in the data than a reflection of actual conditions. .

The Culver City Fault deforms (folds) the base of the mid-Quaternary sedimentary section in cross section H-H' (Figure 36). In addition, the proposed blind Culver City Fault is in the proximity of where Wright (1991) shows Holocene deformation in the form of an approximately east-west trending syncline (Figure 35) deformed by deep regional detachment faults and associated thrust ramps similar to mechanisms proposed by Davis et al. (1989). This model proposes that the Culver City Fault connects with the underlying Compton-Baldwin Hills thrust segment shown on Cross Section K-K' of Figure 35).

The lack of deformation at depth along Wright's (1991) cross sections I-I' and J-J', if accurate, requires an alternative to the single thrust ramp approach. Interpretations considered include multiple thrust ramps that trend northwest-southeast; these faults are referred to as the Culver City Fault Option 2 on Figure 35. However, Holocene east-west synclinal folding in the area identified by Wright (1991), Hummon (1994), and Hummon et al. (1994), is not consistent with the Culver City Fault Option 2 faults. Given this data and the paucity of deep oil well data along Cross Sections I-I' and J-J' (Figure 36) in the area of the proposed Culver City Fault Option 1, Culver City Fault Option 2 was rejected.

In summary, there is sufficient data to warrant concern that a blind thrust ramp fault (Culver City Fault) occurs south of the TRSBLL (Potrero Canyon and Santa Monica Fault System) extending from the Baldwin Hills to the coast. The fault has not yet been identified due to a lack of deep oil well data in the area and a paucity of deep seismic reflection-refraction lines similar to those conducted offshore. The Culver City Fault would be youthful; hence it likely formed during the Quaternary. Based on the tectonic model presented herein, the Culver City Fault formed approximately 1 Ma to accommodate compressional deformation no longer occurring along the TRSB to the north.

7.4 The Dume Fault East Thrust Ramp

An evaluation of Sorlien et al. (2006) and subsequent discussions with C. Sorlien during preparation-review of early versions of this report identified a previously unrecognized northward dipping blind thrust ramp south and below the Dume-Santa Monica Fault (Figure 38).   The Dume-Santa Monica Fault is presumed to connect with the Potrero

Canyon Fault near the coastline (see Sorlien et al., 2006) as shown on Figure 38. This thrust ramp fault is designated as the Dume Fault east because it appears to connect with the Dume Fault south of Point Dume (Figure 38). It is identified on a series of seismic lines within Sorlien et al. (2006) and from C. Sorlien (personal communication, 2014; Plate 8). The fault was initially identified on seismic lines C-C' and D-D' (in green) obtained from Sorlien et al. (2006). C. Sorlien then provided seismic lines W, X, Y and Z during review of an early version of this report which allowed for a collaborative effort to locate the eastward extension of the Dume Fault East across Santa Monica Bay (Plate 8).

The western end of the proposed Dume Fault East connects with the Dume Fault at a longitude due south of Point Dume in Santa Monica Bay (Plate 8, Figure 38). In this region, the Dume Fault East projects to the surface along a seafloor escarpment suggesting that this topographic feature resulted from movement across the fault (Figure 38, Plate 1). The escarpment is associated with anticlinal folding overlying the Dume Fault East as shown on seismic lines W-W′ and X-X′ provided on Plate 8. In this area, the Dume Fault East deforms 1 Ma sediments and apparently "surface" sediments of Holocene age based on the association with the topographic escarpment (i.e. fault scarp). Further to the east at the location of seismic line Y-Y′ (Plate 8), hanging wall anticlinal folding is identified involving sediments less than 2.5 Ma, but possibly only slightly warping sediments younger than 1 Ma. However, in seismic line D-D′ (Plate 8), which intersects seismic line Y-Y′ above the Dume Fault East, sediments 1 Ma appear deformed in the hanging wall anticlinal fold associated with the Dume Fault east.

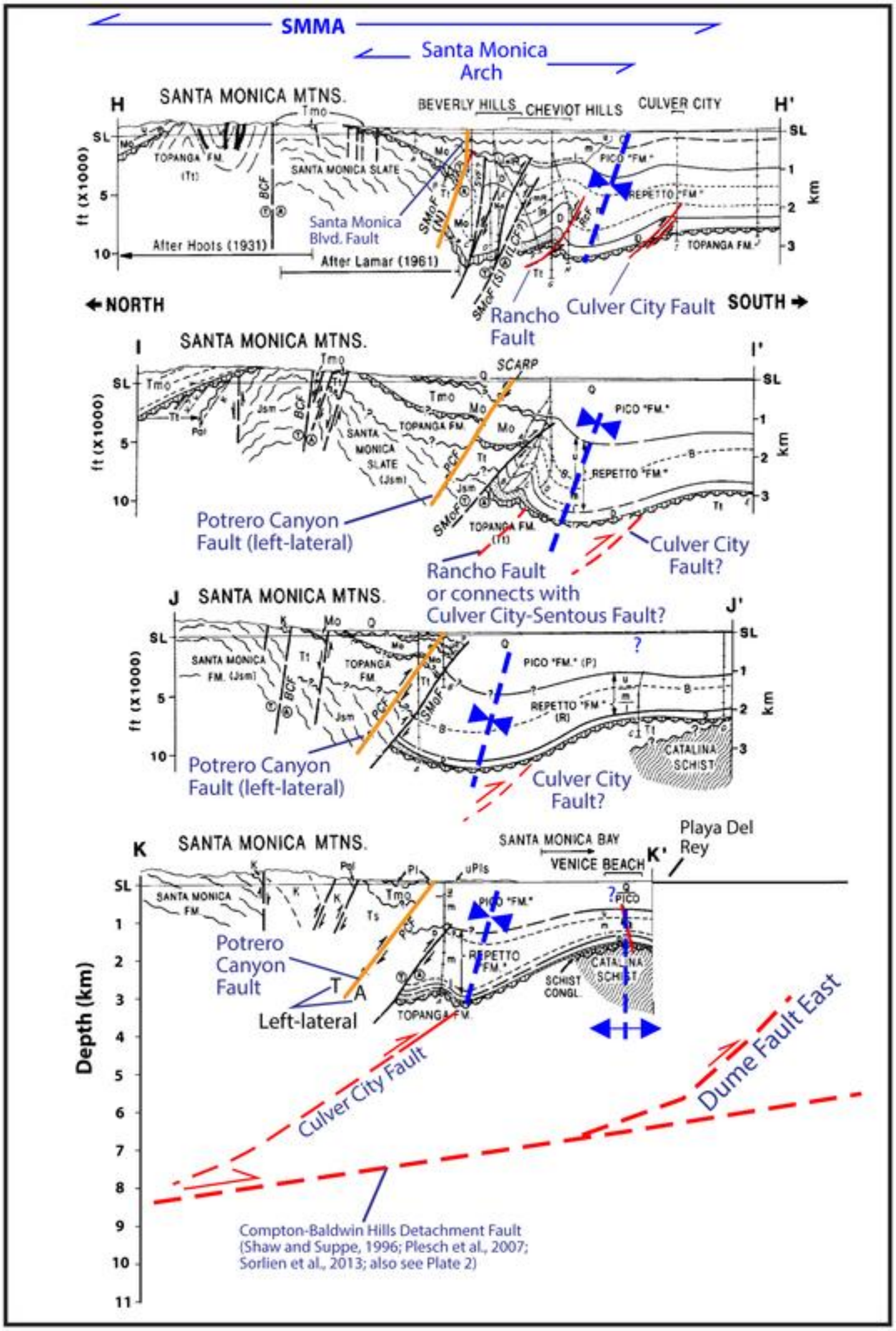
The Dume Fault East and its associated hanging wall anticlinal folding were not identified in seismic section D-D' (blue, Plate 8), indicating that the fault occurs north of this seismic line. As suggested by C. Sorlien (2014 personal communication), the Dume Fault East turns toward the southeast as it approaches land and extends under Playa Del Ray-Marina Del Rey area and all the way to the Newport-Inglewood Fault. This conclusion is based on a series of anticlinal folds extending from the Marina Del Rey-Playa Del Rey area all the way to the Newport-Inglewood Fault along the Newport-Dominguez-Playa Del Rey Trend (as shown on numerous published maps of the Newport-Inglewood Fault summarized by Barrows, 1974). These anticlinal folds, many of which form oil fields, were identified by Wright (1991) in a structure contour map of the 4.5 Ma base of the Repetto Formation (see Plate 8, inset Figure 9). In addition, Sorlien et al. (2013) show a gentle anticlinal fold at the top of the Repetto Formation (~2.5 Ma) along their Cross Section A-A'-A" (Figure 38) in the Playa Del Rey area.

The Dume Fault East is extrapolated toward the southeast to the Dominguez oil fields along the Newport-Inglewood Fault (Figure 39; Plate 8, inset Figure 7). In this oil field, an antiform occurs with a similar strike to that of the proposed Dume Fault East and associated hanging wall anticlines. This series of hanging wall anticlinal folds extending from the Newport-Inglewood Fault to the Playa Del Rey region and offshore in the Santa Monica Bay are proposed to have developed by motion on the Dume Fault East (thrust ramp fault).

Evidence of recent activity of the Dume Fault East in the Playa Del Rey regions is provided by a clustering of relatively small earthquakes exhibiting magnitudes generally between 1.5 and 3.0 that occur in the region of the anticlines. The earthquakes exhibit a trend similar to that of the fold axis but the seismicity is slightly to the northeast of the fold axis (Figure 38).

The proposed location and strike of the Dume Fault East is north and sub-parallel to the Palos Verdes Fault (Figure 38, Plate 1). The location of the Palos Verdes Fault shown on Plate 1 and Plate 2 is from Sorlien et al. (2013). They show the northern Palos Verdes Fault turning from a northwest trend in the southern Santa Monica Bay, to a nearly east-west trend in the center of Santa Monica Bay (Figure 39). The Dume Fault East also trends approximately east-west in the central Santa Monica Bay, and then turns toward the southeast as it approaches the shoreline. Once onshore, the Dume Fault East parallels the Palos Verdes and Newport-Inglewood Faults. The Dume Fault East may extend from the southern Western Transverse Ranges (WTR) tectonic province to the northern Peninsular Ranges (PR) tectonic province, as would the Palos Verdes Fault.

Figure 38: Fault location and depth map of the northwestern Los Angeles Basin, Santa Monica Bay and Palos Verdes region derived from data provided in Plate 1. The approximate locations of the Dume Fault East and associated hanging wall fold are shown on the fault map (see Plate 1 for more detail). Modified cross section A-A'-A" from Sorlien et al. (2013) showing the approximate depth of the Compton thrust. Note that data utilized by Sorlien et al. (2006) for the A'-A" portion was from the SCEC CFM (Plesch et al., 2007) and Shaw and Suppe (1996). The actual depth to the Compton Thrust is poorly constrained. BHUSD – Beverly Hills Unified School District general area; CCF – Culver City Fault, PCFe – Potrero Canyon Fault East; SVF – San Vicente Fault.


SMMA
Santa Monica Arch
H
SANTA MONICA MTNS.
BEVERLY HILLS
CHEVIOT HILLS
CULVER CITY
H'
Santa Monica Blvd. Fault
After Hoots (1931)
After Lamar (1961)
NORTH
SOUTH
Rancho Fault
Culver City Fault
I
SANTA MONICA MTNS.
I'
SCARP
Potrero Canyon Fault (left-lateral)
Culver City Fault?
Rancho Fault or connects with Culver City-Sentous Fault?
J
SANTA MONICA MTNS.
J'
Potrero Canyon Fault (left-lateral)
Culver City Fault?
K
SANTA MONICA MTNS.
SANTA MONICA BAY
VENICE BEACH
K'
Playa Del Rey
Potrero Canyon Fault
Left-lateral
Depth (km)
Culver City Fault
Dume Fault East
Compton-Baldwin Hills Detachment Fault (Shaw and Suppe, 1996; Plesch et al., 2007; Sorlien et al., 2013; also see Plate 2)

8.0 SEISMIC HAZARD IN THE BHUSD REGION – EVIDENCE OF FAULT ACTIVITY, AND FAULT ACTIVITY DESIGNATIONS

This section provides a review and analysis of the existing data regarding the evidence of the age of various fault zones in the region. Fault activity designations are provided for each fault zone based on the specific criteria definitions provided below. Primarily two types of fault zones occur in the region: Strike-slip (left-lateral and right-lateral), and blind compressional faults (reverse, thrust ramps and detachment faults). Some strike-slip faults in the area are considered blind as they are believed to likely not rupture to the surface of the Earth.

It is acknowledged that the fault activity designations provided in this section lean toward conservative, which is reflective in the definition of Geologically Active and Geologically Inactive, and deciding to discard/not utilize the term "geologically potentially active" as it is essentially useless as discussed above. However, it is believed that this approach is very useful for future seismic hazard evaluations in the area.

8.1 Fault Activity Definitions Utilized in This Report

The terms Active Fault and Inactive Fault are defined within this report differently for surface faults and for blind faults. For fault zones believed to have ruptured to the surface sometime in the geological past, the definitions for their activity ("Active", "Potentially Active", and "Inactive") are the same as those described in the California Geological Survey Special Publication 42. For these faults, their level of activity will be designated as Regulatory Active, Regulatory Potentially Active, and Regulatory Inactive in this report.

For blind faults, which, by definition, have never ruptured to the surface during their period of activity, and are generally several thousand feet below the ground surface, the terms Geologically Active and Geologically Inactive will be utilized. The distinction between surface faults and blind faults is necessary because the age range of activity on blind faults can be more difficult to constrain than that for faults that have previously ruptured to the ground surface, and as a result extend to within a few feet to maybe a few tens of feet from the ground, and are thus potentially easier to study.. As such, we have decided to conservatively consider blind faults as "Geologically Active" if there is evidence for mid-late Quaternary (~500 ka) rather than Holocene deformation, especially given that most seismic profiles used to interpret blind faults do not even image the Holocene sedimentary section. Although in the last two decades researchers have developed techniques, typically relying on borings and cone penetration tests, to study the sediments above the tip of a blind fault and infer from these data the earthquake history of the fault, the findings are open to interpretation. The term "Potentially Active" is not utilized here for the blind faults in the BHUSD study region as it is well documented that nearly all of them were active sometime during the Pleistocene.

Definitions for the full set of fault activity designations utilized in this report include:

Active

Regulatory Active: For surface-rupturing fault zones - one which has had surface displacement within Holocene time (about the last 11,000 years) – the same definition provided in Special Publication 42.

Geologically Active: For blind fault zones only - a fault with a reasonably high likelihood of having moved during the past approximately 500,000 years.

Potentially Active

Regulatory Potentially Active: For surface-rupturing fault zones – one which has been shown to displace Pleistocene sediments, but which has not been shown to offset Holocene deposits - the same definition provided in Special Publication 42.

Inactive

Regulatory Inactive: For surface rupturing fault zones - evidence exists that the fault has not ruptured during Holocene time - the same criteria provided in Special Publication 42.

Geologically Inactive: For blind fault zones – a fault is determined to have a reasonably high likelihood of being inactive if it has not deformed sediments that are at least approximately 500,000 years old, and shows no other signs of activity (i.e. seismicity). In general, a designated Geologically Inactive Fault will at a minimum, exhibit no evidence of movement during the past 500,000 years, that is, during and since the middle Pleistocene.

8.2 Strike-Slip Fault Zones in the BHUSD Region

In the BHUSD area, a number of fault zones are identified or inferred to exist that exhibit or exhibited primarily left-lateral strike slip movement. These include the Potrero Canyon Fault (i.e. Santa Monica Fault of Dolan and Sieh, 1992), Potrero Canyon Fault East, Santa Monica Boulevard Fault, the western Hollywood Fault, two cross faults in the western Hollywood Basin, and the North Salt Lake Fault (Plate 4). In addition, it is possible that the Rancho and western San Vicente Faults may also be accommodating some left-lateral motion. These potential seismic sources are discussed individually below.

8.2.1 Potrero Canyon Fault - Regulatory Active

The Potrero Canyon Fault of Wright (1991) is the same fault as the Santa Monica Fault of Dolan and Sieh (1992), Dolan and Pratt (1997), Dolan et al. (2000a) and Catchings et al. (2008). This fault zone is considered active based on findings from Dolan et al. (2000a) evaluated at the VA Hospital (Plate 4). This fault zone has been studied by Crook and Proctor (1992), Dolan and Pratt (1997), Pratt et al. (1998) and Catchings et al. (2008; also see reply by Catchings, et al., 2010). Utilizing seismic reflection data, these studies identify a relatively low angle, north dipping reverse fault that projects to the surface south of the geomorphic scarps identified by Dolan and Sieh (1992).

It is proposed here that the low angle north-dipping "reverse fault" is the southern strand of a left-lateral strike-slip flower structure that includes the steeply north-dipping strike slip faults identified by Dolan et al. (2000a) in fault trenches along the fault scarp in the VA Hospital. Similar structures were also identified by Crook and Proctor (1992) at the University High School, and by Catchings et al. (2008). This wide zone of faulting, ranging from the geomorphic scarps southward to the surface projection of the identified low-angle north dipping fault, is all part of the Potrero Canyon Fault Zone (Plate 3 and Plate 4).

8.2.2 Potrero Canyon Fault East – Geologically Active

The Potrero Canyon Fault East is a previously unmapped fault that is an eastward continuation of the Potrero Canyon Fault. The Potrero Canyon Fault East is a youthful fault that is proposed to have developed during the past several hundred thousand years in response to the transfer of activity from the Santa Monica Boulevard Fault Zone to the north. The Potrero Canyon Fault East developed along pre-existing structures utilized as a strain guide. These include the Santa Monica Fault South of Wright (1991), steeply dipping bedding planes further east along the southern boundary of the Beverly Hills Oil Field, and eastward along a series of structures associated with Las Cienegas Fault Zone.

The Potrero Canyon Fault East's activity and location are based on these data:

- A seismicity swarm of earthquakes (Figure 26), where the largest earthquake in the cluster is a Magnitude 4.2, evaluated by Hauksson et al. (2002) as a left-lateral cross fault to the Newport-Inglewood Fault Zone. The earthquakes in this cluster event are dominated by similar left-lateral nodal plane events (blue lines on Figure 26 shown on epicenter locations) that trend approximately N85E. The seismicity data provides a location of the Potrero Canyon Fault East at depths of 6 to 8 km.

- The N85E trend of the seismic cluster swarm trends westward directly to the intersection of the Potrero Canyon Fault and Santa Monica Boulevard Fault at the Mormon Temple (Plate 3). It is proposed to connect with the active Potrero Canyon Fault Zone west of this point.
- The Potrero Canyon Fault East is presumed to dip steeply to the north similar to the Santa Monica Boulevard Fault Zone and other strike-slip faults in the region, and if projected toward the surface from the 6 to 8 km depth provided by the seismicity, projects to a region in the southern Cheviot Hills where the terrestrial alluvial deposits occur north of the fault but are eroded away south of the fault. In addition, the region north of the fault in the southern Cheviot Hills is approximately 45 feet higher than the top of the Cheviot Hills to the south (Figure 31) suggesting a dip-slip component of slip, possibly associated with a restraining bend may occur along the Potrero Canyon Fault East.
- The Potrero Canyon Fault East surface projection location occurs along a weakly defined geomorphic lineament consisting of swales within the hills, changes in surface geomorphology, and where the upper fan-apex region of the abandoned younger Benedict Canyon Wash Deposits (BCWD1) exist (Figure 18 and Figure 29).
- The western end of the Potrero Canyon Fault East strikes parallel to the structure contours of a ~0.8 Ma marine gravel deposits (likely correlates with the San Pedro Formation) of Hummon et al (1994; Figure 16; Plate 5).
- A strong variation in strike and dip of the 2.5 Ma top of the Pico Formation – base of the Repetto Formation occurs at depth across the Potrero Canyon Fault East at depth (Plate 5).
- InSAR data shows an narrow region parallel to the surface projection of the Potrero Canyon Fault East where uplift south of the Potrero Canyon Fault East is relatively higher along the axis of the north-northwest trending anticline in the southern Cheviot Hills compared to north of the fault (Figure 14).
- The eastern end of the Potrero Canyon Fault East projects along the southern boundary of the Beverly Hills Sub-basin (Figure 14).

- The eastern end of the Potrero Canyon Fault East extends through a region of relatively low red and yellow flagged structures after the 1994 Northridge Earthquake (Figure 27). The fault may provide a boundary between the Beverly Hills Sub-Basin to the north and the Los Angeles Central Trough to the south.

Based on these data, and to a large degree on the recent seismic cluster occurring in 2001, the Potrero Canyon Fault East is considered an active tectonic structure. However, there is no evidence that the fault reaches the surface of the Earth, and in particular, the fault may deepen progressively farther east from its intersection with the Potrero Canyon Fault. Therefore, in a sense the fault may be blind. For these reasons, although the Potrero Canyon Fault is a left-lateral strike-slip fault, which deforms the surface, the Potrero Canyon Fault East's activity designation is Geologically Active.

8.2.3 Santa Monica Boulevard Fault - Regulatory Inactive

The Santa Monica Boulevard Fault extends northeastward across the eastern edge of the Cheviot Hills. The dominantly left-lateral Potrero Canyon Fault connects with the Santa Monica Boulevard Fault near the Mormon Temple where it turns more northeasterly. The turn in the fault is proposed to be associated with the Potrero Canyon and Santa Monica Boulevard Fault connecting at depth with the Santa Monica Fault South and Santa Monica Fault North of Wright (1991) respectively (Figure 32), which were reactivated in the late Pleistocene to accommodate dominantly left-lateral motion when the overlying Potrero Canyon Fault and Santa Monica Boulevard Fault were created ~1 Ma. The activity of the Santa Monica Boulevard Fault at the Mormon Temple is not known, but the fault zone has been demonstrated to be inactive in the Century City and western City of Beverly Hills area (LCI, 2012b; Geocon, 2013b; Helms, 2013; Fault Zone F of KGS, 2014).

8.2.4 Hollywood Fault Zone – Western Hollywood Fault Zone (Regulatory Potentially Active) and the Eastern Hollywood Fault Zone (Regulatory Active)

The Hollywood Fault Zone is partitioned into the western and eastern Hollywood Fault Zone for primarily one reason – the activity along the Hollywood Fault may not be the same. Evidence exists that the eastern Hollywood Fault Zone is active (Dolan et al., 2000b); however, no evidence exists that the western Hollywood Fault Zone is active (Plate 3). Hernandez and Treiman (2014) provide a comprehensive review of numerous fault studies conducted in the City of West Hollywood in the region of this separation into the western and eastern Hollywood Fault Zones. Their analysis indicates that the eastern Hollywood Fault Zone is active westerly until Cross Fault No.2 (discussed below), but numerous studies on the western part of the Hollywood Fault Zone determined that those faults identified were inactive. These findings support that while the western Hollywood Fault may exist at depth in areas of latest Pleistocene and younger sediment cover, it is only exposed at the surface in areas where much older alluvium is exposed.

As discussed earlier, the Hollywood Fault Zone is a dominantly left-lateral strike-slip fault, and due to its change in strike, is a complex, relative wide fault zone that varies along strike from exhibiting pure left-lateral strike slip, to zones exhibiting apparent dip-slip displacement within local releasing and restraining bends (Plate 4). Along the western Hollywood Fault Zone, Dolan and Sieh (1992) mapped a series of scarps near the base of the Santa Monica Mountains that they interpreted to be the location of various western Hollywood Fault Zone strands, as did Crook and Proctor, 1992. However, the geomorphology of the base of the Santa Monica Mountains has been altered by wave erosion (wave cut benches) during the Pleistocene. Based on an evaluation of the age of the abandoned fan surfaces in the Cheviot Hills, the scarps of Dolan and Sieh (1992) are likely associated with fan deposits that are hundreds of thousands of years old. Current evidence indicates that faults in the western Hollywood Fault Zone were likely Active during the early to mid-Pleistocene, but became Inactive during the late Pleistocene, consistent with cessation of activity on the Santa Monica Boulevard Fault Zone (i.e. ~200 kya).

Based on these data, the eastern Hollywood Fault Zone is designated as Active, and the western Hollywood Fault Zone is designated as Potentially Active (Plate 4).

8.2.5 Cross Faults in the western Hollywood – Cross Fault No. 1 (Regulatory Inactive) and Cross Fault No. 2 (NE segment Regulatory Active; SW segment Regulatory Potentially Active).

Two northeast trending fault zones, Cross Fault No. 1 and No. 2, are proposed in the western Hollywood Basin (Plate 3 and Plate 4). These fault zones connect the western Hollywood Fault Zone with the Santa Monica Boulevard Fault Zone, forming a releasing bend that partially explains the development of the western Hollywood Basin during the early to mid-Pleistocene. Evidence for activity on these faults is discussed separately below.

*Cross Fault No. 1 – **Regulatory Inactive***

The southwestern end of Cross Fault No. 1 is referred to as Fault Zone A (KGS, 2013 and 2014), which intersects the Santa Monica Boulevard Fault in Century City (Figure 11). The Cross Fault No. 1 fault zone exhibits apparent reverse displacement and tilting of beds near the intersection with the Santa Monica Boulevard Fault Zone. This "compressional" style of deformation is associated with the restraining bend turn that occurs at the intersection of the Cross Fault No. 1 and Santa Monica Boulevard Fault Zones. However, toward the northeast along Cross Fault No. 1, the fault zone exhibits down to the southeast apparent normal displacement (Figure 29).

Cross Fault No. 1 (Fault Zone A) occurs along a geomorphic fault scarp identified by Dolan and Sieh (1992; also see Dolan et al., 1997, and Dolan et al., 2000a) trending northeast through the Los Angeles Country Club. The magnitude of apparent vertical separation of the underlying early to middle Pleistocene age sediments across Fault Zone A is consistent with the general height of the geomorphic scarp (KGS, 2014), however, it is clear that the scarp has been altered by stream action and erosion during the past several hundred thousand years. Based on approximately equal (but opposite sense) magnitudes of apparent vertical separation across Fault Zone A at both the intersection of the Avenue of the Stars and Santa Monica Boulevard, and at El Rodeo School, it is proposed that Fault Zone A likely extends east of the Cheviot Hills and across the western Hollywood Basin (Cross Fault No. 1; Figure 29; KGS, 2014). Fault Zone A was interpreted to be active by Geocon (2014) performed at 9900 Wilshire Boulevard based primarily on CPT data; however a recent fault investigation at the El Rodeo School conducted by LCI (2016) that included borings and extensive trenching concluded that all strands of Fault Zone A are Regulatory Inactive since ~200 kya.

Cross Fault No. 2 - Northeast Segment of Cross Fault No. 2: ***Regulatory Active;*** *Central Hollywood Basin Segment of Cross Fault No .2:* ***Regulatory Potentially Active;*** *Southwestern Segment of Cross Fault No. 2:* ***Regulatory Potentially Active***

Cross Fault No. 2 extends from the intersection point of the western and eastern segments of the Hollywood Fault Zone and trend nearly parallel and beneath Santa Monica Boulevard across the western Hollywood Basin (Figure 29; Plate 3 and Plate 4). Evidence for Cross Fault No. 2 includes; a change in slope across the alluvial fan deposits in the western Hollywood Basin, and it bounds the northern limit of near surface groundwater identified by Mendenhall (1905). The northeastern end of Cross Fault No. 2 connects with a N46E trending identified active fault zone by William Lettis and Associates (see Hernandez and Treiman, 2014, WLA - Fault No. 1) that trends away from the general strike of the Hollywood Fault Zone across the western Hollywood Basin (Plate 3). Cross Fault No. 2 may extend all the way to Beverly Hills High School, as part of the northern strands within Fault Zone F (Santa Monica Boulevard Fault Zone; Figure 29), which were demonstrated to be inactive (LCI, 2012a, Geocon, 2013).

Cross Fault No. 2 geologically consists of three sections in terms of evaluating its activity. A northeastern section where the fault intersects the Hollywood Fault Zone, a middle section where it transverses across the central and western Hollywood Basin, and a southwestern section where likely splays from the Santa Monica Boulevard Fault Zone.

Northeast Segment of Cross Fault No. 2 – ***Regulatory Active***

The northeast segment of Cross Fault No. 2 has been drawn to connect with the N46E trending Fault No. 1 of the WLA fault investigation, as discussed in Hernandez and Treiman (2014). This fault is considered active based on the findings in Hernandez and Treiman (2014) who placed the fault within a newly designated AP Act Surface Fault Rupture Hazard Zone. This fault is designated Regulatory Active.

Central Hollywood Basin Segment of Cross Fault No. 2. – ***Regulatory Potentially Active***

As interpreted, the Central Hollywood Basin segment of Cross Fault No. 2 trends along a change in slope of an alluvial fan as identified on the Hoots (1931) geologic map (Plate 3). Careful review of the Hoots (1931) topographic map exhibits an unusual moderately well-defined narrow drainage that may be left-lateral deflected by the fault (Plate 4). Cross Fault No. 2 occurs immediately north of a region of pumping near surface groundwater identified by Mendenhal (1905), which is also bound immediately to the south by the Santa Monica Boulevard Fault Zone (Plate 3). Based on these data and interpretations, the Hollywood basin segment of Cross Fault No.2 will be designated as Regulatory Potentially Active.

Southwestern Segment of Cross Fault No. 2 - Fault Activity Designation of ***Regulatory Potentially Active***

The southwestern segment of Cross Fault No. 2 occurs in a region where the alluvial fan surface does not exhibit any change in slope, and there are no other data obtained or evaluated to suggest that Cross Fault No. 2 is active in this area, nor that the fault ever extended this far. This segment is extended to a location sufficient to connect with the Santa Monica Boulevard Fault Zone based on the observation that Cross Fault No. 1 does connect with the Santa Monica Boulevard Fault Zone in Century City. Fault evaluation studies (KGS, 2012, 2014) and fault investigations (LCI, 2012 and 2016) provide strong evidence that the age of alluvial sediments in the southwestern Hollywood Basin are approximately 40,000 years old at a depth of only 10 to 12 feet. Hence, due to the lack of any geomorphic expression of the southwestern segment of Cross Fault No. 2 on the fan-alluvial surface overlying its projected trend, this fault segment is likely inactive. However, without actual data to refute the fault in this area, or if present, that the fault is shown to not have displaced Holocene age sediments, it is prudent to designate the southwestern segment of Cross Fault No. 2 as Regulatory Potentially Active.

8.2.6 North Salt Lake Fault – Regulatory Potentially Active

The North Salt Lake Fault occurs along the southern boundary of the eastern Hollywood Basin and steps over to the Santa Monica Boulevard Fault Zone (Plate 3). Although the North Salt Lake Fault is documented to have exhibited dominantly normal displacement during the early to late Pliocene, and early Pleistocene activity on the fault remains uncertain (Tsutsumi et al, 2001), this report shows that the late Pleistocene sense of slip was left-lateral. The North Salt Lake Fault forms a groundwater barrier in Pleistocene sediments and bounds a zone of active subsidence immediately along the north side of the fault in the Hollywood Basin (Hill et al., 1979). Wright (1991) shows offset soil contacts from geotechnical studies along the North Salt Lake Fault in a region above the surface projection of structure contours of the fault at depth (Figure 32). This is observed by comparing the orange dashed line (offset soil "s" contacts line) with the yellow "0" structure contour (yellow line) on Figure 32. The surface projection location of the North Salt Lake Fault is poorly constrained, but based on the location of the offset soil contacts shown by Wright (1991), it suggests that a more recent strand of the North Salt Lake Fault projects upwards from the deeper "main" older strand. If the relatively shallow soil contacts are displaced and the fault zone exhibits a shallow groundwater barrier associated with active subsidence, then it suggests that the North Salt Lake Fault along the southern boundary of the Hollywood Basin projects fairly close to the surface. This in turns suggests that the fault ruptured to the surface sometime in the Pleistocene.

Along the eastern portion of the North Salt Lake Fault in the northern Elysian Park Hills, Weber (1979) shows a series of linear topographic features (lineaments) that Wright (1991) interpreted as strands of the North Salt Lake Fault at the surface. One of these fault strands occurs at the same location as a fault shown by Dibblee and Ehrenspeck (1991). They show the un-named fault striking east northeast, parallel to the North Salt Fault, and exhibiting down to the north apparent offset similar to that of the North Salt Lake Fault. The Dibblee and Ehrenspeck (1991) fault is shown to occur at the surface where it offsets Tertiary age sediments in the northern Elysian Park Hills and south of their mapped location of their Santa Monica Fault (now referred to as the Hollywood Fault). Evaluating the local topography of the area of the Dibblee and Ehrenspeck's

(1991) un-named fault on the Hoots (1931) topographic map suggests that a local drainage crossing the un-named fault may be deflected left-laterally.

Tsutsumi et al. (2001) evaluated the North Salt Lake Fault and indicated that the fault may be a branch of the Hollywood Fault, and that it may extend all the way to the Cheviot Hills. Both of these proposed ideas are consistent with the kinematic model presented in this report. In addition, Tsutsumi indicates that the North Salt Lake Fault extends fairly close to the surface, and should therefore be considered a potentially active structure.

This report proposes that the North Salt Lake Fault was re-activated during the early Pleistocene to accommodate dominantly left-lateral strike-slip displacement during the same time period as the Santa Monica Boulevard Fault Zone, which became active approximately 1 Ma. The Santa Monica Boulevard Fault Zone is documented as becoming inactive approximately 200 kya (LCI, 2012a; Geocon, 2013). No similar age data exist for the North Salt Lake fault. In addition, the western North Salt Lake Fault exhibits no geomorphic features on the fan-alluvial surface as evaluated on the 5-contour topographic map of Hoots (1931).

These observations collectively indicate that while there is no definitive data demonstrating that the North Salt Lake Fault was active during the Holocene, that it was active during the mid- to late-Pleistocene, and probably left-lateral. The North Salt Lake Fault is designated as a Regulatory Potentially Active Fault.

8.2.7 Newport-Inglewood Fault – Regulatory Active (southern segment), Regulatory Potentially Active (middle segment), and Geologically Inactive (northern segment)

The Newport-Inglewood Fault Zone (NIF), which is discussed in great detail within the body of this report in terms of location and long term history, will be partitioned into three sections for the discussion of fault activity. These include the southern segment located mostly in the Baldwin Hills, the middle segment occurring from Ballona Gap to southern Cheviot Hills, and the northern segment located in the northern portion of the southern Cheviot Hills segment. These fault segments are shown on Plate 4.

The Southern Segment of the Newport-Inglewood Fault Zone – ***Regulatory Active***

The Newport-Inglewood Fault Zone is considered active by the State of California (Bryant and Hart, 2007), which has published Fault Rupture-Hazard Zones to the north side of the Baldwin Hills. This is the limit of the Southern Segment, and hence, this portion of the Newport-Inglewood Fault Zone is designated as Regulatory Active.

The Middle Segment of the Newport-Inglewood Fault Zone – ***Regulatory Potentially Active***

The Middle Segment of the Newport-Inglewood Fault Zone extends from the southern Ballona Gap to the Potrero Canyon Fault East in the southern Cheviot Hills (Plate 4). None of these fault strands are currently zoned active by the State of California under the AP Act. There is considerable evidence indicating that the Newport-Inglewood Fault Zone extends across Ballona Gap and across the eastern side of the southernmost Cheviot Hills. Two strands of the Newport-Inglewood Fault are proposed in this segment. The interpretation herein is that if one of these two fault strands is active, it is likely the eastern strand referred to as the West Pico Fault No.4 (Plate 4). The data suggests that this strand likely extends to shallower depths than the western strand, which might be confirmed by a LiDAR image a small scarp in presumably younger alluvial sediments flanking the Cheviot Hills (Figure 25).

The data provided in this report demonstrates that the San Pedro Formation, which is locally approximately 1 million years old (KGS, 2014; consistent with regional dating of the San Pedro formation - Blake 1991; Powell and Stevens, 2000), exhibits a vertical dip-slip separation of 110 to 75 feet in Ballona Gap (Plate 7). In addition, the faults also exhibit a strong groundwater barrier within San Pedro Formation sands (Poland et al. 1959)

Based on these data, the Middle Segment of the Newport-Inglewood Fault Zone is designated as Potentially Active.

The Northern Segment of the Newport-Inglewood Fault Zone – ***Regulatory Inactive***

The Northern Segment of the Newport-Inglewood Fault Zone shown on Plate 4 extends from the Potrero Canyon Fault East in the south, north to the Santa Monica Boulevard Fault Zone. None of these fault strands are currently zoned active by the State of California under the AP Act. No strands of the Newport-Inglewood Fault Zone have been positively identified in this region, however numerous lines of evidence are provided in this report suggesting that strands of the fault zone do occur this far north.

KGS (2014) correlated a north-northwest trending fault zone (Fault Zone H in Figure 11) to the Newport-Inglewood Fault Zone although that correlation has not been confirmed. Fault Zone H, lying immediately east of the Beverly Hills High School, was determined to be inactive in KGS (2014) as it appeared to not displace sediments of the younger Benedict Canyon Wash Deposits (BCWD1) that were deposited between approximately 480 to 40 kya (see Figure 22). In addition, Geocon (2013) investigated across a portion of Fault Zone H near Santa Monica Boulevard and did not find any faulting in sediments of late Pleistocene age.

Toward the east, two strands of the Newport-Inglewood Fault Zone have been interpreted, Poland et al. (1959) and Wright (1991) for the western strand, and Erickson and Spaulding (1975) for the eastern strand (West Pico Fault No.4, Plate 3). These authors show the faults extending to within the southern region of the BHUSD. The western fault strand of Poland et al. (1959) and Wright (1991) does occur within a prominent swale within the southeastern Cheviot Hills suggesting that the fault zone occurs within the early to mid-Pleistocene sediments exposed in the hills. However, no geomorphic evidence of faulting was identified in either the LiDAR data (Figure 25) or the 5-foot contour topographic map from 1925 of Hoots (1931) in the northern reaches of this fault strand where it occurs under a planar alluvial surface. In this region, late Pleistocene alluvial sediments of approximately 40 kya occur within 10 to 15 feet of the surface as was demonstrated at the Beverly Hills High School site nearby (see LCI, 2012). If the fault had ruptured only a few times during the past 40 thousand years it would have resulted in some noticeable geomorphic expression.

Other evidence also suggests that fault strands of the Newport-Inglewood Fault Zone extend north of the southeastern Cheviot Hills across the alluvial plain and into the southern BHUSD. These include a variation in relative density of red and yellow flagged structures associated with the 1994 Northridge earthquake (Figure 27), and deep oil well data (Erickson and Spaulding). Poland et al. (1959) that show a ground water barrier within a sandstone unit of San Pedro Formation age (~1 million years old) at depths of 200 to 100 feet below the surface in this region (Plate 6).

Although it is risky to determine fault activity based on tectonic kinematic models, it is proposed here that fault strands of the Northern Segment of the Newport-Inglewood Fault Zone are likely inactive due to the genesis of the Potrero Canyon Fault East that likely formed only within the past several hundred thousand years to accommodate left-lateral slip once the Santa Monica Boulevard Fault Zone became inactive. In this model, once the Potrero Canyon Fault East formed, it cut off the Northern Segment of the Newport-Inglewood Fault Zone, causing these faults to also become inactive.

These observations and interpretations suggest that strands of the Newport-Inglewood Fault Zone do extend as far north as the southern BHUSD, but that the faults have not ruptured the surface for at least tens of thousands of years, and where identified were determined to be inactive (Fault Zone H), faults associated with the northern segment of the Newport-Inglewood Fault Zone are designated as Regulatory Inactive.

8.3 Geologic Activity Level Designations for Blind Rupturing Fault Zones in the BHUSD Region

The faults in the region that fall under the criteria as "Blind" include: The San Vicente Fault, Santa Monica Fault North, Santa Monica Fault South, Rancho Fault, and the Culver City Fault. In addition, although farther away, the proposed Dume Fault East will be discussed in this section.

Blind faults are quite complex, and this may indicate that deep blind fault zones have been provided different names, or that there are multiple faults at various depths or at various geologic times. In the northern Los Angeles Basin, east of the Newport-Inglewood Fault, numerous faults have been proposed, and there is strong data to indicate that, regardless of the name, or the depth of the faults, active blind compressional faults occur in the region. These faults include the Wilshire Fault (Hummon et al., 1994; which may also be the 6th Street Fault), Los Angeles Fault (Schneider et al., 1996), Las Cienegas Fault (Wright, 1991, among others), Puente Hills Thrust, and the very deep Lower Elysian Park Fault and Compton Detachment fault. All of these very deep and blind compressional faults will be discussed collectively.

The opposite is true for published blind faults west of the Newport-Inglewood where no active blind fault zones have been documented in the Beach Cities Region with the exception of the deep Compton-Baldwin Hills Detachment Fault. Similar geologic conditions suggest that compressional blind thrust faults (i.e. thrust ramps) probably occur west of the Newport-Inglewood similar to those identified to the west. Researching this idea led to the identification of two proposed blind thrust ramp faults in the Beach Cities Region, the Culver City Fault and the Dume Fault East (Figure 35).

There are many justifications for the approach for designating fault activity levels for blind structures applied herein, some of which include:

- The "Santa Monica Fault Zone" is typically described in the literature as those faults referred to herein as the Potrero Canyon and Santa Monica Boulevard Fault Zone. This is very confusing primarily because in the literature, including fault hazard maps and databases, this fault zone is described as an oblique reverse left-lateral fault zone. One of the primary purposes of this report is to change that dogma and begin to realize that this fault zone is dominantly left-lateral, which indicates that compressional deformation must be occurring on some other fault zones.
- Santa Monica Fault North and Santa Monica Fault South Fault System, which are blind compressional faults, are commonly shown on most fault hazard maps

and within most fault hazard databases; however, the primary publications describing these blind faults indicate that these faults are likely inactive.

- The Rancho Fault is described by Tsutsumi et al. (2001) as being one of the most probable sources of an active blind fault in the area; however this fault is commonly not shown in fault hazard publications.
- The San Vicente Fault is very commonly also shown on seismic hazard geologic maps and databases, however Tsutsumi (2001) provides compelling evidence that the entire eastern half of the fault has not ruptured since the Miocene. As such, only a western portion of the San Vicente Fault is shown on most plates and figures in this report.
- The Wilshire Fault and Los Angeles Faults, do not seem to appear on any fault hazard map, and were not included within the California Fault Model (Plesch, et al., 2007).
- Kinematics in the region have been remarkably dynamic during the Quaternary (past ~2 million years) with many faults becoming inactive, new faults being activated, some faults switching from one style of displacement to another, and other older faults possibly becoming reactivated. One of the key findings in this report is that it was not only during the early Pliocene that major kinematic changes occurred, but that they have continued to evolve to the present day.
- One of the issues posing difficulty in the evaluation of fault activity in the BHUSD region is that tectonic stress rates in the area are relatively low which leads to relatively long recurrence intervals between major earthquakes.
- Many modern faults utilized older faults that may not be oriented in a preferred orientation to the existing tectonic stress, leading to additional segmentation of faults.

Individual blind faults within the BHUSD are discussed below.

8.3.1 San Vicente Fault – Geologically Active

The western San Vicente Fault occurs in the southern BHUSD and is considered a blind reverse fault that extends upwards to a depth of approximately 1.0 to 2.0 km (Tsutsumi et al., 2001; Plate 3). This fault is generally considered inactive. However, recent data suggest that the western part of the San Vicente Fault may be active, particularly the evaluation of two recent small earthquakes that appear to reside on the western San Vicente Fault (ECI, 2015; see Plate 3). Close examination of Cross Section E-E′ of Tsutsumi et al. (2001), which is very similar to that of Hummon et al. (1994; Cross

Section A-A′ of Figure 17), shows that the 0.8 million year old gravels (unit Qmg of Figure 17) are deformed by the underlying San Vicente Fault.

Also, Hummon et al. (1994) shows the San Vicente Fault connecting with their active Wilshire Fault at depth, and it is reasonable that a component of the deformation they describe for the active development of the overlying Wilshire Arch could be accommodated on the San Vicente Fault.

Close examination of the Hoots (1931) topographic map with 5-foot contours does exhibit a slight rise in elevation of the alluvial fan surface over the surface projection of the San Vicente Fault. The trend of the change in slope of the alluvial fan overlying the San Vicente Fault is approximately parallel to the strike of the underlying fault zone.

Based on these observations, the fault zone may have been active during the late mid-Pleistocene through recent times. Although the western San Vicente Fault exhibits a laterally short length fault zone (~5 km), thus likely limiting its potential maximum magnitude earthquake, the fault is designated as a Geologically Active fault zone.

8.3.2 Santa Monica Fault North - Geologically Inactive

This fault zone occurs within the west central region of the BHUSD as shown partially on Plate 4 (western end), and fully on Figure 32 (Wright, 1991). As discussed in this report, the Santa Monica Fault North is a blind reverse fault in a location essentially where Wright (1991) shows the fault (Figure 32).

This fault is considered inactive by Wright (1991). Tsutsumi et al. (2001) show the fault within a zone of blind reverse faulting, however, they considered the blind reverse faults in this area as becoming inactive in the early Pleistocene. The conclusions in this report are consistent with Wright (1991): that the Santa Monica Fault North is inactive as it appears to not deform the 580 kya fan-terrace surfaces overlying the fault. The fault also does not appear to fold the 1 Ma San Pedro Formation but does fold Pico Formation (Figure 30). It is worth noting that the near vertical faults shown on Figure 30 that do deform the San Pedro Formation represent the Santa Monica Boulevard Fault Zone, which has been determined to be Regulatory Inactive.

These data indicate that the Santa Monica Fault North has not ruptured during the past 1 Ma indicating a fault activity designation of Geologically Inactive.

8.3.3 Santa Monica Fault South – Geologically Inactive

Santa Monica Fault South is the same fault (in terms of names) for both Wright (1991) and Tsutsumi et al. (2001), however, they both show the fault in slightly different locations. In general, the location utilized throughout this report is that of Wright (1991).

This fault occurs west of the BHUSD and was indicated as inactive by both Tsutsumi et al. (2001) and Wright (1991) who identified un-deformed Quaternary sediments overlying the fault. Wright (1991) does indicate that active monoclinal folding is occurring south of the Santa Monica Fault South, but does not directly connect that deformation with this fault. Instead, he suggests that deeper regional faults might be responsible that would require additional research to identify. Tsutsumi et al. (2001) also indicates that this fault is inactive because it is overlain by undeformed mid- to late Pleistocene strata, but that it was active during deposition of upper Pico Formation in the early Pleistocene. Tsutsumi et al. (2001) shows that the period of major reverse faulting and folding associated with the “Santa Monica Fault System” pre-dates upper Pico Strata and middle to late Quaternary strata. Therefore, Tsutsumi et al. (2001) are suggesting that the Santa Monica Fault South strand (Figure 34; SMF [S Strand]) became inactive by the time the uppermost upper Pico Formation was deposited about 0.9 Ma.

The ~0.9 Ma upper Pico Formation of Tsutsumi et al (2001) correlates temporally (in time) with the marine San Pedro Formation identified in the Century City area. Both the Santa Monica Fault North (described above) and the Santa Monica Fault South appear to have become inactive at approximately 1 Ma. As discussed throughout this report, this is the same time that the Potrero Canyon Fault and the Santa Monica Boulevard Faults were created. It was at this time that the “Santa Monica Fault Zone System” switched from an oblique reverse left-lateral fault zone system, to one that accommodated dominantly left-lateral strike displacement and this was the time of the creation of the local Transverse Ranges Southern Boundary System “Left-Lateral” (TRSBLL). At this point in time, the compressional deformation previously accommodated by the Santa Monica Fault Zone System was required to occur elsewhere (i.e. to the south and/or north).

Based on these data and interpretations, the Santa Monica Fault South of Wright (1991) and Tsutsumi (2001) is designated as Geologically Inactive.

8.3.4 Rancho Fault – Geologically Active

The Rancho Fault is located southwest of the BHUSD, essentially underlying the southwestern Cheviot Hills (Plate 4). The fault is best described by Tsutsumi et al. (2001; Plate 4), but also discussed by Wright (1991; Figure 32) who both indicate that the Rancho Fault is a blind reverse fault that was active during a similar period of time as the Santa Monica Fault North and South. Tsutsumi et al. (2001) however also indicates that the Rancho Fault exhibits a steep 80 degrees northward dip and suggests that since reverse faults of >60 degrees are rarely observed in historical earthquakes (he references Sibson and Xie, 1998), that the Rancho Fault may have a significant strike-slip component of displacement. These observations collectively indicate that the Rancho Fault exhibited oblique reverse strike-slip displacement, or possibly, that the Rancho Fault was initially a dominantly reverse fault, and may have subsequently transitioned into a left-lateral strike-slip fault. Both Tsutsumi et al. (2001) and Wright (1991) describe subtleties to the development of the Rancho Fault and related structures and oil reserve development suggesting that the observed fault identified as the Rancho Fault in their cross sections (Figure 33) may have developed associated with a deeper reverse (thrust) structure.

In terms of the age of the Rancho Fault, Tsutsumi et al. (2001) provides the best data indicating that the fault zone exhibited major structural growth during the deposition of middle Pico strata, which he indicates occurred during the latest Pliocene to earliest Pleistocene (i.e. prior to ~0.9 Ma). This indicates, as Tsutsumi et al. (2001) conclude, that the Rancho Fault is younger than the Santa Monica Fault South that developed in the early Pliocene. Tsutsumi et al. (2001) shows that middle to late Quaternary strata are flat over the Rancho Fault, indicating that the Rancho Fault ceased apparent vertical displacement around ~0.9 Ma, which is their age of the upper most members of the upper Pico Formation

Wright (1991) does not discuss the Rancho Fault in great detail, but does show a Holocene age anticline above the Rancho Fault and with a similar strike (Figure 37). In addition, Wright (1991) shows the anticlinal fold parallel to where he turns the east-west trending monoclinal structure in the Beach Cities Region (Figure 37). Careful evaluation of the Hoots (1931) 5-foot contour map shows possible surface warping in an abandoned fan lobe of the younger Benedict Canyon Wash Deposits (BCWD1) (Figure 18).

These data appear to show that the Rancho Fault is not active, however, due to the steep dip of the Rancho Fault that motivated Tsutsumi et al. (2001) to suggest it may exhibit a strong strike-slip component of displacement, it is reasonable to consider whether or not the Rancho Fault may exhibit more recent strike-slip displacement that would go unrecognized in a two dimensional analysis.

Lang and Dreessen (1975) interpret the Rancho Fault as a northern strand of the Newport-Inglewood Fault, suggesting it is a right-lateral strike-slip fault connecting the Newport-Inglewood Fault in the Baldwin Hills westward to the “Santa Monica Fault Zone” (Potrero Canyon Fault in this study). However, Wright (1991) indicates that if this were true, their strike-slip fault would have to intersect one of more deep exploratory wells that were directionally drilled in the area between the Inglewood and Rancho fault zones, and that data from those wells show no evidence for the proposed fault connection.

It is possible, based on the Quaternary kinematic model proposed in this report that the Rancho Fault transitioned into a strike-slip fault ~0.9 Ma, around the time that it ceased exhibiting a dominantly reverse displacement style. This idea would support an aspect of both Tsutsumi et al. (2001) and Lang and Dreessen (1975) in that the Rancho Fault could exhibit strike-slip motion. Exploring this further, it is interesting to consider whether the fold structures currently associated with the Rancho Fault actually developed from a currently unknown deeper thrust fault and that the Rancho Fault subsequently developed to accommodate dominantly strike-slip displacement. In this model, the magnitude of total strike-slip displacement would likely be relatively small (i.e. <1 km) and may not be readily observed in the local oil well data. In short, it is possible that the Rancho Fault is active to accommodate left-lateral slip in a similar way as the development of the Potrero Canyon Fault and Santa Monica Boulevard Fault approximately 0.9 Ma, and more recent (i.e. past several thousand years) development of the Potrero Canyon Fault East.

In consideration of all these data and interpretations, the Rancho Fault will be designated as Geologically Active.

8.3.5 Culver City Fault – Geologically Active

This report concludes that the Culver City Fault extends as a blind reverse thrust ramp westward to the coast where it underlies the Santa Monica Fault South (Figure 39). Supportive evidence for this is that movement on the Culver City Fault is considered responsible for the oil capturing anticlinal structure associated with the Culver City and Riviera oil reserves (Figure 35). This is observed on Cross Section H-H′ by Wright (1991, Figure 36) that shows an un-named reverse-thrust fault immediately underlying the Culver City oil reserve (compare Figure 35 and Figure 36).

The Culver City Fault is proposed to be a blind thrust ramp fault that connects with the active Compton-Baldwin Hills Detachment Fault at a depth of approximately 8 km (Figure 36, Cross Section K-K′). The Compton-Baldwin Hills Detachment Fault extends from a depth of approximately 10 km beneath the Newport-Inglewood Fault to approximately 5 km beneath the Palos Verdes Fault in Santa Monica Bay (Plate 1, Plate 2, and Figure 38). The upward termination depth of the Culver City Fault is unknown, but based on an interpretation of structures in cross sections provided by Wright (1991; Figure 36), the Culver City Fault may reach depths of at least 3 km at its western end (Wright, Cross Section K-K' in Figure 36), and a depth of 2 km at its eastern end (Wright, Cross Section H-H' in Figure 36, Plate 4). The very deep depth and immature development of both the Riviera and Culver City oil reserves, suggests that the Culver City Fault is youthful. In addition, the approximately east-west trending Holocene age syncline identified by Wright (1991) extends along the hanging wall of the Culver City Fault, which may be the causative agent for the development of the syncline (Figure 35 and Figure 36).

It is proposed that the Culver City Fault formed to accommodate compressional stress in the region once the "Santa Monica Fault System" shut down in terms of an active compressional entity, which occurred approximately 1 Ma.

Upon consideration of these observations, the Culver City Fault is designated as Geologically Active.

8.3.6 Dume Fault East – Geologically Active

The Dume Fault East is a thrust fault ramp that connects with the Dume Fault south of Point Dume, and extends eastward near the coastline under the Playa Del Rey area. The identification and location of this fault is based on analysis conducted for this report in collaboration with C. Sorlien (personal communication during review of an early version of this report in 2014). The Dume Fault East emanates upwards from the Santa Monica Bay thrust in the west to the Compton-Baldwin Hills Detachment Thrust in the east (Figure 36, Figure 37 and Figure 39). However, the northwestern extent of the Compton-Baldwin Hills Detachment Thrust is not fully understood so the Dume Fault East may simply connect to the Compton-Baldwin Hills Detachment Thrust along its entire length.

The fault is identified via a series of seismic profile sections in Santa Monica Bay and extended onshore via correlation with related structures primarily involving documented anticlines (Plate 8). The Dume Fault East location in eastern Santa Monica Bay is restricted to a region north of the northern projection of the Palos Verdes Fault as demonstrated by Fisher et al., 2003. The Dume Fault East formed sometime after 1.5 Ma based on the observation that sediments deposited from approximately 4.0 to 1.5 Ma are all folded equally (Plate 8).

There is a high likelihood that the western portion of the Dume Fault East is active. Toward the east, the fault could be considered potentially active until the postulated fault is further evaluated. Therefore, the Dume Fault East is designated as Geologically Active.

8.3.7 The Northern Los Angeles Basin Compressional Fault System East of the Newport-Inglewood Fault Zone

Hummon et al. (1994) suggest that the Wilshire Fault is a potentially active seismic source (Figure 21, also see Figure 7). Their determination that the Wilshire Fault may be active is based on the identification of a zone of seismicity believed to have occurred on the fault, and that the motion across the fault deformed 1.0 to 0.8 Ma Quaternary sediments defining their near surface expression of the Wilshire Arch. Hummon et al. (1994) estimate that the slip rate on the Wilshire Fault may be in the range of 1.5 to 3.2 mm/yr. The Wilshire Fault may be the same fault as the Las Cienegas Fault (Plate 1 and Plate 2).

The Las Cienegas Fault at depth likely connects with the active Puente Hills Thrust well to the east. The Los Angeles Fault of Schneider et al. (1996) is proposed to be active and possibly at a depth below the Wilshire Fault. Motion across all of these faults is believed to have contributed to the actively developing Los Angeles Central Trough, East Beverly Hills Monocline (Plate 3, Plate 4), and Wilshire Arch (Figure 7, Figure 20, and Figure 21). Regardless of exactly what the fault names are, or their exact location, it appears clear that active tectonic shortening is occurring immediately southeast of the BHUSD. It is difficult to estimate anticipated moment magnitudes for potential earthquakes on these faults, but for reasonable seismic hazard assessments, it would be prudent to minimally anticipate that a major reverse/thrust earthquake event will occur sometime in the future.

- *Las Cienegas Fault- Wilshire-Los Angeles Fault Zones:* The Las Cienegas and Wilshire Faults are considered the same structures, and all are located southeast of the BHUSD (see Dolan et al., 2001). Motion across these faults has contributed to the development of the East Beverly Hills-Las Cienegas monocline, which is considered an active structure. The Los Angeles deep thrust ramp by Schneider et al., (1996) which contributes to the development of the East Beverly Hills-Las Cienegas monocline and Los Angeles Central Trough may also occur beneath the La Cienegas ramp. These faults are considered potentially active to active.
- *Puente Hills Thrust:* This fault system occurs immediately southeast of the Las Cienegas-Wilshire-Los Angeles Faults and consists of numerous segments (Plate 1 and Plate 2). The Puente Hills Thrust contributed to the development of the active East Beverly Hills-Las Cienegas monocline (Plate 3). Evaluated by Shaw et al. (2002), this fault system is considered the southernmost extent of the Western transverse Ranges and likely should be considered active. It is possible that the Puente Hills Thrust may connect with the Los Angeles Fault of

Schneider et al. (1996). The Whittier 1987 earthquake occurred on a segment of the Puente Hills Thrust (Shaw and Shearer, 1999; Shaw et al., 2002; Hauksson and Stein, 1989).

9.0 FAULT ACTIVITY AND TYPE OF FAULTING HISTORY ALONG THE LOCAL TRSBLL SINCE THE EARLY PLIOCENE

The findings in this report provide critical information regarding the dynamic tectonic history in the region of the Beverly Hills Unified School District (BHUSD) during the Quaternary (i.e. past ~2.6 million years). Numerous fault zones have become inactive, some have been created, and others changed their style of displacement. The dynamic tectonic changes now occurring in the Quaternary along the Transverse Ranges Southern Boundary Fault System (TRSB), where the BHUSD resides, are not unique, similarly dramatic tectonic changes occurred during early Pliocene approximately 5.0 to 4.5 Ma and during the early Miocene (~16 Ma).

Understanding this complex history is critical for performing seismic hazard assessments regarding the two primary hazards associated with earthquakes: fault surface rupture and ground shaking. It is important to have the best understanding possible regarding which faults are active, inactive and potentially active, which faults may breach the surface, and the type of fault motion expected (i.e. reverse, thrust, and strike-slip). The findings of this report provide a basis to critically challenge an entrenched dogma within the scientific, regulatory, and industrial communities regarding the age, location and style of faults in the region. This report provides a framework for future studies to focus attention on regions with a higher probability of exhibiting an active fault by identifying areas where certain types of faults are likely to occur although not yet positively identified. This report also provides a basis to remove or lower the currently held seismic hazard potential for specific fault zones.

Although dynamic Quaternary tectonic changes have been proposed by numerous authors, this report for the first time provides an integrated model for what happened, where, and when. The primary findings in this report include:

- **Major tectonic change along the TRSB at ~1.0 Ma.**

  This phase of the structural history involved cessation of oblique reverse left-lateral slip along the TRSB (Santa Monica Fault North and South became inactive) and the creation of the Potrero Canyon and Santa Monica Boulevard Fault Zone. The Hollywood Fault and North Salt Lake Fault Zones transitioned at this time to accommodate dominantly left-lateral motion. Cross Faults were created in the western Hollywood Basin to connect the Hollywood with the newly created Santa Monica Boulevard Fault Zone which led to the development of the western Hollywood Basin and the northern West Beverly Hills Lineament. The Newport-Inglewood Fault continued its northward migration to the Santa Monica Boulevard Fault Zone. Compressional deformation no longer occurred on the now inactive Santa Monica Fault North and South; compressional deformation migrated both northward to the northern and central Western Transverse Ranges, and southward to the local Transverse Ranges Southern Boundary System "Left-Lateral" (TRSBLL, Figure 39). The local Transverse Ranges Southern Boundary System "Left-Lateral" (TRSBLL, Figure 39) was created at this time that includes the Potrero Canyon-Santa Monica Boulevard, Hollywood and North Salt Lake Fault Zones, all of which exhibit dominantly left-lateral motion starting approximately 1 Ma. Compressional deformation rates across numerous thrust faults increased in the region east of the Newport-Inglewood Fault Zone and south of the TRSBLL faults. Two new thrust ramp faults were created west of the Newport-Inglewood Fault to accommodate a component of the compressional deformation no longer "absorbed" by the Santa Monica Fault South. These include the Dume Fault East and the Culver City Fault.

- **Local tectonic change ~200 kya**

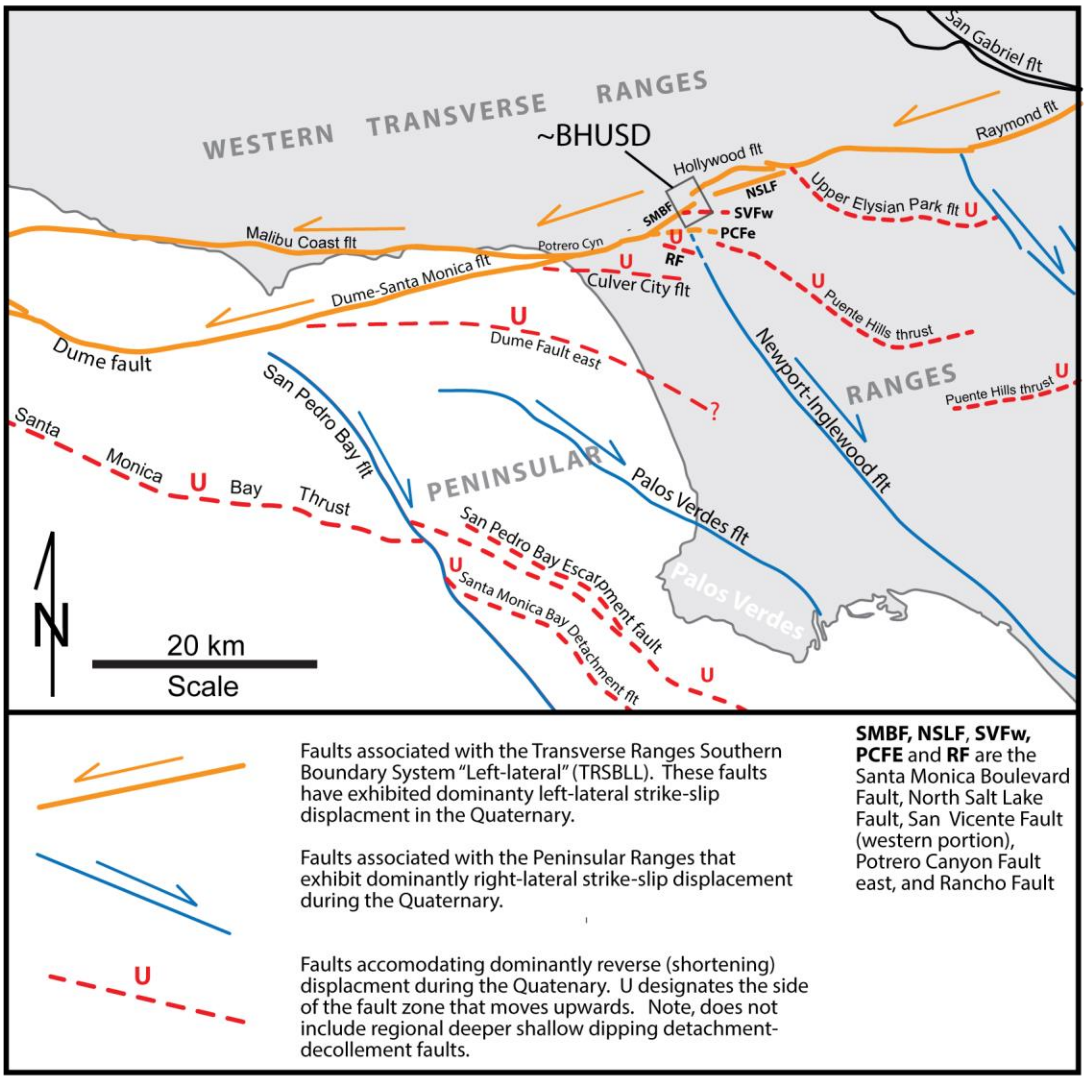
  At this time, the Santa Monica Boulevard Fault Zone, the western Hollywood Fault Zone and associated cross faults in the western Hollywood Basin all became inactive. The North Salt Lake Fault Zone may also have become inactive at this time. Left-lateral displacement no longer occurring on these fault zones began to occur on the newly developed Potrero Canyon Fault East, and possibly the San Vicente and Rancho Fault Zones. The northern strands of the Newport-Inglewood Fault Zone located north of the east-west trending Potrero Canyon Fault East became inactive at this time.

This tectonic history is displayed via a series of temporal figures (Figure 40 through Figure 45) that show the location and type of fault zones active during various periods of time since the early Pliocene. These time periods include:

- Figure 40: Early Pliocene
- Figure 41: Late Pliocene to ~1 Ma (Early Pleistocene)
- Figure 42: ~1 Ma (Early Pleistocene) to 200 kya (Middle Pleistocene)
- Figure 43: Regional perspective from Middle Pleistocene to present
- Figure 44: 200 kya to present (Middle Pleistocene through Holocene).

Note that the older alluvial and marine deposits shown represent current outcrops of these units and have nothing to do with the types or limits of deposits forming at the time of the time series figures.

Figure 39: Generalized fault map of the southern Western Transverse Ranges and northern Peninsular Ranges. Map shows faults associated with the Transverse Ranges Southern Boundary System "left-lateral" (TRSBLL) that have exhibited dominantly left-lateral motion since approximately 1 Ma (i.e. Early Pleistocene, orange faults). Dominantly compressional dip-slip faults, most of which are blind are shown as red dashed lines, and dominantly right-lateral strike-slip faults associated with the Peninsular Ranges are shown as blue lines.



9.1 Early Pliocene

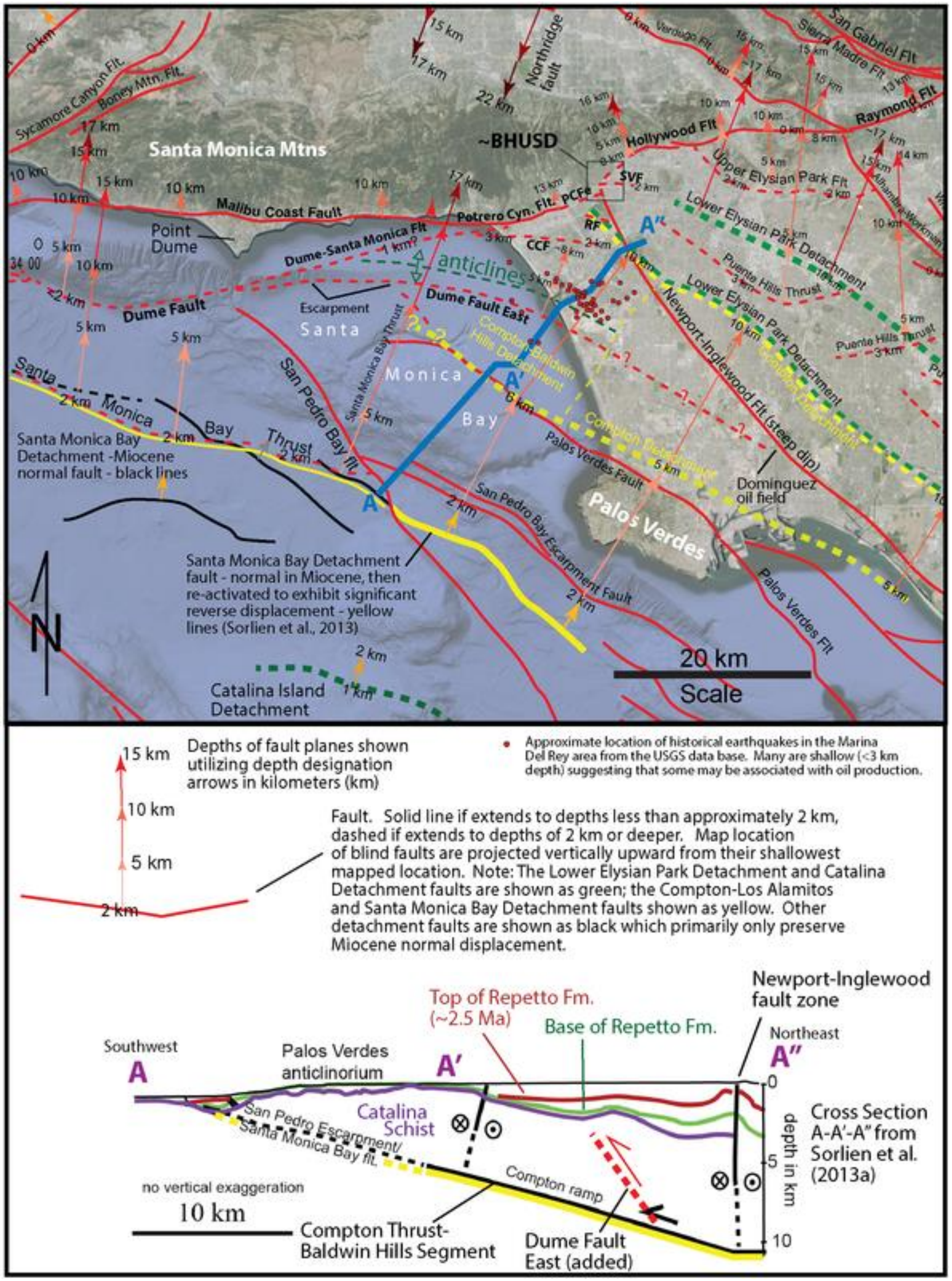
During the early Pliocene, compressional reverse and thrust ramp faults developed along the Transverse Ranges Southern Boundary System (TRSB). Wright (1991) refers to this deformational event as the Pasadena Orogeny that began in the early Pliocene (Figure 40). The TRSB is characterized by a series of oblique reverse left-lateral fault zones.

The Santa Monica Anticlinorium developed during this time resulting in uplift of the Santa Monica Mountains with the axis of the anticlinorium occurring in close proximity to the approximately east-west trending axis of the mountain range. During the early Pliocene, reverse faulting occurred along the southern limits of the Santa Monica Anticlinorium primarily via the Santa Monica Fault South, Santa Monica Fault North, Rancho Fault, and the Hollywood Fault. The Santa Monica and San Vicente fault zones were normal "extensional" faults during the Miocene that were re-activated as reverse faults during the Early Pliocene. The North Salt Lake Fault is believed to have developed during this time period and accommodated dominantly normal displacement.

The Wilshire Arch began to form during the Pliocene, possibly after the initial uplift of the Santa Monica Anticlinorium in association with compressional faults at depth in the northern Los Angeles Basin. These blind compressional fault zones include the Wilshire, Los Angeles, Puente Hills and Las Cienegas fault zones (Figure 40). Based on new and ongoing research by Bergen et al. (2013), the Puente Hills Thrust (detachment fault) experienced an increase in fault activity after a period of quiescence approximately 0.78 Ma. This is approximately the same time that compressional strain is proposed herein to have migrated away from the TRSBLL. Hence, the Puente Hills Thrust (detachment) fault is shown as active during the early Pliocene, but likely accommodated more strain (increased stress rate) since the early-middle Pleistocene.

The Las Cienegas Fault represents a Miocene normal fault that was re-activated during the early Pliocene to accommodate reverse deformation similar to those discussed previously. Note that at this time the Newport-Inglewood right-lateral strike-slip fault zone had not yet reached the Baldwin Hills in terms of a near surface rupturing fault. The Inglewood anticline was in the early stages of development in the Baldwin Hills based on formational thinning of early Pliocene deposits observed across the Baldwin Hills (Wright, 1991). This indicates that the Newport-Inglewood Fault likely occurred at depth resulting in transpressional deformation near the surface.

Figure 40: Active faults and near surface folds during the Early Pliocene. Oblique reverse left-lateral faulting occurred along the TRSB during this time, which coincides with inception of Wright's (1991) Pasadena Orogeny.


Santa Monica Mtns
~BHUSD
Northridge fault
Hollywood Flt
Sierra Madre Flt
San Gabriel Flt
Raymond Flt
Verdugo Flt
Sycamore Canyon Flt.
Boney Mtn. Flt.
Malibu Coast Fault
Potrero Cyn. Flt.
PCFe
SVF
RF
CCF
Upper Elysian Park Flt
Lower Elysian Park Detachment
Puente Hills Thrust
Newport-Inglewood Flt (steep dip)
Point Dume
Dume-Santa Monica Flt
anticlines
Dume Fault
Dume Fault East
Escarpment
Santa Monica Bay
Santa Monica Bay Thrust
San Pedro Bay flt
Compton-Baldwin Hills Detachment
Compton Detachment
Palos Verdes Fault
San Pedro Bay Escarpment Fault
Palos Verdes Flt
Palos Verdes
Dominguez oil field
A
A'
A"
Santa Monica Bay Detachment -Miocene normal fault - black lines
Santa Monica Bay Detachment fault - normal in Miocene, then re-activated to exhibit significant reverse displacement - yellow lines (Sorlien et al., 2013)
Catalina Island Detachment
N
20 km
Scale
15 km
10 km
5 km
2 km
Depths of fault planes shown utilizing depth designation arrows in kilometers (km)
Approximate location of historical earthquakes in the Marina Del Rey area from the USGS data base. Many are shallow (<3 km depth) suggesting that some may be associated with oil production.
Fault. Solid line if extends to depths less than approximately 2 km, dashed if extends to depths of 2 km or deeper. Map location of blind faults are projected vertically upward from their shallowest mapped location. Note: The Lower Elysian Park Detachment and Catalina Detachment faults are shown as green; the Compton-Los Alamitos and Santa Monica Bay Detachment faults shown as yellow. Other detachment faults are shown as black which primarily only preserve Miocene normal displacement.
Southwest
Northeast
Palos Verdes anticlinorium
Top of Repetto Fm. (~2.5 Ma)
Base of Repetto Fm.
Newport-Inglewood fault zone
Catalina Schist
San Pedro Escarpment/ Santa Monica Bay flt.
Compton ramp
no vertical exaggeration
10 km
Compton Thrust- Baldwin Hills Segment
Dume Fault East (added)
depth in km
0
5
10
Cross Section A-A'-A" from Sorlien et al. (2013a)

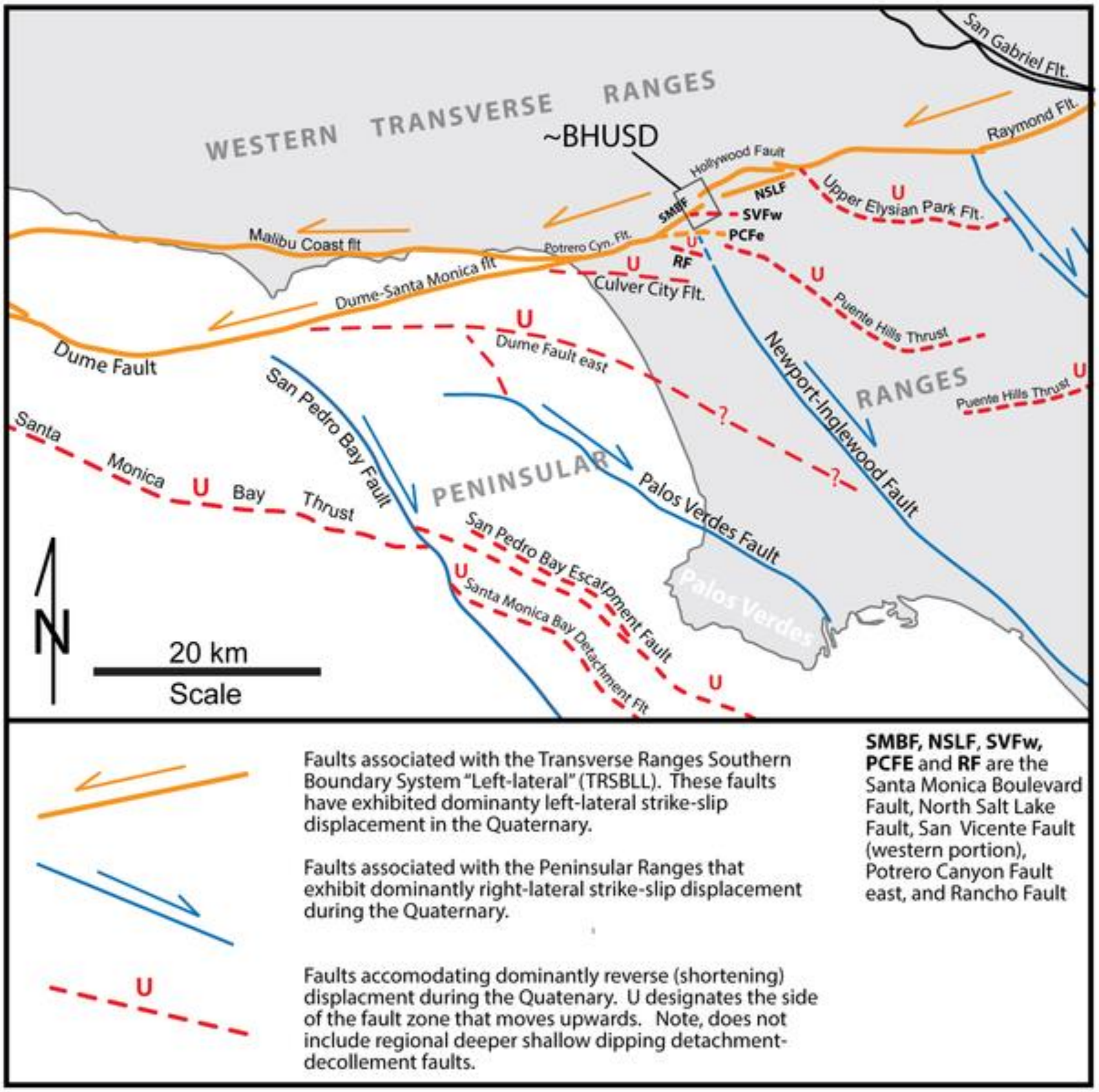
9.2 Late Pliocene to ~1 Ma (early Pleistocene)

During the Late Pliocene to the early Pleistocene (~1 Ma) the Pasadenian Orogeny continued with oblique reverse (thrust) left-lateral displacement along essentially the same fault system as the Early Pliocene with the addition of the development of the Rancho Fault (thrust) fault in the southeastern Cheviot Hills. The Rancho Fault may have developed to accommodate compression and warping in the southern Cheviot Hills as the Newport-Inglewood Fault Zone migrated to the Baldwin Hills and across the Ballona Gap. At this time, the Baldwin Hills are born via growth of the Inglewood Anticline, and during the latest Pliocene the Newport-Inglewood Fault Zone ruptures to the surface offsetting the axis of the Inglewood Anticline. The eastern Santa Monica Fault South and the northwestern Los Angeles Trough syncline were deformed at this time associated with right-lateral displacement of the Newport-Inglewood Fault as it migrated northward.

Some uplift occurred in the southern Cheviot Hills during this time, but depositional and erosional processes outpaced uplift. Hence, the southern Cheviot Hills had not yet developed during this period of time.

The Dume Fault East developed during the early Pleistocene to produce a series of anticlinal structures the extend from the central Santa Monica Bay to onshore near Playa Del Rey (Figure 43; Plate 8).

Figure 41: Active faults and their dominant style of displacement from the late Pliocene to early Pleistocene (~1 Ma).



9.3 ~1 Ma (Early Pleistocene) to 200 kya (Middle Pleistocene)

A major tectonic kinematic change occurred approximately 1 Ma along the local TRSB (Figure 42). This zone of faulting switched from accommodating oblique reverse left-lateral slip to accommodating dominantly left-lateral strike slip faulting. It was at this time that the local Transverse Ranges Southern Boundary Fault System "left-lateral" (TRSBLL) formed. The Potrero Canyon Fault and the Santa Monica Boulevard Fault were created approximately 1 Ma to accommodate the left-lateral slip. These faults connect at depth with the Santa Monica Fault South and Santa Monica Fault North respectively. As shown in Figure 34, the Potrero Canyon Fault also connected with and re-activated older Miocene normal faults resulting in a steeper fault than the Santa Monica Fault South. The development of the Potrero Canyon Fault may have completely abandoned the Santa Monica Fault South and cut directly across it (Figure 34).

The Hollywood Fault transitioned from an oblique reverse left-lateral fault to a dominantly left-lateral strike-slip fault at this time and produced a system of cross faults that connected it to the Santa Monica Boulevard Fault Zone. At this time the western Hollywood Basin began to form, and due to cross-basinal faulting, led to the development of the West Beverly Hills Lineament (Section 5.6). The North Salt Lake Fault, which had been a dominantly normal fault, transitioned to a dominantly left-lateral strike-slip fault. The North Salt Lake Fault extended westward via a restraining bend step over to the eastern end of the Santa Monica Boulevard Fault Zone (Section 4.3.1).

During this period of time, the Newport-Inglewood Fault continued northward to the Santa Monica Boulevard Fault Zone. The northern migration formed a north-northwest trending anticline and facilitated the uplift of the Cheviot Hills. The north-northwest trending anticline and the Beverly Hills Sub-basin syncline formed as a result of left-lateral motion across the TRSBLL faults (Santa Monica Boulevard Fault and North Salt Lake Fault Zones) buttressed by the new northward location of the Newport-Inglewood Fault Zone. Transpression along the Newport-Inglewood Fault Zone also contributed to the uplift of the southern Cheviot Hills. Erosion associated with Moreno Creek through the southern Cheviot Hills led to the development of the West Beverly Hills Lineament (Section 5.6).

At this time or soon before, two new compressional thrust ramp faults developed south of the TRSBLL: the Culver City Fault (Figure 42) and the Dume Fault East (Figure 43, Plate 8). These faults developed as a consequence of compressional deformation no longer occurring along the TRSBLL Fault System. Previous to this report, no compressional thrust ramp faults have been mapped in the region west of the Newport-

Inglewood Fault and east of the Palos Verdes Fault (Beach Cities Region). These faults complement very similar thrust ramp faults east of the Newport-Inglewood Fault Zone (e.g. Puente Hills Thrust, Upper Elysian Park Fault, Wilshire Fault, and Los Angeles Fault). The Culver City Fault and Dume Fault East are considered Geologically Active (Section 8.2.5 and 8.2.6). As discussed earlier, the Puente Hills Thrust (detachment fault) experienced an increase in fault activity (slip rate increase) after a period of quiescence approximately 0.78 Ma (Bergen et al., 2013, and Harvard web site). This is approximately the same time that compressional strain migrated away from the TRSBLL.

The Culver City Fault and northern most portion of the Dume Fault East exhibit north west-west trends consistent with north-south shortening stress in the region immediately south of the TRSBLL (Hauksson, 1990). The Dume Fault East turns progressively more southeasterly toward the southeast as it extends through Santa Monica Bay and onshore (Figure 43). This southeastward turn, which is similar to a turn in the Palos Verdes Fault to the west, results from compressional stress oriented N36E, essentially perpendicular to the Peninsular Ranges right-lateral strike-slip faults (Bawden et al., 2001). A similar northwestward turn of compressional faults in the north Peninsular Ranges also occurs at the northwestern end of the Puente Hills Thrust as shown on Figure 43.

Activity on the San Vicente Fault and Rancho Fault decreased during this time, but both faults may have remained active to the present time (Section 8.2.1 and 8.2.4) as continued activity may have occurred to accommodate right-lateral slip on the Newport-Inglewood Fault Zone in addition to left-lateral motion on the TRSBLL Fault System.

Figure 42: Region view of active faulting in the northern Los Angeles Basin, Beach Cities Region and along the TRSBLL during the past several hundred thousand years. Active faults shown in the region of the BHUSD include those for the past 200 kya (Figure 43), and elsewhere fault activity since the mid-Pleistocene to the present time. The newly developed Dume Fault East Thrust Ramp developed as a new fault sometime soon before approximately 1 Ma.

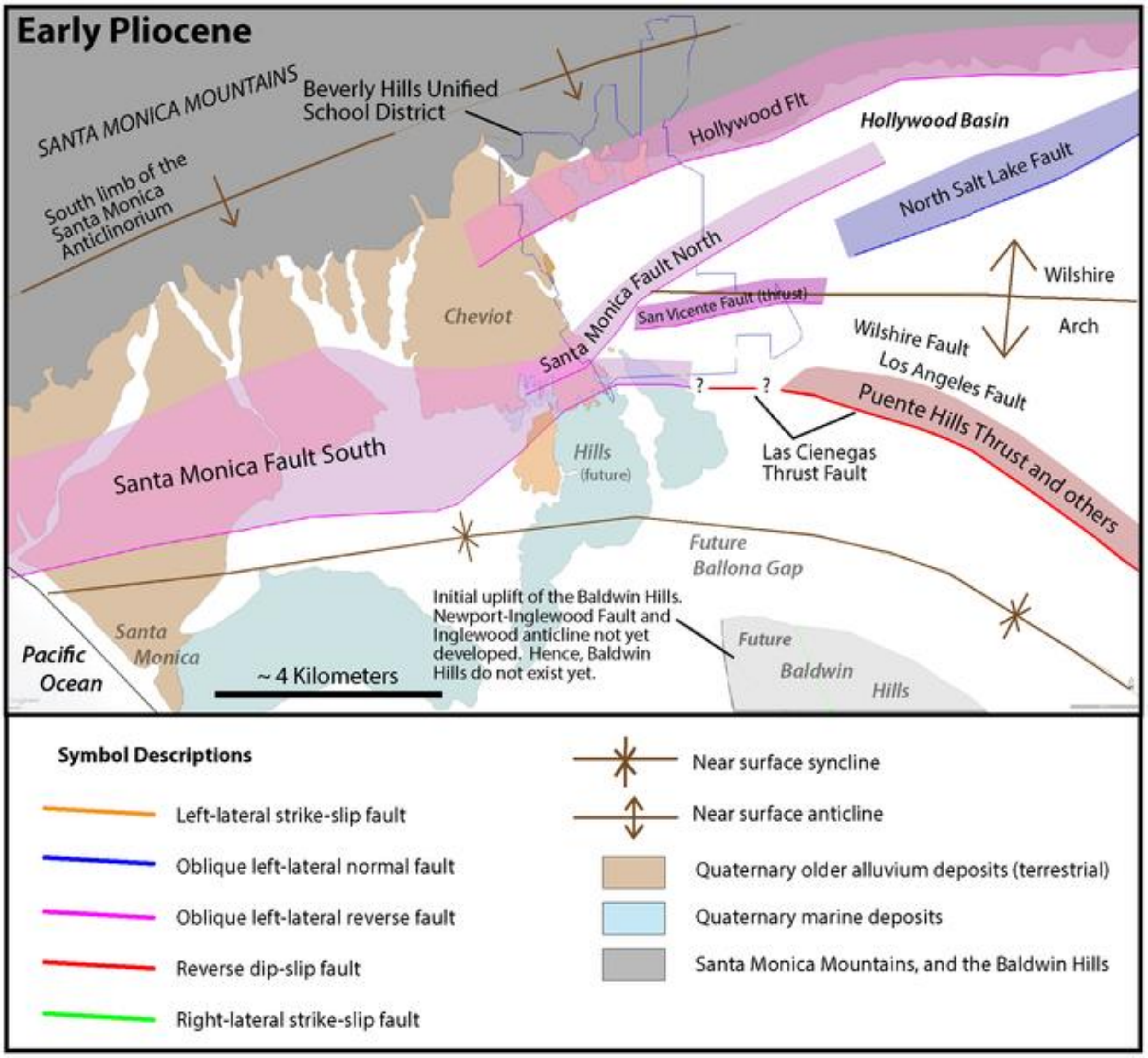
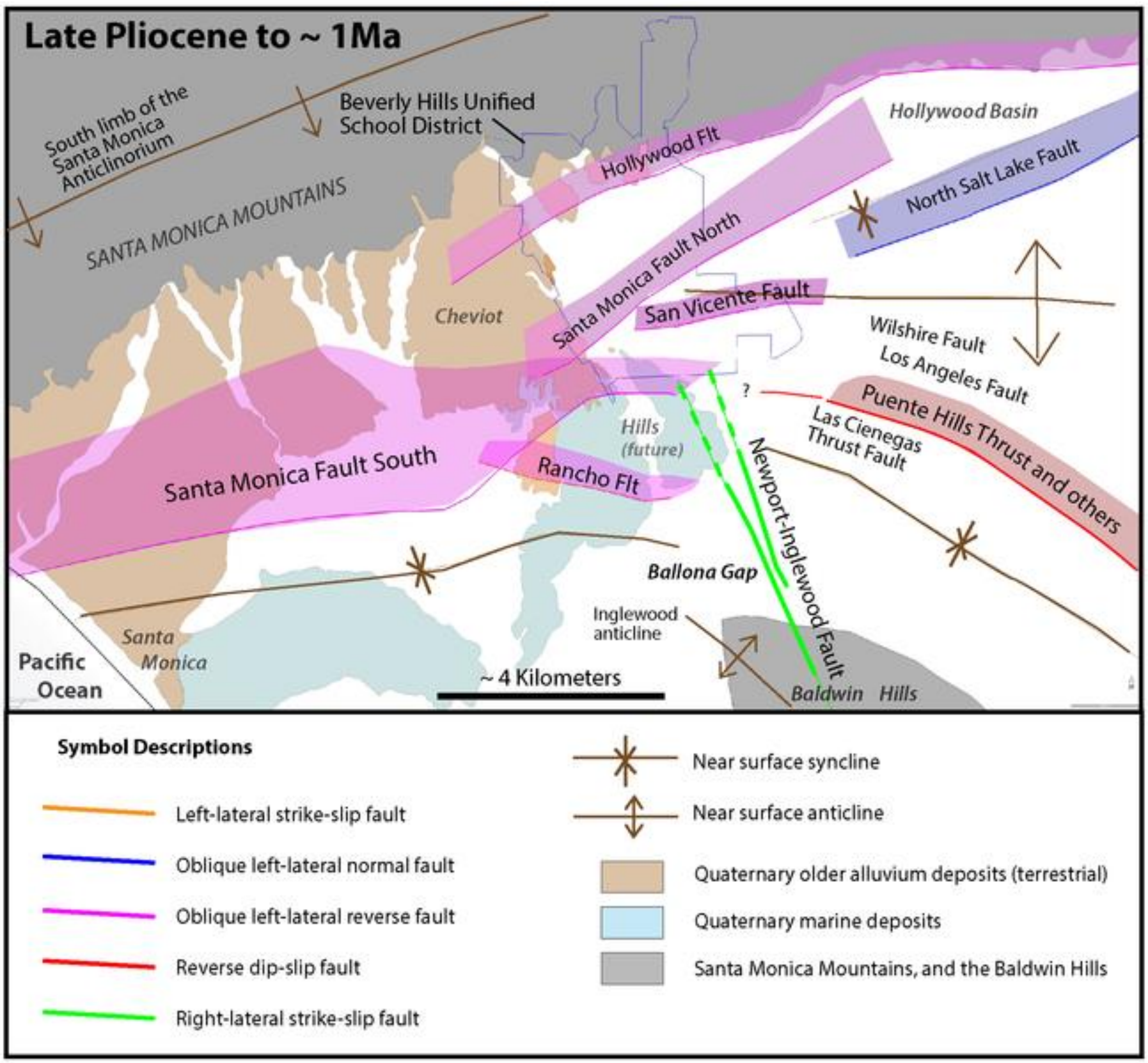


Figure 43: Active faults and their dominant style of displacement from approximately 1 Ma (early Pleistocene) to 200 kya. A major tectonic change occurred during this time with the abandonment of compressional faulting along the TRSBLL (Santa Monica Fault North and South became inactive), and the development of the dominantly left-lateral Potrero Canyon and Santa Monica Boulevard Fault Zones, upper strand of the North Salt Lake Fault, and Cross Faults No. 1 and No.2 in the western Hollywood Basin. Compressional deformation began to occur on the Culver City Fault and Dume faults to the south west of the Newport-Inglewood Fault. East of the Newport-Inglewood Fault compressional deformation increased via larger strain rates across existing reverse faults and possible development of deep blind thrust ramp faults. Some "lost" compressional deformation also migrated northward to the Camarillo Fold and Thrust Belt in the central Western Transverse Ranges and in the Ventura Basin area (Figure 5).



9.4 200 kya (Middle Pleistocene) to present (Holocene)

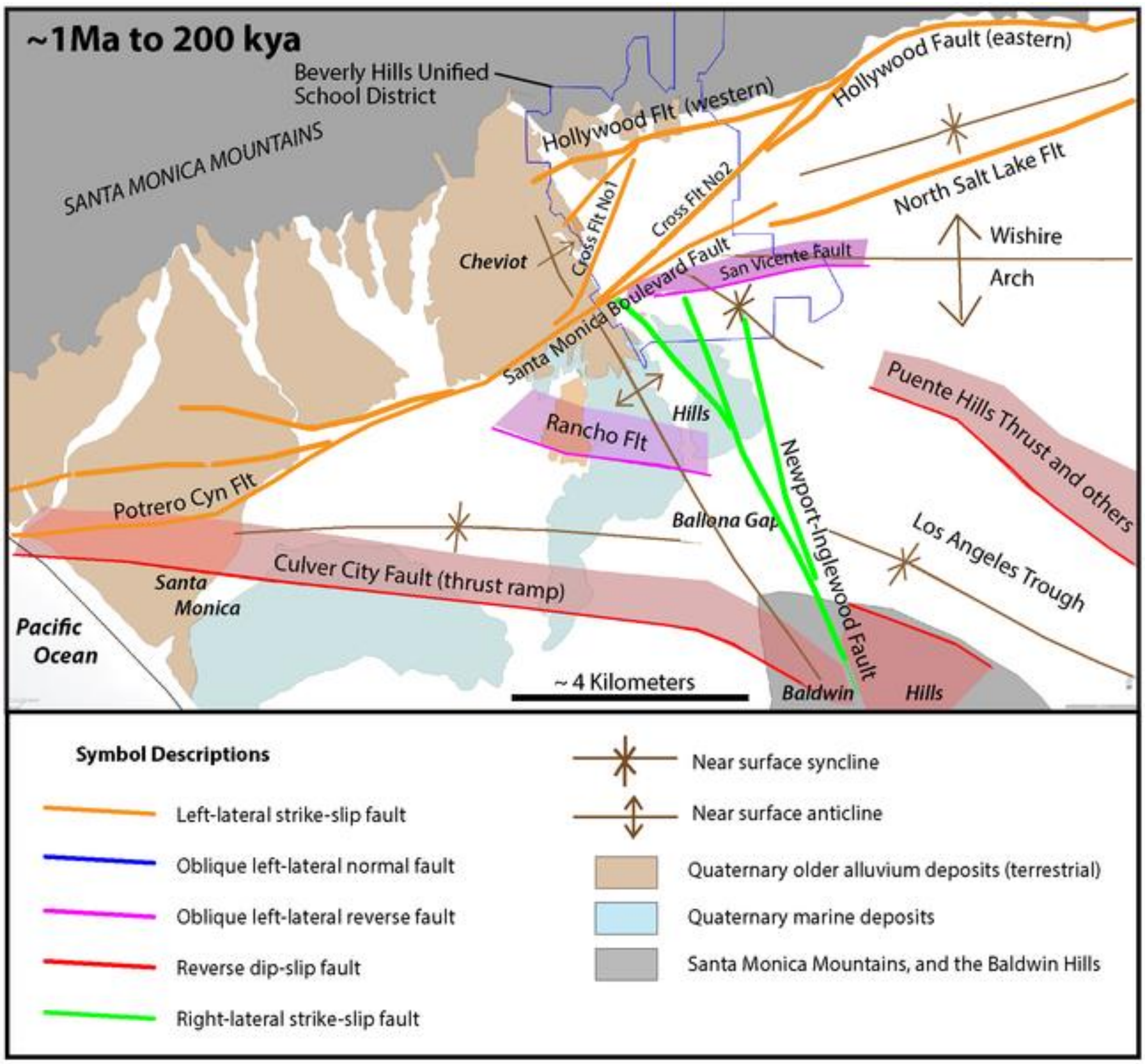
Approximately 200 kya a dramatic local tectonic change occurred that greatly affected the BHUSD and the central Western Transverse Ranges. Around this time, the Santa Monica Boulevard Fault and Cross Fault No. 1 became inactive. Faults associated with the western Hollywood Fault Zone, the southwestern end of Cross Fault No. 2 and the North Salt Lake Fault may also have become inactive at this time. Many of the faults that had accommodated left-lateral strike-slip motion along the TRSBLL were rendered inactive.

Left-lateral slip began to be accommodated on the Potrero Canyon Fault East sometime around 200 kya (+/-1 kya). The Potrero Canyon Fault continues activity to present time and now connects with the newly formed Potrero Canyon Fault East at the western edge of the Cheviot Hills (Figure 44). The Potrero Canyon Fault East exists at relatively shallow depths near its intersection with the Potrero Canyon Fault, but likely occurs at progressively deeper depths towards the east. The Potrero Canyon Fault East is identified in the eastern Cheviot Hills at depths of 6 to 8 km based on historical earthquakes (Section 5.3 and Section 8.1.2) however, there is no direct evidence of surface rupture along the eastern end of the Potrero Canyon Fault East.

The Newport-Inglewood Fault Zone remains active during this time; however, the northernmost strands of the fault are cut off by the development of the Potrero Canyon Fault East in the southern Cheviot Hills (Figure 44; Section 8.1.7). This causes the strands of the Newport-Inglewood Fault Zone north of the Potrero Canyon Fault East to become inactive. The Newport-Inglewood Fault Zone between Ballona Gap and the Potrero Canyon Fault exhibits no proof of being active as well.

In the central Western Transverse Ranges, compressional deformation rates increased dramatically within the Camarillo Fold and Thrust Belt, which began relatively rapid uplift approximately 125 kya (Devecchio et al., 2012a and 2012b; Figure 5). The Culver City Fault and Dume Fault East remained active during this time to accommodate compressional deformation along the TRSB and into the northern Peninsular Ranges (Figure 44 and Figure 43). The San Vicente and Rancho Fault Zones may remain active during this time as oblique reverse, left-lateral strike slip faults.

Figure 44: Active faults and their dominant style of displacement from approximately 200 kya to the present time. The dominantly left-lateral strike-slip Santa Monica Boulevard Fault, the western Hollywood Fault, and Cross Fault No.1 have all become inactive. The Potrero Canyon Fault remains active, but lengthens towards the east by the development of the Potrero Canyon Fault East. The northeast portion of Cross Fault No.2 and the newly developed Potrero Canyon Fault east accommodate left-lateral displacement from the now inactive Santa Monica Boulevard Fault along this section of the TRSBLL. The portion of the Newport-Inglewood Fault north of the Potrero Canyon East fault remains inactive. Minor left-lateral slip may also be accommodated on the Rancho and San Vicente Fault Zones.



9.5 Impacts on seismic hazard analyses and future studies for the BHUSD region

The Quaternary tectonic history presented in this report, and summarized in this section provides valuable information for seismic hazard evaluations in the BHUSD area and surrounding regions. Some of the faults presented herein are new: the proposal of new strike-slip faults (e.g. Potrero Canyon Fault East, Cross faults No. 1 and No. 2 in the western Hollywood Basin); and the proposal of new blind reverse thrust ramp faults (e.g. Culver City Fault and the Dume Fault East). The report also provides support and additional insights regarding previously identified fault zones regarding their age, tectonic history, and where these faults may occur and whether or not they may be active or inactive.

The major findings of this report that should be considered for future seismic hazard evaluations include:

- Well-documented tectonic changes in the type of slip across fault zones that occurred on various fault zones in the early Pliocene also occurred in the Quaternary. Pre-existing structures that strongly controlled where new styles of slip occurred during periods of tectonic transition during the early Pliocene continued to influence fault development in the region during the Quaternary.
- The Hollywood, North Salt Lake, Santa Monica Boulevard and Potrero Canyon Fault System should be considered a dominantly left-lateral strike slip fault zone system. Existing literature is inconsistent regarding whether or not these fault zones are dominantly left-lateral strike slip, or oblique reverse left-lateral reverse but this report clarifies that issue.
- The Santa Monica Fault North, Santa Monica Fault South, and eastern San Vicente Faults Zones should be considered inactive, and removed from future seismic hazard analysis and fault databases. These faults are commonly shown in regional seismic hazard maps and utilized in seismic hazard evaluations.
- The western Hollywood Fault Zone is designated as Regulatory Potentially Active, but is likely inactive. Multiple fault investigations in this area have failed to find evidence of active faulting.
- Proposed Cross Fault No. 1 in the western Hollywood Basin has been shown to be Regulatory Inactive by fault investigations where it was exposed in Century City and Beverly Hills.
- The Santa Monica Boulevard Fault Zone has been shown to be Regulatory Inactive by fault investigations where it was exposed in Beverly Hills. Inactivity of

the Cross fault No. 1 and Santa Monica Boulevard Fault Zones is kinematically consistent with the creation of the youthful Potrero Canyon Fault East in the central Cheviot Hills.

- The western end of the San Vicente Fault Zone has displayed recent seismic activity. Both the Rancho and western San Vicente Fault Zones may be active, and may be accommodating a component of left-lateral slip in addition to reverse thrust motion.
- The Newport-Inglewood Fault Zone did at one time migrate north to the Santa Monica Boulevard Fault Zone, but those strands became inactive once the Potrero Canyon Fault East developed and cut off the northern strands of the Newport-Inglewood Fault Zone.
- The Newport-Inglewood Fault Zone exists between Ballona gap and the Potrero Canyon East. While there is no evidence of recent activity in the segment, kinematic modeling indicates that compression is being absorbed by this portion of the Newport-Inglewood Fault Zone in combination with the Potrero Canyon East Fault.
- The Wilshire and Los Angeles thrust ramp reverse faults are likely active, but rarely shown on seismic hazard maps and databases.
- Kinematic modeling and other evidence indicates a progressive shifting southward of compressional loading resulting in the creation and activation of new faults and the gradual inactivity of older faults across the Beach Cities Region. Newer active faults include the Culver City Fault, which may lead to a future shortening of the active portion of the Newport-Inglewood Fault Zone similar to the shortening effected by the creation of the Potrero Canyon East Fault.
- The recognition that fault structures occurring in the marine environment are likely to extend onto land. The Dume Fault East is one highly likely example.

The recent burst of seismic investigation within the BHUSD and the adjacent Cheviot Hills has prompted a significant revaluation of prevailing wisdom. However, research on many of the major fault systems that are present has been concentrated outside of the Beach Cities Region leaving a significant gap and lack of hard data across much of the Beach Cities Region. It is hoped that this model will prompt additional studies to corroborate the observations and conclusions presented.

APPENDIX A

GENERAL TECTONIC SETTING ALONG THE BOUNDARY OF THE WESTERN TRANSVERSE RANGES AND PENINSULAR RANGES

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Note: Plates utilized in this Appendix are the same as for the report.

1.0 REGIONAL TECTONIC SETTING

The Beverly Hills Unified School District (BHUSD) is located within a tectonic boundary zone associated with the Western Transverse Ranges (WTR) to the north and the Peninsular Ranges (PR) to the south. The WTR and PR are distinct geologic provinces geomorphically, lithologically, and tectonically. It is clear that both dip-slip compressional and strike-slip faulting continues to occur both in the WTR and to the south within the PR; however, major tectonic differences continue between these terrains in terms of the general strike and sense of fault slip and folding.

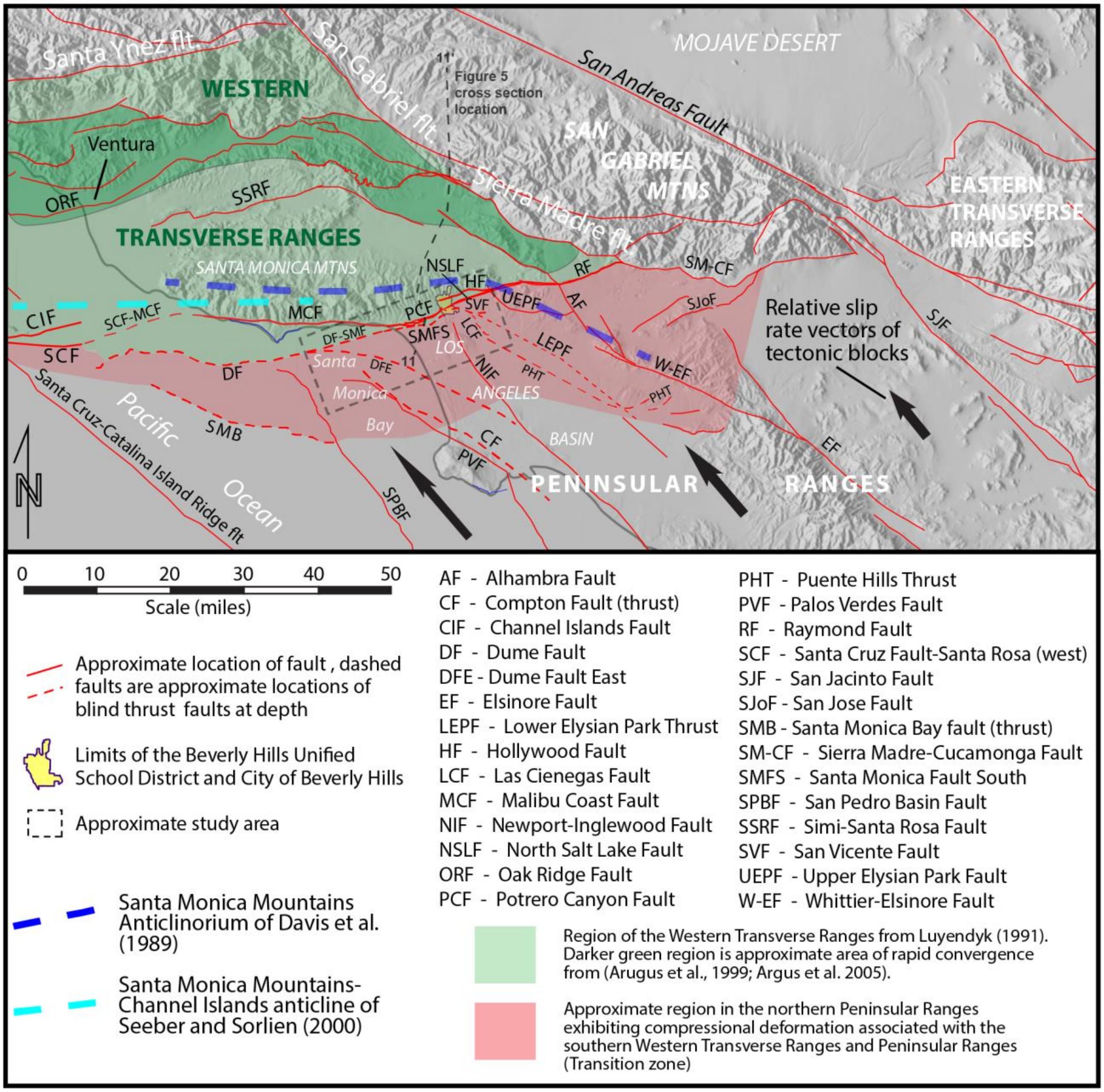
The WTR generally exhibits east-west to east-northeast striking oblique reverse left-lateral faulting deformation, and the PR generally exhibits northwest striking right-lateral and reverse faulting. However, strain partitioning is occurring in both terrains to varying degrees where strike-slip and reverse dip slip deformation occurs on independent fault zones (see Hauksson, 1990). The zone between the WTR and PR, where the BHUSD is located, exhibits tectonic characteristics of both the WTR and the PR and has been changing (evolving) during the Quaternary as these two provinces converge. The general tectonic characteristics of the WTR and PR are discussed below.

1.1 General tectonic setting of the Peninsular Ranges

The PR located south of the WTR exhibit numerous northwest trending right-lateral strike slip fault systems extending from the Channel Islands in the Pacific Ocean eastward to the San Andreas Fault (Figure 1, Plate 1). That right-lateral movement along the PR faults progressively moves the Santa Monica and Los Angeles tectonic blocks toward the northwest relative to stable North America (Figure 1). Many of these faults evolved into strike slip faults during the early Quaternary (past 1 to 1.5 Ma) from old Miocene extensional normal faults (Wright, 1991). The PR also exhibit numerous compressional reverse fault structures that also trend toward the northwest. This suggests that compressive forces in the PR are essentially normal (perpendicular) to the strike-slip fault system; hence undergoing transpression. This observation is supported by the Bawden et al. (2001) analysis of global positioning system (GPS) station’s movement that revealed the Los Angeles Basin is experiencing approximately 4.4 mm/year of uniaxial contraction oriented at N36E, essentially perpendicular to the major strike-slip faults in the region.

The boundary between the WTR and PR is a fairly wide area that extends south of the Transverse Ranges and its southern boundary of oblique reverse and left-lateral faults (Transverse Ranges Southern Boundary Fault System – TRSB). One explanation for the wide zone is provided by Yeats (2001, 2003) that describes evolving (dynamic) tectonics in the northern Los Angeles basin during the past 1 M.y. due to the northward migration of active, northwest trending strike-slip faults in the Peninsular Ranges. In the Yeats model, the northwest fault migration caused some reverse faults to decrease or become inactive in the northern Los Angeles basin. These dynamic tectonic changes along the TRSB suggest that this zone of deformation is evolving over the Quaternary, involving changes in the location and style of faulting and activity of various faults.

Figure 1: Map of major fault zones in southern California identifying the Western Transverse Ranges and Peninsular Ranges.

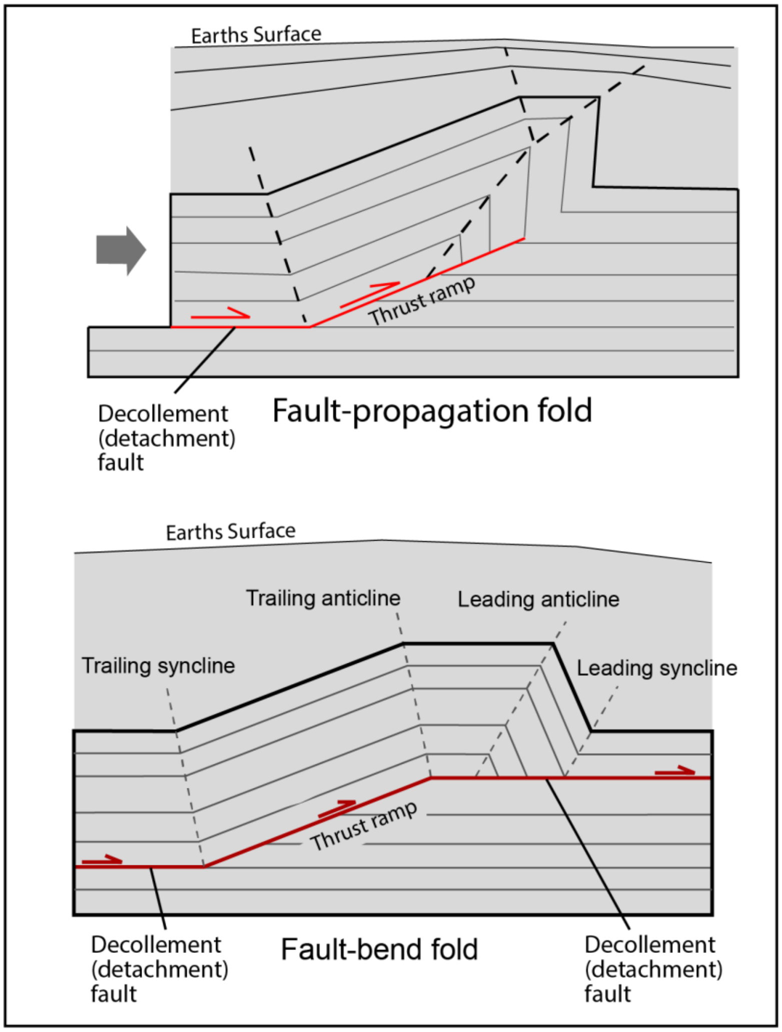


1.2 General tectonic setting of the Western Transverse Ranges

The region of the Western Transverse Ranges (WTR) has been identified for decades (Klamerling and Luyendyk, 1979). This report utilizes the definition of the Western Transverse Ranges (WTR) from Luyendyk (1991) as the region bounded by the Santa Ynez Fault to the north, the San Gabriel-Sierra Madre Faults to the east, and the Malibu Coast Fault to the south (Figure 1). Tectonically, the WTR has undergone a complex history of block rotation and left-lateral reverse oblique faulting (Kamerling and Luyendyk, 1979; Luyendyk et al., 1980; Yerkes and Lee, 1979; Hornafius et al., 1986; Luyendyk, 1991). Block rotation in the WTR has occurred since the early Miocene, associated with crustal extension, but continued during development of tectonic shear between the North American and Pacific Plates (i.e. development of the San Andreas Fault System approximately 19 to 15 Ma; Luyendyk, 1991). Nicholson et al. (1994) provides a tectonic model for the cause of rotation of the WTR associated with capture of the partially subducted Monterey microplate by the Pacific plate approximately 20 Ma.

Rates of tectonic shortening across the WTR escalated since the late Pliocene approximately 3 to 2 Ma (Namson and Davis, 1988; Wright, 1991). The shortening is accommodated by displacement across numerous approximately east-west trending reverse faults; however, most of these faults are documented to be oblique with a left-lateral component (see Dickinson, 1996 for review). Some of the reverse faults reach the surface and are relatively easy to identify; however, others like the Northridge Fault (also referred to as the Pico Thrust) that produced the 1994 Northridge Earthquake (Davis and Namson, 1994) do not reach the surface and are referred to as “blind” (Plate 1). Many of the blind reverse faults are considered thrust ramps that are generally deeper in the east to northeast (Figure 2), and which typically connect at depth with a regional, very low dipping detachment fault.

Figure 2: General characteristics of fault propagation folds and fault-bend folds associated with thrust (reverse dip-slip) ramps.



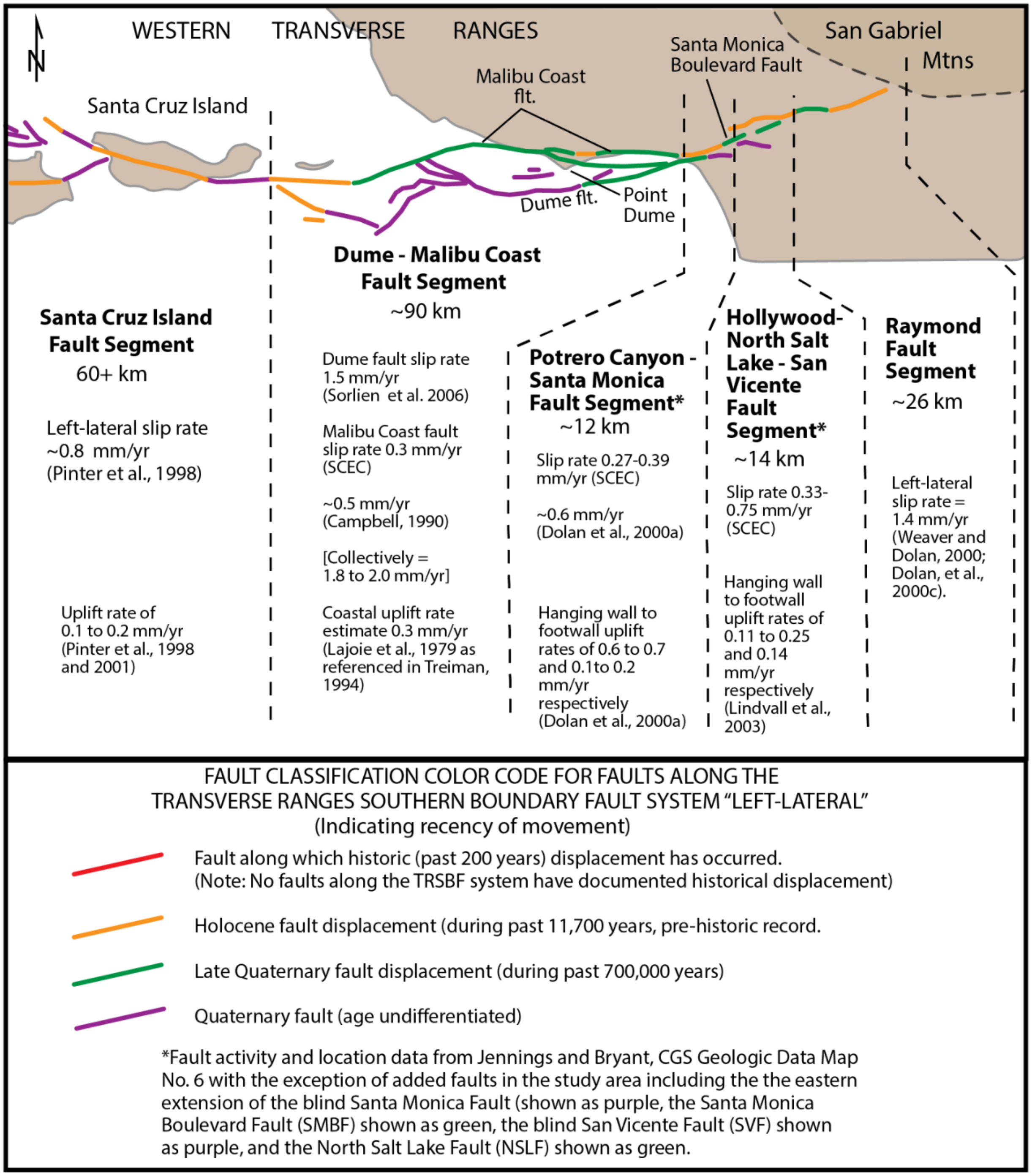
2.0 TRANSVERSE RANGES SOUTHERN BOUNDARY SYSTEM (TRSB)

The boundary between the Western Transverse Ranges (WTR) and the Peninsular Ranges (PR) to the south is a complex and evolving tectonic zone of deformation involving strike-slip, oblique slip, and dip-slip compressional faults, and folding. Numerous compressional deformation models have been proposed to explain how tectonic shortening is occurring in the region. These partially include fault bend folds and fault propagation folds associated with thrust ramps many of which are blind (faults do not reach the surface). Fault bend folds result when layers are displaced along a non-planar fault; the overlying rocks bend as they are displaced along a fault that exhibits a corresponding bend (Figure 2). Active folding occurs as the overlying rocks/sediments are moved over the fault bend. Fault propagation folds occur near the upward termination of blind thrust faults (reverse faults and thrust ramps), where the rocks are not faulted and folding absorbs the compressional deformation (strain; Figure 2). There appears to be relatively wide agreement that mid-upper crustal, shallow dipping, regional décollement-detachment thrust faults occur across the WTR and northern PR; however the true lateral extent of these faults remains unknown. Some décollement-detachment faults may be local within a particular region, whereas some models continue these fault systems across much of southern California. These low angle faults are difficult to evaluate due to their depths often deeper than 10 km, and that once at depths sufficient to be within the ductile middle crust may be aseismic. However, some of the proposed detachment faults do extend into seismogenic depths, which may generally be in the range of 12 to 15 km, but this is currently poorly constrained.

The boundary between the WTR and PR is often described as including a series of surficial faults extending from Santa Rosa Island in the west, eastward to the San Gabriel Mountains. These faults include from west to east: Santa Rosa, Santa Cruz, Malibu Coast-Dume, Santa Monica (Potrero Canyon of Wright, 1991), Hollywood and Raymond. However, most of these faults dip steeply to the north and primarily exhibit left-lateral displacement. The dominant strike-slip displacement across these faults may be the primary reason they rupture to the surface. Within this report, this fault system will be referred to as the Transverse Ranges Southern Boundary Fault System "left-lateral" (Figure 3, Plate 1, TRSBLL). Understanding where active compressional faulting and associated fold structures exist, both north and south of the TRSBLL, is problematic in terms of indicating whether or not they are associated with the WTR or the PR, and exactly where active compressional deformation is occurring. Many thrust and reverse faults and associated folds have been identified, but they also exhibit a dynamic history of activity and cessation of activity for various faults. The boundary of the WTR and PR has been dynamic and evolving not only during the late Tertiary, but also during the Quaternary and includes a zone much wider than just the TRSBLL Fault System.

For the purposes of this report, the tectonic boundary between WTR and PR adopts the terminology of Dolan et al. (2000a), which defined a west-trending fault system of reverse, oblique-slip, and left-lateral strike-slip faults that extend for >200 km along the southern edge of the WTR as the Transverse Ranges Southern Boundary Fault System (TRSB; Figure 1 and Figure 3). Within their definition, they clearly include the faults of the TRSBLL, which they indicate are a fault subsystem of the TRSB that exhibit left-lateral and oblique-reverse sense of displacements. However, this definition of the TRSB does not clearly delineate the full width of the boundary between the WTR and PR, nor the complexities of the faults within the transition zone. Most of the faults of the TRSBLL represent upper plate faults exhibiting dominantly early Quaternary to late Quaternary left-lateral displacement. They are not likely to be "absorbing" much of the tectonic shortening known to occur in the region bounding the WTR and PR. The deeper dominant fault that the TRSBLL faults connect with may be the Elysian Park Thrust (EPT), which is a compressional fault allowing for tectonic shortening in the region. As proposed by Davis et al. (1989) and expanded on in Davis and Namson (1994), the nearly horizontal “detachment” portion of the EPT occurs at depths of approximately 15 km beneath the Santa Monica Mountains, and 10 to 15 km beneath the Repetto Hills and northwestern Puente Hills where the fault trends northwestward. However, it should be mentioned that these studies do not have adequate control on the true depth of the “regional” detachment faults. It is currently unclear whether or not the shallow-dipping regional detachment faults are capable to produce major earthquakes (i.e. seismogenic) in areas where they occur presumably within the ductile aseismic region of the continental crust. This is debated due to a paucity of historical earthquakes on these regional faults; however, some data suggest that the detachment fault may gradually reach shallower depths toward the west-southwest suggesting that as some point they would reach seismic depths and produce major earthquakes. Thrust ramp faults that project upwards from detatchment faults are known to be seismogenic. Most of the identified thrust ramp faults in the WTR and northern PR are shown on Plates 1 and 2.

Figure 3: Fault segments along the Transverse Ranges Southern Boundary Fault System showing faults associated with the TRSB "left-lateral" fault system (TRSBLL), but not showing major folds and relatively deep thrust faults also considered part of the TRSB Fault System as defined within this report.



2.1 Fault segments and activity along the TRSB Fault System defined by the TRSBLL

The concept of strain partitioning is important in understanding potential seismic hazards along the TRSB Fault System as it may occur along its entire length. Along the TRSB, two modes of faulting appear to occur where one accommodates most of the left-lateral strike slip motion, and a deeper fault system that accommodates most of the dip-slip reverse displacement. The connectivity of these two fault systems remains unclear. One question to ask during an evaluation of the TRSB Fault System is whether or not fault zones have been adequately evaluated to determine which are dominantly left-lateral strike-slip, dominantly reverse-thrust dip-slip, or a combination of the two (oblique).

For the purpose of this report, tectonics along the TRSB are divided into numerous fault segments primarily based on established fault zone names associated with the TRSBLL (Figure 3). Most of the fault zones identified in Figure 2 likely reach the surface because they are dominantly left-lateral strike-slip. From west to east, these fault segments include: the Santa Cruz (~100 km long), the Dume-Malibu Coast (~90 km), Potrero Canyon-Santa Monica (~12 km), Hollywood-North Salt Lake-San Vicente (~14 km), and the Raymond (~26 km).

At this scale, mapped traces of these fault zones generally connect, suggesting that they are a system of faults likely accommodating similar styles and timing of deformation consistent with findings of Seeber and Sorlien (2000). Wright (1991) indicates that the TRSBLL Fault System was a relatively linear and likely a more singular connected fault zone prior to the Quaternary when the fault system was deformed associated with the development of northwest trending strike-slip faults in the Peninsular Ranges (i.e. Newport Inglewood, Elsinore Fault Zones to name two).

At larger scales however, this apparent linear fault connectivity breaks down as geological details emerge that force questions about the fault segment interactions. The deformation of the TRSB during the Quaternary likely resulted along numerous fault segments that may now behave independently to some degree; hence possibly exhibiting various levels of activity and style of deformation. There are numerous examples of this including a decrease in activity to a cessation of activity in the late Pleistocene of the Malibu Coast Fault (Treiman, 1994), the Santa Monica Boulevard Fault in Century City (LCI, 2012b; Geocon, 2013a; KGS, 2014), possibly the western Hollywood Fault, and the western Raymond Fault in the Elysian Park-Repetto Hills area. Potentially inactive fault “gaps” along the TRSBLL suggest that various strands may rupture independently, decreasing the potential magnitude of major earthquakes. No faults in the TRSBLL are known to have ruptured during the historic time (past 200 years; Figure 3); however, all fault segments do exhibit strands documented to have ruptured during the Holocene (~past 11,700 years). At least tectonically on a regional scale, the TRSBLL should be considered an active fault system.

2.2 Rotation of the Western Transverse Ranges (WTR)

This section discusses the history of clockwise rotation of the WTR since the Miocene. The clockwise rotation of the WTR relative to the Peninsular Ranges (PR) to the south is believed to be the kinematic cause for left-lateral motion both within the WTR and along the boundary of the WTR-PR (i.e. TRSBLL). Data regarding the magnitude and timing of rotation of the WTR and associated left-lateral slip is provided from numerous sources. Some include:

- Kamerling and Luyendyk (1979) indicate that 64 to 81 degrees of clockwise rotation occurred in the Santa Monica Mountains region, which includes the Santa Cruz and Anacapa Islands, since the middle to late Miocene but that the majority of the rotation (60 degrees) occurred during the middle to late Miocene.

- Luyendyk et al. (1980) proposed a model predicting left-lateral slip along the TRSB due to clockwise rotation of the WTR. Hence, that clockwise rotation of tectonic blocks is accommodated by left-lateral slip across strike-slip faults.

- Kamerling and Luyendyk (1985) determined that 69 to 81 degrees of clockwise rotation occurred within the northern Channel Islands (southern WTR) since the early Miocene, which are similar to their results for the Santa Monica Mountains (Kamerling and Luyendyk, 1979).

- Hornafius et al. (1986) provides tectonic rotation data within the WRT that reveals variations in cumulative rotation during the past 15 Ma. They indicate that the western (near Pacific Ocean coast) verses eastern (San Gabriel Mountains) WTR have rotated approximately 92 and 34 degrees clockwise respectively. They also suggest that the WTR rotated clockwise about 56 degrees between approximately 16 to 10 Ma (mid-Miocene), but has slowed considerably during the past 6 Ma. This suggests that left-lateral slip on the TRSB (i.e. Dume-Santa Monica-Hollywood-Raymond Fault System) has also decreased during the past 6 M.y.

- Jackson and Molnar (1990) based on evaluation of major historical earthquake focal mechanism (slip vector) data suggest that the WTR are currently undergoing clockwise rotations via oblique left-lateral thrust (reverse) faults and determined a rotation rate of 2.8 to 5.3 degrees per million years.

- Liddicoat (1990) determined that approximately 81 degrees of post-Oligocene clockwise rotation occurred in the Santa Ynez Range, and that rotation may not have commenced until the middle Miocene about 15 Ma.

- Luyendyk (1991) indicates the WTR rotated over 90 degrees clockwise relative to the Peninsular Ranges to the south since approximately 17 Ma and may have continued even during a transition in regional tectonic style (Figure 4 and Figure 5).

- Dickinson, (1996) indicates that left-lateral displacement along the TRSB occurred during the early Miocene associated with widespread crustal extension, and continued during the middle Miocene to more recent related to shear between the Pacific and North American Plates (i.e. development of the San Andreas Fault System).

- McCulloh et al. (2001) indicates that left-lateral motion across the Santa Monica-Hollywood-Raymond Fault Zone (part of the TRSBLL Fault System) began later than 8 to 7 Ma, and prior to 3.7 Ma.

During clockwise rotation of the WTR, the TRSB Fault System has rotated from an orientation of approximately north-south during the Miocene, to nearly east-west during the Quaternary (Figure 4 and Figure 5). Wright (1991), who summarizes considerable existing data determined that the TRSB Fault System accommodated dominantly left-lateral strike-slip displacement (horizontal) during the middle to late Miocene (16 to 9 Ma), then transitioned into a dominantly normal fault system (extension), during the late Miocene to mid-Pliocene (7 to 3 Ma), and then transitioned into an oblique reverse left-lateral fault system since the mid-Pliocene. Wright (1991) also suggests that rotation and associated left-lateral slip along the TRSB has continued into the Quaternary.

The work by Hornafius et al. (1986) suggests that left-lateral slip on the TRSB (i.e. Dume-Santa Monica-Hollywood-Raymond Fault System) has decreased during the past 6 M.y, which implies the possibility that long term slip rates on the TRSBLL fault may also have decreased.

A second model for left-lateral displacement along the TRSB is associated with westward movement of the WTR to accommodate regional compression south of the “big bend” (restraining bend) in the San Andreas Fault extending from Tejon Pass in the north to the southern San Bernardino Mountains to the south. This idea is supported by Humphreys, (1995) and Walls et al., (1998) who suggest that the TRSB Fault System

(Figure 3) is dominantly left-lateral to allow for the westward "escape" of the WTR relative to the Peninsular Ranges to the south. Rotation of the WTR and "escape" tectonics are not mutually exclusive; both mechanisms could occur at the same time. However, one of the problems with the "escape" tectonic model is that it suggests left-lateral faulting is occurring to minimize thrust faulting, and it is clear that many active thrust fault systems occur in the WTR.

Figure 4: Modified from Luyendyk (1991) showing the location of the Western Transverse Ranges between 13 – 14 Ma prior to clockwise rotation. Major normal faulting occurred during the Miocene along the southern boundary of the Western Transverse ranges and the northwest trending strike-slip faults in the Peninsular Ranges had not yet developed however some experienced normal faulting as well (also see Lekic et al., 2011).

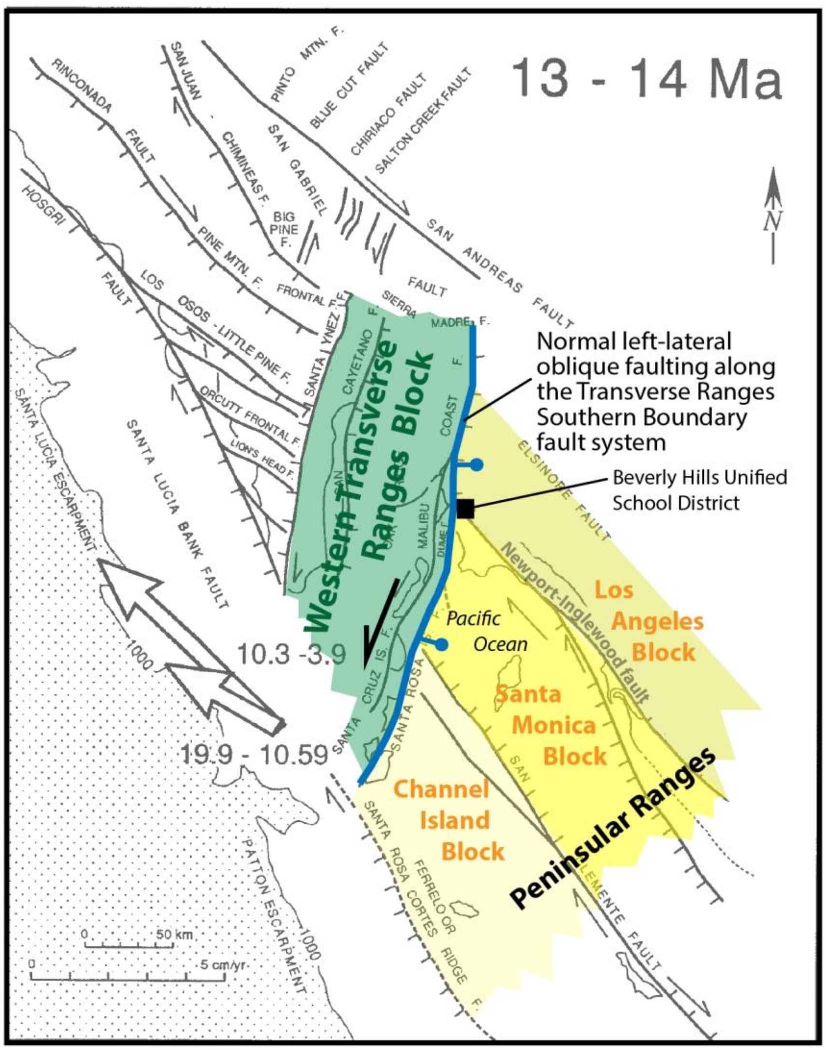
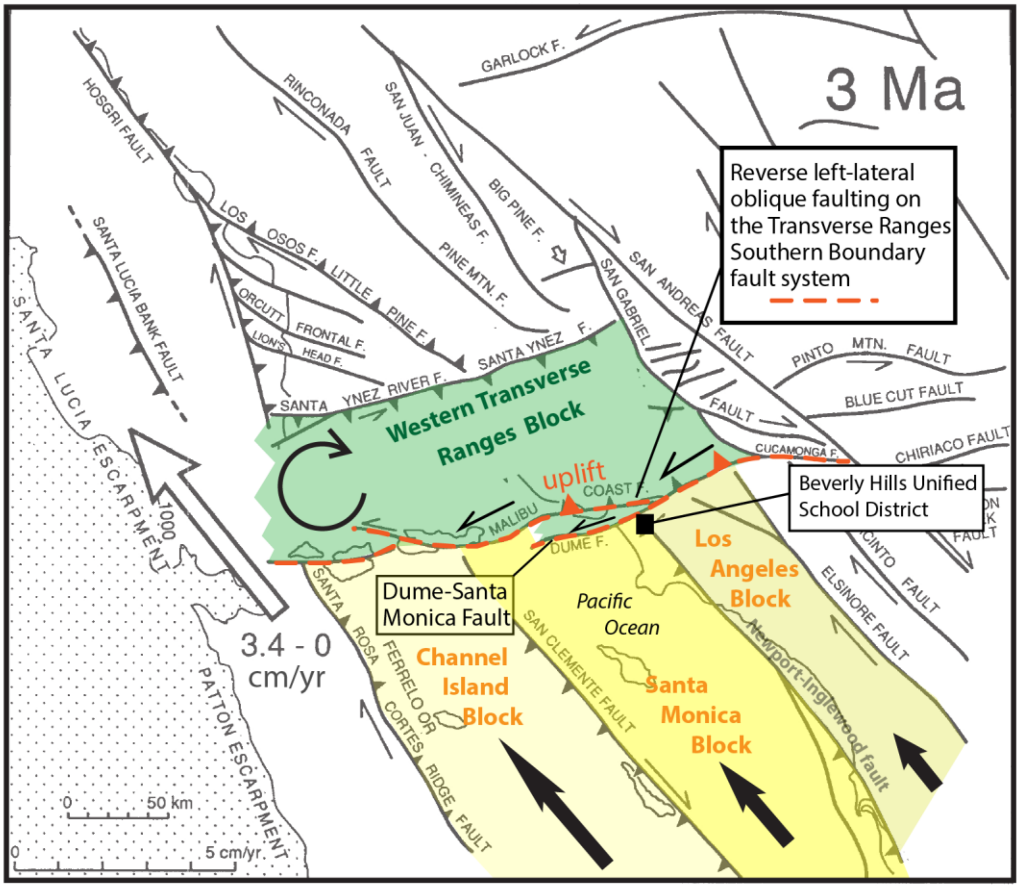


Figure 5: Modified from Luyendyk (1991) showing the position of the Western Transverse Ranges tectonic block after clockwise rotation occurred from the Miocene to the Pliocene. Clockwise rotation has continued since 3 Ma during continued motion between the North American and Pacific Plates. Deformation along the Transverse Ranges Southern Boundary Fault System (TRSB F.S.) experiences left-lateral reverse (oblique) strain to accommodate the WTR clockwise rotation.



2.2.1 Internal rotations within the WTR

A paleomagnetic study by Liddicoat (1992) in the eastern Ventura Basin, northwestern WTR, indicates that approximately 20 degrees of clockwise rotation has occurred since Pico Formation deposition 1 to 3 Ma (Pliocene to early Pleistocene). Their study was conducted on sediments north of the active left-lateral reverse Oak Ridge and Simi-Santa Ana Faults and could have been rotated primarily due to motion across those faults (local) and not across the TRSB to the south. This suggests that some regions of the WTR have faster rotation associated with local active left-lateral reverse faults. The Oak Ridge Fault exhibits some of the highest, if not highest, slip rates and strain rates of all the east-west trending faults in the WTR (Yeats, 1988; Argus et al., 1999). Most active faults in the northwestern WTR exhibit a left-lateral component of slip. These include the Oak Ridge Fault (Smith, 1977a; Sorlien et al., 2000; Fisher et al., 2005a), the Mission Ridge-Arroyo Parida and Santa Ana Faults (Smith, 1977a; Bortugno, 1977) in addition to the Simi-Santa Rosa Fault zone (Treiman, 1997; Treiman, 1999a; Figure 1). Argus et al. (1999) indicates that the region between the western Oak Ridge Fault (mountains) and the Santa Ana Mountains constitutes a rigid block that is rotating as a unit (Figure 1). These studies suggest the possibility that the northern two-thirds of the WTR may be experiencing higher rotation rates compared to the southern third based on the relatively higher slip rates for east-west trending faults in that region. If true, it suggests that the WTR is not rotating evenly across the entire terrain and that sub-rotational systems may occur that exhibit active left-lateral fault zone and areas no longer rotating may exhibit inactive left-lateral fault zones.

2.3 Left-lateral displacement along the TRSBLL Fault System

Considerable evidence exists concerning left-lateral displacement across the TRSBLL both as a collective system (regional) and for various fault zones.

2.3.1 Cumulative Left-lateral displacement along the TRSBLL since the Miocene

Estimates on long-term cumulative left-lateral slip across the Transverse Ranges Southern Boundary Left-lateral (TRSBLL) Fault System is provided from numerous studies. These include:

- Truex (1976) estimates that approximately 60 km of left-lateral slip occurred since the late Miocene.
- Cole (1977) estimates approximately 90 km of left-lateral displacement based on offset lower Miocene shorelines.
- McCulloh et al. (2001) determined that 13 to 14 km of left-lateral displacement occurred during the past 7 Ma at the eastern end of the TRSBLL Fault System based on a displacement evaluation of the Mountain Meadows Dacite across the Raymond Fault. The relatively smaller cumulative left-lateral slip on the eastern end of the TRSB by McCulloh et al. (2001) may have resulted from a lower cumulative rotation in the eastern portion of the WTR identified by Hornafius et al. (1986).

2.3.2 Left-lateral displacement for various fault zones along the TRSBLL

Considerable evidence for left-lateral motion across numerous fault segments along the TRSBLL exists with most of it indicating activity since the latest Pleistocene and Holocene (i.e. active). Evidence for each fault segment from west to east along the TRSBLL are discussed below (Figure 2):

- *Raymond Fault Segment:* Weaver and Dolan (2000; also see Dolan et al., 2000c) indicate that the ~N66E striking Raymond Fault is dominantly left-lateral and last ruptured approximately 1 to 2 kya. Hauksson and Jones (1991) based on historical earthquake data indicate that the Raymond Fault is an important left-lateral fault along the southern boundary of the WTR. McCulloh et al. (2001) indicate that the eastern TRSB Fault System has experienced approximately 13-14 km of left-lateral displacement during the past 7 Ma, which suggests a slip rate of 1.9 mm/yr. McCulloh proposed that approximately 20 degrees of clockwise rotation has occurred in the eastern WTR north of the Raymond Fault since approximately 4 to 3 Ma.

- *Hollywood Fault Segment:* Dolan et al. (1997) provides a detailed evaluation of the Hollywood Fault based on geotechnical boreholes and trenches, and geomorphology concluding that this fault zone is likely dominantly left-lateral. Lindvall et al. (2003) also concluded that the Hollywood Fault is dominantly left-lateral and that the presumed component of shortening (i.e. reverse motion) is in the range of only 0.0 to 0.11 mm/year. This shortening rate is nearly insignificant compared to an estimated 3.8 mm/yr between the UCLA campus and the San Andreas Fault near the San Gabriel Mountains, and 4.2 mm/yr between near downtown Los Angeles and the San Andreas Fault near the San Gabriel Mountains (Argus et al., 2005). Hence, Lindvall et al. (2003) determined that most shortening in the northern Los Angeles basin likely occurs on structures south of the Hollywood Fault. It is proposed herein that the east-northeast trending North Salt Lake Fault along the southern boundary of the Hollywood basin may have also accommodated some left-lateral slip during the Quaternary and that this fault zone connects with the Santa Monica Boulevard fault in the BHUSD to the west.

- *The Potrero Canyon-Santa Monica (Boulevard) Fault Segment:* KGS (2014) suggests that the Santa Monica Boulevard Fault located at the eastern end of the Santa Monica Fault of Dolan and Sieh (1992) in Century City is dominantly strike-slip, hence, likely nearly pure left-lateral. This report concludes that the entire Potrero Canyon-Santa Monica Boulevard Fault segment is a dominantly left-lateral fault system that extends eastward along the southern boundary of the Hollywood Basin to connect with the North Salt Lake Fault. The Santa Monica Boulevard fault zone ceased activity approximately 200 kya (LCI, 2012; KGS, 2014) suggesting that the North Salt Lake Fault may be inactive as well. The Potrero Canyon-Santa Monica Boulevard faults are considered upper plate dominantly left-lateral faults and that compressional shortening dominantly occurs on other faults to the south (Figure 43). Left-lateral motion has likely migrated southward since the middle Pleistocene along the Malibu Coast-Dume Fault Segment and this may have occurred in the Cheviot Hills region due to the cessation of activity along the Santa Monica Boulevard Fault.

- *The Malibu Coast-Dume Fault Segment:* Treiman (1994) indicates that the approximately E-W trending Malibu Coast Fault exhibited dominantly left-lateral displacement in the Quaternary but that activity on the fault has decreased if not ceased by 124 kya (late Pleistocene). However, Drumm (1992) performed a fault investigation across a single splay (their central splay) near Point Dume and suggested that this fault strand was active during the latest Pleistocene, and likely active during the Holocene. Additionally, Fisher et al. (2005b) provides evidence that the Malibu Coast fault is active and exhibits oblique left-lateral reverse displacement, and that the Dume fault is dominantly reverse. Sorlien et al. (2003; 2006) indicates that the Dume-Dume Santa Monica Fault is dominantly left-lateral (Figure 1). Sorlien et al. (2006) indicates that approximately 5 km of left-lateral motion and 11 degrees clockwise rotation of the Santa Monica Mountains to the north have occurred during the last 4 M.y across the Dume-Santa Monica Fault System and western offshore portion of the Malibu Coast Fault collectively (Figure 1). Hauksson and Saldivar (1989) based on evaluation of historical seismicity suggest that the region of Santa Monica Bay south of the Dume Fault is currently experiencing dominantly compressional tectonic stress. These findings suggest that left-lateral motion associated with WTR rotation is primarily occurring along the western offshore portion of the Malibu Coast Fault, the Dume-Dume Santa Monica Fault Zone, and a much lesser extent on the onshore Malibu Coast Fault since the mid-Pleistocene.

- *The Santa Cruz Island Fault Segment:* Junger (1979) identified stream channels that were left-laterally deflected across the Santa Cruz Island Fault by as much as 300 m, suggesting dominantly left-lateral displacement in late Quaternary time. Pinter and Sorlien (1991) provide similar results and identified at least one channel deflected as much as 600 m across the Santa Cruz Island Fault. Pinter et al. (1998) indicate that the Santa Cruz Island Fault is active, predominantly left-lateral and exhibits a slip rate of not more than 1.1 mm/yr and probably about 0.8 mm/yr and a reverse component of approximately 0.1 to 0.2 mm/yr. Pinter et al. (2001) indicate that Santa Rosa Island has experienced 15+ m of vertical motion by folding, resulting in anticlinal grown of at least 0.12 mm/yr since the late Quaternary. It is unknown whether this uplift and folding is associated with a

> local restraining bend orientation of the Santa Cruz Island Fault or due to regional tectonic compression (shortening); evidence for a restraining bend model is the more northwesterly trend of the Santa Cruz Island Fault in the region of maximum uplift.

Evaluation of historical earthquake locations and focal mechanisms along the TRSB Fault System suggests dominantly left-lateral displacement across at least across some fault segments in the zone (Real, 1980; Hauksson and Jones, 1991).

These data indicate that the Santa Cruz-Malibu Coast-Dume and the Potrero Canyon-Santa Monica-Hollywood-Raymond Faults comprise an approximately east-west to northeast trending, dominantly left-lateral strike slip fault system (i.e. TRSBLL; Figure 2). These faults have collectively accommodated most of the Quaternary left-lateral motion along the boundary between the WTR and PR (i.e. TRSB) associated with clockwise rotation of the WTR. The general strike of the TRSBLL Fault System ranges from N70E in the region from the Raymond Fault to just south of Point Dume, to nearly east-west from Point Dume west to the Channel Islands (Figure 2).

2.3.3 Local restraining bends along the TRSBLL

Individual fault sections that trend away from the generalized strikes along the TRSBLL often exhibit local releasing and restraining beds, and it is in these areas that these faults may be mistaken as faults accommodating regional compressional stress. Restraining bend orientations occur along the eastern Hollywood Fault (Plate 3), the en-echelon fault strands of the Santa Monica Fault near Santa Monica of Dolan and Sieh (1992; Plate 3), the local bends along the western Dume Fault (Sorlien et al., 2006), and possibly the Santa Cruz Island Fault. A local restraining step-over is proposed where slip was transferred from the western end of the North Salt Lake Fault and the eastern Santa Monica Boulevard Fault (Figure 7).

Local releasing bends and step-overs also exist, although to a lesser extent than the restraining bends possibly due to the compressional component of deformation along the TRSB. A minor releasing bend orientation may occur along the Santa Monica Boulevard Fault (SMBF) in Century City where normal apparent displacement is observed across the fault zone (KGS, 2014). A potential releasing step over may occur between the western Hollywood Fault and the Santa Monica Boulevard Fault in the region of the western Hollywood Basin and the Cheviot Hills, originally proposed by Dolan et al. (1997). Another possible releasing step may also occur between the eastern Hollywood Fault and the North Salt Lake Fault as proposed by Tsutsumi et al. (2001).

2.4 Defining the tectonic boundary between the Western Transverse Ranges and the Peninsular Ranges – the TRSB and TRSBLL

That the faults associated with the Transverse Ranges Southern Boundary Fault System "left-lateral" (TRSBLL) are dominantly left-lateral, and that compressional deformation is occurring either north, below, and/or south of the TRSBLL suggests that the boundary between the WTR and PR may be quite wide and extends into the northern Los Angeles Basin and north to include the Santa Monica Mountains (Figure 1). In this report, the term Transverse Ranges Southern Boundary Fault System (TRSB) will include the zone of compressional structures extending both north and south of the TRSBLL and the dominantly left-lateral fault system comprising the TRSBLL. This definition implies that strain partitioning is occurring along the boundary of the WTR and PR within the TRSB.

The definition for the TRSB herein is consistent with that of Pinter et al. (1998; 2001) and Seeber and Sorlien (2000) that define the Transverse Ranges Boundary Fault System as involving strain partitioning: left-lateral motion on upper plate faults and deeper reverse and thrust faults accommodating tectonic shortening. The TRSB Fault System represents a fold and thrust belt similar to that described by Hauksson and Saldivar (1989) which they referred to as the Elysian Park Fold and Thrust Belt. Meigs and Oskin (2002) also describe the region between the WTR and Peninsular Ranges as a structurally complex transition zone between approximate latitude 33.75 N and 34.25N. Their defined zone is approximately 55 km wide and encompasses nearly the entire region of the WTR and the entire northern half of the Los Angeles Basin (i.e. from Palos Verdes to the northern San Fernando Valley). Shaw et al. (2002) suggest that the active Puente-Hills Blind-Thrust System represents the southernmost of the east-west trending fault systems that they associate with the WTR (Figure 1). However, the regional Lower Elysian Park Fault (thrust) is believed to occur below the Puente Hills thrust "ramps", and continues toward the southwest as it shallows to near surface depths west of Palos Verdes offshore. Hence, the Lower Elysian Park Fault should likely be considered part of the PR (Davis et al., 1989; Shaw and Suppe, 1996; Argus et al. 2005; Shaw).

Although not supporting significant if any left-lateral slip in their kinematic models, Davis et al. (1989) do provide a compressive model for the deformation west of the San Andreas Fault in southern California. They propose a regional, shallow dipping detachment (décollement) fault extends from near the San Andreas Fault in east, all the way to the Los Angeles Basin, and offshore (Figure 6). They refer to this regional décollement fault as the Los Angeles Basin Detachment Fault. They indicate that numerous thrust ramp faults extend upwards from the regional décollement fault, which are seismogenic. Although their cross sections have been refined by more recent work, their Cross Section 11 (Figure 6) shows the Elysian Park and Santa Monica Thrust Ramps. Their second observation is the identification of a large compressional antiform extending along the axis of the Santa Monica Mountains and then turning toward the southwest at the eastern end of the Santa Monica Mountains (Figure 1). They refer to this compressional (shortening) structure as the Santa Monica Mountains Anticlinorium. Their third observation is that they extend the shortening several kilometers south of the TRSBLL where folding occurred in the upper crust. The third idea is interesting because they propose that rocks/sediments and older reverse faults (hanging wall and footwall rocks) that are likely no longer active are folding as a collective mass. This folding is occurring south of the TRSBLL Fault System in the northern Los Angeles basin. However, their model does not propose that active thrust ramp faults are producing this folding.

If the TRSBLL Fault System accommodates dominantly left-lateral displacement, then the question arises regarding what compressional structures accommodate shortening along various fault segments along the TRSB considered part of the WTR or transition zone between the PR and WTR (Figure 3). It is presumed that compressional structures associated with the southern WTR would exhibit relatively east-west trending structures compared to those of the PR, which trend northwest-southeast.

3.0 Tectonic shortening within the TRSB deformation zone

As suggested earlier, the Santa Rosa, Santa Cruz, Malibu Coast-Dume, Santa Monica (Potrero Canyon), Santa Monica Boulevard, Hollywood-North Salt Lake, and Raymond faults comprise a Quaternary, approximately east-west trending, dominantly left-lateral strike slip fault system (TRSBLL; Figure 3). The Santa Monica Boulevard and North Salt Lake faults are discussed in detail later in this report (Figure 7). Faulting across the TRSB Fault System however is commonly considered oblique; hence accommodating left-lateral and reverse components of strain (Wright, 1991; Dolan et al., 1997; Dolan et al., 2000a; Dolan et al. 2000b). This assertion is generally considered true for the collective strain across the TRSB since at least the early Pliocene (~4.5 Ma), but the question arises regarding how that strain is accomplished. Strain partitioning is one solution whereby steeply north-dipping faults in the hanging wall accommodate left-lateral slip (TRSBLL) and other faults accommodate reverse-thrust dip-slip faulting. It is clear that a number of faults in the TRSBLL accommodate dominantly left-lateral motion, however it is unclear if or how these faults are related to compressional fault structures. Regardless, the question then becomes, where is the compressional strain occurring along the TRSB? This is a critical question for evaluating seismic hazards along the TRSB in which the Beverly Hills Unified School District resides.

Numerous fault systems with varying histories of activities and location have accommodated shortening within the TRSB that occur north, south and under the TRSBLL. Hence the region has exhibited a dynamic and evolving history during Pliocene to present time in terms of which compressional structures (i.e. blind thrust ramps, folds and reverse faults) were active at various times. This is partially the result in the northern Los Angeles basin due to the northward migration of the right-lateral strike slip faults in the Peninsular Ranges during the past 1 to 2 million years (Wright, 1991), which according to Yeats (2001) has essentially caused numerous reverse faults and associated folds to cease activity and for other faults systems to become active.

Wright (1991) indicates that a northwest trending anticline developed in the Baldwin Hills prior to right-lateral strike-slip displacement across the Newport-Inglewood Fault that began in the late Pliocene and no later than the early Pleistocene. This indicates that the Newport-Inglewood Fault migrated northwestward during the Pleistocene. Dorsey et al. (2012) indicate that the Elsinore Fault was initiated approximately 1.2 Ma. Similarly, work by Janecke et al. (2010) determined that the San Jacinto Fault initiated approximately 1.07 Ma. These data indicate a dramatic tectonic change within the northern Peninsular Ranges in the early Pleistocene that likely had a major impact on the behavior such as activity and associated deformation along the TRSB.

Folding associated with faulting in the form of re-activated listric faults, fault propagation folds and fault bend folds likely all occur within the TRSB. These structures are associated with compressional deformation. Numerous thrust ramps occur that veer upwards from either regional or local detachment/décollement faults such as the Lower Elysian Park Thrust (LEPT; Figure 6, Plate 1 and Plate 2) among others (Namson and Davis, 1988; Davis et al., 1989; Davis and Namson, 1994; Shaw and Suppe, 1996; Seeber and Sorlien, 2000; Shaw et al., 2002; Geiser and Seeber, 2008). Sorlien (personal communication, 2014) indicated that the LEPT may connect westward with the Catalina Island Detachment Fault (Plate 1 and Plate 2). It should be noted that although it is clear that the thrust ramps emanating from the regional décollement faults are seismogenically active, it is debated whether or not the deeper décollement faults themselves are seismogenically active. It seems reasonable that as the décollement faults progressively extend to shallower depths toward the southwest that at some depth they would become seismogenic.

Three thrust ramps considered associated with the WTR have experienced major earthquakes in historical times: the 1994 Northridge Earthquake on the Pico Thrust, the 1989 Whittier Narrows earthquake occurring on the Elysian Park Thrust or more likely on the Puente Hills Thrust (see Shaw and Shearer, 1999), and the 1971 San Fernando Earthquake occurring on the Sierra Madre Fault (Davis and Namson, 1994). Note that the 1994 Northridge and 1971 San Fernando earthquakes occurred north of the TRSBLL, and the 1989 Whittier earthquake (Hauksson and Jones, 1989) occurred south of the TRSBLL supporting the observation that the TRSBLL occurs within the boundary zone of the WTR and PR (TRSB).

Davis et al. (1989) proposed that motion across the EPT has led to the development of the Santa Monica Mountains Anticlinorium (SMMA), which they extend from the Santa Barbara Channel in the west, along the axis of the entire Santa Monica Mountains, then turning southeastward parallel to the Whittier Fault (Figure1). Seeber and Sorlien (2000) extend the SMMA westward to include antiformal uplifts near the Channel Islands (Figure 1). The SMMA may be as much as ~260 km long and over 20 km wide and it is important to point out that the SMMA extends further south than the faults associated with the hanging wall dominantly left-lateral TRSBLL Fault System. However, it is unclear how active the SMMA currently is as it may be an older structure. The tectonic model of a regional deep crustal detachment fault that is difficult to identify but exhibits numerous seismically active thrust ramps that veer upwards to shallower depths but are generally blind, suggests that many of the thrust ramps have yet to be identified. Hence, a primary question to ask in the evaluation of seismic risk in the northern Los Angeles basin is where are the active compressional thrust ramps extending into the upper crust occur for each TRSBLL fault segment shown in Figure 2. This question is evaluated in the following sections.

3.1 Shortening stress rates across the TRSB

Argus et al. (1999) indicates based on modeling of recent continuous GPS data that ~6 mm/yr of contraction is occurring between Pasadena at the foothills of the San Gabriel Mountains and downtown Los Angeles. This number was revised to a contraction rate of approximately 4.2 mm/yr occurring between the San Gabriel Mountains (San Andreas Fault) and Los Angeles (Argus et al., 2005). These studies also indicate that shortening rates across the WTR are not equally distributed. They identify a zone of rapid convergence occurring within the WTR located north of the Santa Monica Mountains (Figure 1). For example, that deformation in the approximately 5 km wide Ventura Basin area is accommodating a north-south contraction rate of 6 mm/yr. This finding is consistent with Donnellan et al. (1993) determination based on geological and geophysical observations and modeling that the Ventura Basin is experiencing contraction rates (convergence) of approximately 7 to 10 mm/yr. It is also consistent with Marshall et al. (2013) evaluating GPS and Instar data and performing three-dimensional mechanical and kinematic models determination of a contraction rate across the Ventura Basin of 7 mm/yr. Donnellan et al. (1993a) evaluating geological and geophysical observations and modeling determined that the Ventura Basin is experiencing contraction rates (convergence) of 7 to 10 mm/yr (also see Donnellan et al., 1993b)

South of the Ventura Basin, Argus et al. (1999) indicates that the region between the Ventura Basin and the Santa Monica Mountains (i.e. the TRSB) is a relatively stable block not currently experiencing contraction. Argus et al. (1999) also indicate that the Santa Monica Mountains are moving southward approximately 3-7 mm/yr with respect to Channel Islands to Long Beach. This suggests that compressional strain is occurring south of the TRSB. Sorlien (2006) based on the findings of Argus et al. (1999, 2005), indicates that active compressional strain across the deep thrust faults underneath the TRSBLL Fault System in the Santa Monica Bay region (the Santa Monica Mountains Thrust) is permissible.

West of the Beverly Hills Unified School District, Treiman (1994) indicates that compressional deformation has also possibly moved south of the TRSBLL (i.e. the Malibu Coast and Dume Faults) during the Pleistocene. Findings from Schneider et al. (1996) indicate a similar southward migration of compressional shortening in the northern Los Angeles Basin along the Hollywood Fault segment (Figure 3). East of the Beverly Hills Unified School District, Argus et al. (1999) indicates that compressional stress and associated deformation (i.e. mountain building) has shifted southward away from its 3 Ma locus in the San Gabriel Mountains to its current locus in the northern metropolitan Los Angeles today (Fuis, et al., 2001).

Bawden et al. (2001) indicates that ~4.4 mm/yr of uniaxial contraction is occurring across the northern Los Angeles basin oriented at N36E, which is perpendicular to the northwest trending right-lateral strike-slip faults of the Peninsular Ranges. This stress direction is oriented appropriately for northwest trending (striking) thrust faults similar to the Compton Thrust of Shaw and Suppe (1996), Lower Elysian Park Thrust, and presumably the blind (deep) Los Angeles Fault of Schneider et al. (1996). Most of these faults are currently mapped southeast of the Beverly Hills Unified School District.

Schneider et al. (1996) proposes that compressional faulting has migrated southward since the Pliocene in the region of the BHUSD based on abandonment of the San Vicente and Las Cienegas reverse faults and development of their active blind Los Angeles Fault producing the Las Cienegas monocline and northern central Los Angeles trough (Plate 3, Plate 4a and Plate 4b). They estimate horizontal convergence rates of 1.1 to 1.3 mm/yr in the region of the east Beverly Hills and 1.3 to 1.5 mm/yr near Las Cienegas associated with the blind Los Angeles Fault. Tsutsumi et al. (2001) suggests that crustal shortening across the northern Los Angeles Basin (their northern Los Angeles Fault System) accounts for less than a third of the current rate of shortening between the San Gabriel Mountains and Palos Verdes Hills based on global positioning system observations. All of these horizontal compressional rates are for the region east of the Newport-Inglewood Fault. Active convergent rate estimates west of the Newport-Inglewood Fault along the Santa Monica-Potrero Canyon Fault segment were unfortunately not identified.

Evaluating historical seismicity, Hauksson and Saldivar (1989) indicate that the northern Santa Monica Bay region is experiencing nearly north-south oriented compressional stress (i.e. maximum horizontal compressive stress orientation). This stress direction is responsible for their east-west trending Elysian Park Fold and Thrust Belt (EPFTB). They also indicate that southern Santa Monica Bay is exhibiting southwest-northeast compressional stress associated with their northwest trending Torrance-Wilmington Fold and Thrust Belt (TWFTB). In their model, the EPFTB trends along the TRSB and extends all the way to the City of Los Angeles and is considered deformation associated with the southern boundary of the WTR (the TRSB). This zone of compressional stress exhibits a similar trend and location to that described by Davis et al. (1989), Geiser and Seeber (2008) and Sorlien et al. (2013). In all of these tectonic models for the boundary between the WTR and PR, approximately north-south compression is occurring south of the TRSBLL and that this compression extends into the northern Los Angeles Basin on land, and south of the northern Channel Islands offshore (red area on Figure 3).

Although these data are incomplete to fully evaluate compressional strain in the region of the BHUSD, local stratigraphic-structural studies in the region provide many insights regarding where active faulting may exist. Active compression is occurring along the TRSB but it appears to have slowed or essentially abandoned many reverse faults that were active during the Pliocene. These include the Santa Monica Fault South, Santa Monica Fault North, Rancho, San Vicente, and possibly the Las Cienegas Faults (see Wright, 1991, Schneider, et al., 1996, and Tsutsumi et al., 2001; Plate 1 and Plate 2 and Figure 7). Although published reports indicate that the faults are inactive, these faults are still commonly shown on fault hazard maps suggesting that, fault hazard maps are not staying current with research.

3.2 Compressional structures in the western TRSB along the Santa Cruz Island and Dume-Malibu Coast fault segments

Similar to the eastern TRSB, deep detachment faults and thrust ramps have been proposed associated with the boundary between the WTR and PR. In addition, the thrust décollement faults are proposed to extend under the TRSB Fault System and then ramp upwards under and south of the TRSBLL along the Santa Cruz Island and Dume-Malibu Coast Faults segments (Figure 2, Plate 1 and Plate 2).

Immediately north of the TRSBLL, Shaw and Suppe (1994) proposed that the Channel Island Thrust is active and occurs as a detachment fault under Santa Barbara Channel but ramps upwards beneath Santa Cruz Island (Plate 1 and Plate 2). Similarly, Seeber and Sorlien (2000) identified the regional Santa Monica-Channel Islands thrust (Santa Monica Bay thrust, Plate 2) which they indicate includes the Channel Island Thrust of Shaw and Suppe (1994) in addition to the Elysian Park Thrust under the Santa Monica Mountains proposed by Davis and Namson (1994). However, this regional fault system is likely segmented.

Deep thrusts below the TRSBLL are proposed in Santa Monica Bay, the region south of the mainland coast, centered on Point Dume (Figure 3). Geiser and Seeber (2008) propose that a deep detachment thrust fault occurs under Santa Monica Bay and the TRSBLL that extends eastward beneath the City of Santa Monica. Sorlien et al. (2006) identify a deep "detachment" type fault they referred to as the Santa Monica Mountains thrust, which is now referred to as the Santa Monica Bay Thrust (Plate 1 and Plate 2). The active Dume Fault, which is dominantly left-lateral (Sorlien et al., 2006), likely connects with the Santa Monica Bay Thrust Fault at depth (Plate 2). However, the Santa Monica Bay Thrust Fault may no longer be active south of its intersection with the Dume Fault (Sorlien et al., 2006). Sorlien et al. (2013) also show the generally WNW-striking, NNE-dipping strands of the Santa Monica Mountains Thrust, called the Santa Monica Bay Detachment. This fault may be the same as the Compton Thrust of Shaw and Suppe (1996), which occurs onshore under the City of Santa Monica (Plate 2). Davis et al (1989) have a comparable thrust ramp in the same area, but at a deeper level. In addition, a deeper major Miocene detachment (low angle normal fault) is imaged in data used by Sorlien et al (2013), which they refer to as the Catalina Island detachment (Plate 1 and Plate 2). The 70 km-long Palos Verdes anticlinorium has been folding above both of these faults during Pliocene-Quaternary time (mostly Quaternary; Sorlien et al., 2013).

The active Compton Thrust (Leon et al., 2009) generally trends toward the northwest, parallel to the strike slip faults associated with the PR. As discussed earlier, Hauksson and Saldivar (1989) indicate that recent seismicity in northern Santa Monica Bay is primarily experiencing N13E directed compression and that this region is part of the WTR. They also indicate that this compression is in a region of the merging of two fold and thrust belts: their generally east west trending Elysian Park fold and thrust part which is associated with the EPT, and the northwest trending Torrance-Wilmington fold and thrust fault associated with northwest trending compressional structures like the Compton Thrust. This model is consistent with the orientation of the proposed Dume Fault East (Plate 1) that turns towards the southeast as it approaches the shoreline in the region of the boundary between the Santa Monica Bay Fault associated with the WTR, and the Compton Thrust typically considered associated with the PR. In fact, the northern end of the Palos Verdes Fault is shown to turn toward the northwest in the central Santa Monica Bay (Sorlien, 2014, personal communication). This evidence suggests that this is the likely region of the transition between the WTR and PR (southern boundary of the TRSB).

In summary, it is clear that regional deep thrust faults extending under the WTR and south of the TRSBLL occur along the Santa Cruz Island and Dume-Malibu Coast Fault segments, and that these faults likely extend onshore beneath the Potrero Canyon-Santa Monica Fault segment. However, the southern extent of these detachment faults, their exact depths in the region, the location of their associated thrust ramps and their activity remains unclear.

3.3 Compressional structures along the Potrero Canyon-Santa Monica Fault segment

Very little area-specific data exists regarding the potential for deep detachment thrusts and thrust ramps in the eastern Santa Monica Bay and eastward under the City of Santa Monica to the Newport-Inglewood Fault. This is the region of the Potrero Canyon-Santa Monica Fault segment of the TRSBLL (Figure 3). Geiser and Seeber (2008) evaluated deep structures in this region and postulated that a deep thrust fault and associated thrust ramps exist in the area. Shaw and Suppe (1996) propose that the Compton-Baldwin Hills Segment Fault Ramp, a fault segment located northwest of their Compton Thrust Ramp exists under the region of the City of Santa Monica and extending offshore (Plate 2). The boundary between these two fault segments trends northeast and occurs in the southernmost Baldwin Hills. Findings by Sorlien et al. (2013) support the existence of the northeast-southwest convergent Compton Thrust Ramp as identified by Shaw and Suppe (1996) in the Baldwin Hills area that extends offshore. Sorlien et al. (2013) propose that the Compton Thrust extends to near surface depths (upper 1 km) along the Santa Monica Bay Detachment Fault and the San Pedro Bay Escarpment Fault (Plate 1).

The regional NW-striking Lower Elysian Park Thrust occurs at depths of approximately 10 km between Los Angeles and the Baldwin Hills, then gradually shallows to eventually reach within 1 km depth offshore along the Catalina Island Detachment Fault (Plate 1 and Plate 2). The Compton Thrust is considered a thrust ramp associated with the regional Lower Elysian Park Thrust. It is unclear, and debated, whether or not these types of regional compressional structures are seismogenic. Many of these detachment faults gradually reach shallower depths toward the southwest, and presumably, at some depth would become seismogenic. This may be the case across much of the Los Angeles Basin however as the fault is considered to reside at a depth of approximately 10 km.

Numerous reverse faults have been identified along the Potrero Canyon-Santa Monica Fault segment. These include the Santa Monica Fault South of Wright (1991; same as the Santa Monica Fault So. of Tsutsumi et al. 2001), the Santa Monica Fault North of Wright (1991), and the Rancho Fault (Wright, 1991; Hummon, 1994; Tsutsumi et al., 2001). Most of these faults occur at depths where they were identified via oil well data (1 to 3 km). It is unclear whether or not these faults connect at depth with a detachment fault, however, most of these faults are considered inactive due to a paucity of deformation in Quaternary sediments.

The dominantly reverse Santa Monica Fault South of Wright (1991; Tsutsumi, et al., 2001) extends from the coast to the northern Newport-Inglewood Fault (Figure 7; Plate 4a). The northwest trending Rancho Fault identified by Wright (1991), Hummon, (1994), and Tsutsumi et al. (2001) occurs immediately west of the Newport-Inglewood Fault (Figure 7; Plate 4a). Tsutsumi et al. (2001) determined that the Rancho Fault dips steeply to the north (~80 degrees; Plate 4a), which raises the possibility that it may have exhibited strike-slip motion. The youngest sediments deformed by the Santa Monica Fault South and the Rancho Fault appears to be early Pleistocene, hence, these faults are generally considered inactive by most authors.

However, Wright (1991) identifies an active approximately east-west trending monocline and syncline located south of the Santa Monica Fault South and Rancho Fault. He suggests that blind thrust ramps consistent with the tectonic model proposed by Davis et al. (1989) may account for these structures. With this model in mind, this report concludes that a NWW trending thrust ramp fault may occur south of the Santa Monica Fault South and Rancho Fault (Culver City Fault, Plate 4a and Plate 4b).

It should be pointed out that the currently identified “Santa Monica Fault” that deforms late Quaternary sediments and surfaces (scarps) and identified from approximately Potrero Canyon at the coast to the BHUSD has been assigned numerous names in the literature and various styles of deformation. Of note, Wright (1991) refers to this fault as the Potrero Canyon Fault and that it terminates, in terms of a near surface faulting, towards the west in the western Cheviot Hills (Figure 7). Dolan and Sieh (1992), Pratt et al. (1998), Dolan et al. (2000a), and Catchings et al. (2010) all refer to this fault as the Santa Monica Fault. Dolan and Sieh (1992) and Dolan et al. (2000a) extend this fault from the coast at Potrero Canyon to the east the eastern side of the Cheviot Hills based on a series of evaluated fault scarps. Dolan et al. (2000a) conducted a fault investigation across a strand of this fault zone (Plate 3) and concluded that the Santa Monica Fault is active. Tsutsumi et al. (2001), refers to this fault as the Santa Monica Fault North and that it connects with the Santa Monica Fault South at a depth of approximately 2 km. This report adopts the name Potrero Canyon Fault from Wright (1991) and agrees with the findings of Tsutsumi et al. (2001) that the Potrero Canyon Fault connects with the Santa Monica Fault South of both Tsutsumi et al. (2001) and Wright (1991). In addition, this report supports Tsutsumi et al. (2001) that his Santa Monica Fault North (Potrero Canyon Fault) likely initiated movement (formed) approximately 1 Ma.

Most publications however suggest that the Potrero Canyon Fault likely exhibits oblique left-lateral reverse motion. As discussed within the body of this report, the Potrero Canyon Fault has exhibited dominantly left-lateral strike-slip displacement since its inception approximately 1 Ma, and that observed uplift (reverse dip-slip motion) has occurred along the Potrero Canyon Fault due to a local restraining bend orientation.

Toward the east in the Cheviot Hills, and as discussed in the body of this report, a similar kinematic relationship occurs. Namely, that the previously identified Santa Monica Fault associated with a series of scarps identified by Dolan and Sieh (1992; also see Dolan et al., 2000a) is a dominantly left-lateral strike-slip fault referred to herein as the Santa Monica Boulevard Fault (SMBF). This fault is believed to connect with the Santa Monica Fault North of Wright (1991) and Tsutsumi et al. (2001) at a depth of approximately 0.6 to 1 km and also formed approximately 1 Ma.

3.4 Compressional structures along the Hollywood Fault segment

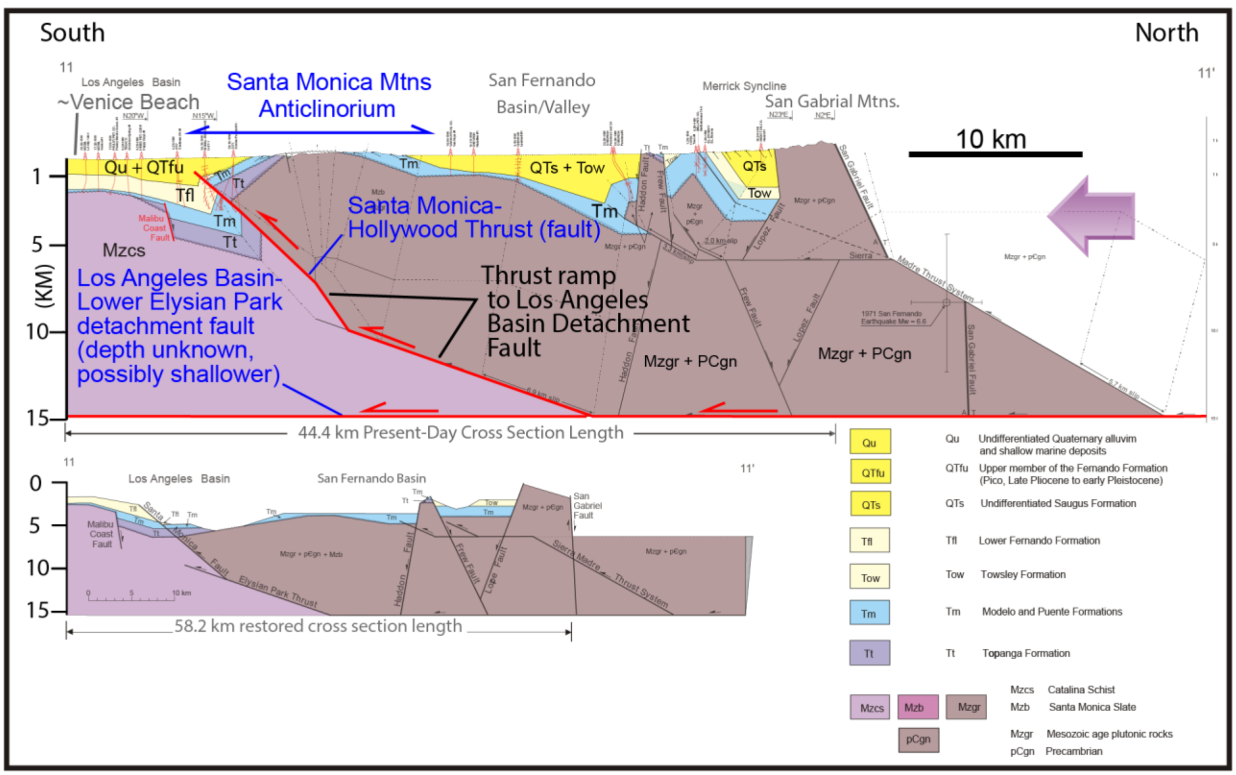
Numerous compressional faults and associated fold structures are proposed along the Hollywood Fault segment within the TRSB that are located both north and south of the TRSBLL. Some of these structures are located within the Beverly Hills Unified School District. From north to south these include: the Santa Monica Thrust beneath the Santa Monica Mountains (Dolan et al., 1995), which is part of the regional Los Angeles Basin Detachment-Lower Elysian Park Thrust of Davis et al. (1989; Figure 6), the Hollywood Fault, the Santa Monica Fault North of Wright (1991), the San Vicente Fault, and thrust faults associated with the development of the East Beverly Hills-Las Cienegas Monocline and Los Angeles Central Trough. Some published reports regarding these fault systems are described below:

Santa Monica Thrust beneath the Santa Monica Mountains

The proposed active Santa Monica Thrust (Dolan et al., 1995) exists beneath the Santa Monica Mountains and is essentially part of the regional Lower Elysian Park-Los Angeles Basin Detachment Thrust System of Davis et al. (1989; Figure 6). This fault zone extends along the length of the Santa Monica Mountains. In the Davis et al. (1989) model, motion across this fault zone has led to the development of the Santa Monica Mountains Anticlinorium and has led to reverse faulting across the Hollywood fault and mass folding south of the Hollywood fault (Figure 1 and Figure 6). Their regional fault structure models suggest that a mid-crustal detachment thrust fault extends further south than the Santa Monica and Hollywood Faults (Davis et al.; 1989; Davis and Namson, 1994). However, there is currently no direct evidence to support that the Hollywood Fault connects with a deeper detachment thrust fault or that it exhibits a considerable reverse component of dip-slip motion as shown by Davis et al. (1989).

It should be pointed out however, that dominantly reverse motion across the Santa Monica and Hollywood Fault Zones likely ceased during the early Pleistocene. At that time, their dominant sense of slip likely changed to left-lateral strike-slip (see body of report). At that time, compressional deformation likely migrated southward as proposed by Tsutsumi et al. (2001).

Figure 6: Modified Cross Section No.11 from Davis and Namson extending from the northern San Gabriel Mountains in the northeast to Venice Beach in the southwest (http://www.davisnamson.com/downloads/index.htm). This section crosses the Santa Monica Fault South in the region of Cross Section H-H' by Wright (1991).



Hollywood Fault

The Hollywood Fault occurs near the base of the Santa Monica Mountains bounding the northern edge of the Hollywood basin (Figure 7). The fault zone dips relatively steeply to the north and is considered active with its last surface rupturing event occurring in the early Holocene (see Dolan et al., 1997; Dolan et al., 2000b). This eastern Hollywood

Fault in the approximate area shown in Plate 4a was recently zoned by the State of California under the Alquist-Priolo fault-rupture hazard zone Act of 1972 (Bryant and Hart, 2007; CGS, 2014).

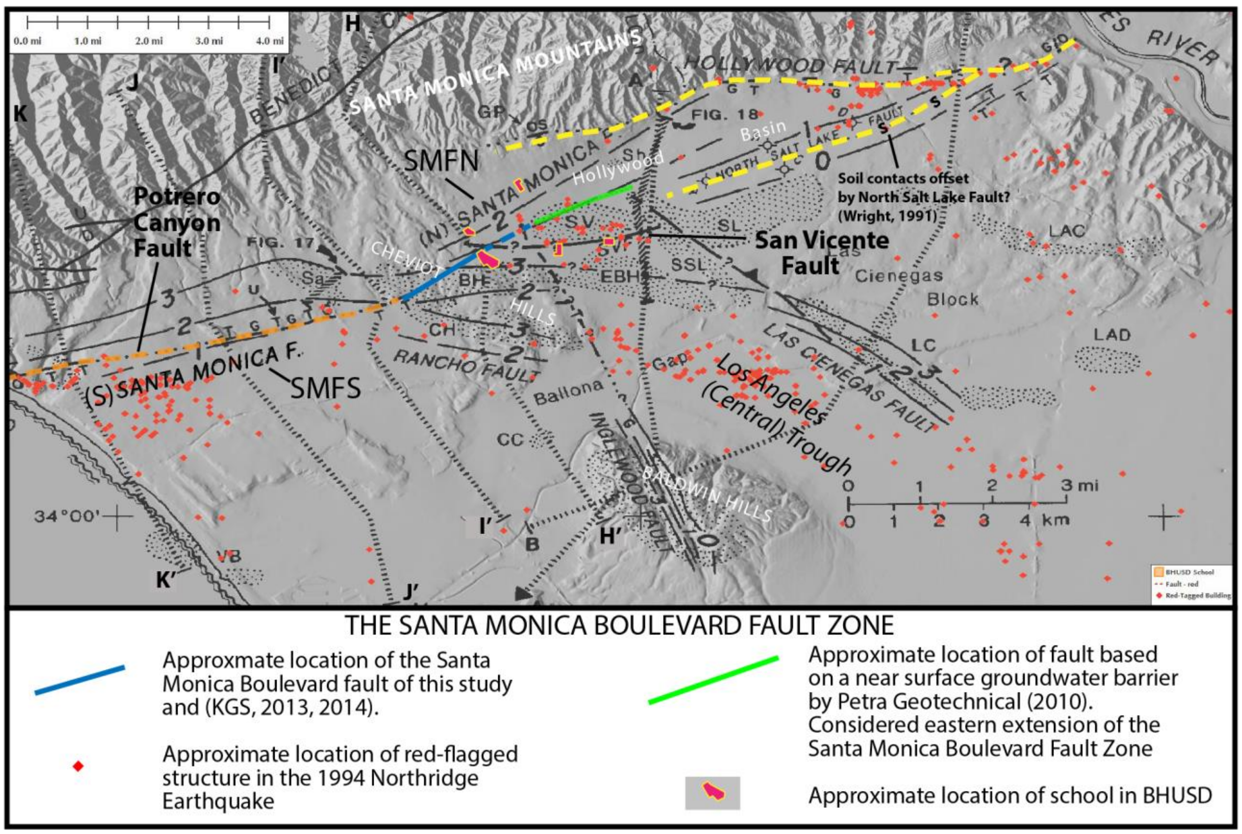
In a tectonic model proposed by Davis et al., (1989), the Hollywood Fault zone was proposed to be an upper crust, dominantly reverse fault that connects at depth with the Santa Monica-Elysian Park Thrust Fault Ramp beneath the Santa Monica Mountains. This may have been the case during the Pliocene through early Pleistocene; however, most data suggest that the Hollywood Fault has dominantly exhibited left-lateral displacement (Dolan et al., 2000b; Lindvall et al., 2003) since the end of the early Pleistocene. It is likely that the Hollywood Fault does not accommodate significant shortening, and that other faults and folds in the region are accommodating compressional strain along the TRSB Hollywood Fault segment.

Santa Monica Fault North of Wright (1991)

The Santa Monica Fault North (SMFN) of Wright (1991) trends approximately east-northeast from the Cheviot Hills into the central Hollywood Basin (Figure 7 and Plate 4a). This fault zone crosses the boundary between the Potrero Canyon-Santa Monica Fault Segment in the west, and the Hollywood Fault Segment in the east. The boundary between these fault segments is along the eastern Cheviot Hills along the northwestern project of the Newport-Inglewood Fault. The Santa Monica Fault North dips steeply to the north and occurs near the northern limits of numerous oil fields (West Beverly Hills, San Vicente, and Salt Lake). Tsutsumi et al. (2001) identified the Santa Monica Fault North in the Cheviot Hills but did not extend the fault east of the Cheviot Hills. Wright (1991) identifies the upper limits of the fault extending to a depth of approximately 0.6 km. In contrast, Tsutsumi et al. (2001) extends the SMFN to the surface to coincide with fault scarps identified by Dolan and Seih (1991), Dolan et al. (1997) and Dolan et al. (2000a), which is the Santa Monica Boulevard Fault in this study. A northeast striking reverse-separation fault identified by the California Division of Oil and Gas (1998, page 456) occurring along the northern limits of the San Vicente Oil Field likely represents the Santa Monica Fault North. Further to the east, within the eastern Hollywood Basin, Hildenbrand et al. (2001) utilizing gravity data identifies a fault that may represent the Santa Monica Fault North (Plate 3 and Plate 4a). However, an evaluation of the Hoots (1931) topographic-geologic map does not indicate any geomorphic expression on the relatively plainer alluvial fan surface above the surface projection of the Santa Monica Fault North.

As discussed in the body of the report, the evaluation by Wright (1991) and Tsutsumi et al. (2001) that the Santa Monica Fault North does not extend to the surface and does extend to the surface respectively, may both be correct because they identified two different fault that both exist. The Santa Monica Fault North of Wright (1991) likely occurs as a blind, reverse dip-slip fault that exhibited most of its compressional shortening history during the Pliocene through early Pleistocene when the fault essentially became inactive. The Santa Monica Fault North of Tsutsumi et al. (2001) is a steeply north-dipping left-lateral strike-slip fault that connects with the Santa Monica Fault North at a depth of ~0.6 to 1 km. This fault is referred to herein as the Santa Monica Boulevard Fault (SMBF), which developed approximately 1 Ma. The SMBF is proposed to have developed when the style of slip switched from oblique left-lateral reverse to dominantly left-lateral.

Figure 7: Map of the northwestern Los Angeles Basin showing fault and oil subsurface data from Wright (1991), the location of the Santa Monica Boulevard Fault from KGS (2014), and a proposed fault from Petra Geotechnical, Inc. (2010) proposed herein to be the eastern extension of the Santa Monica Boulevard Fault. The approximate locations of red-tagged structures from the 1994 Northridge Earthquake are also shown.



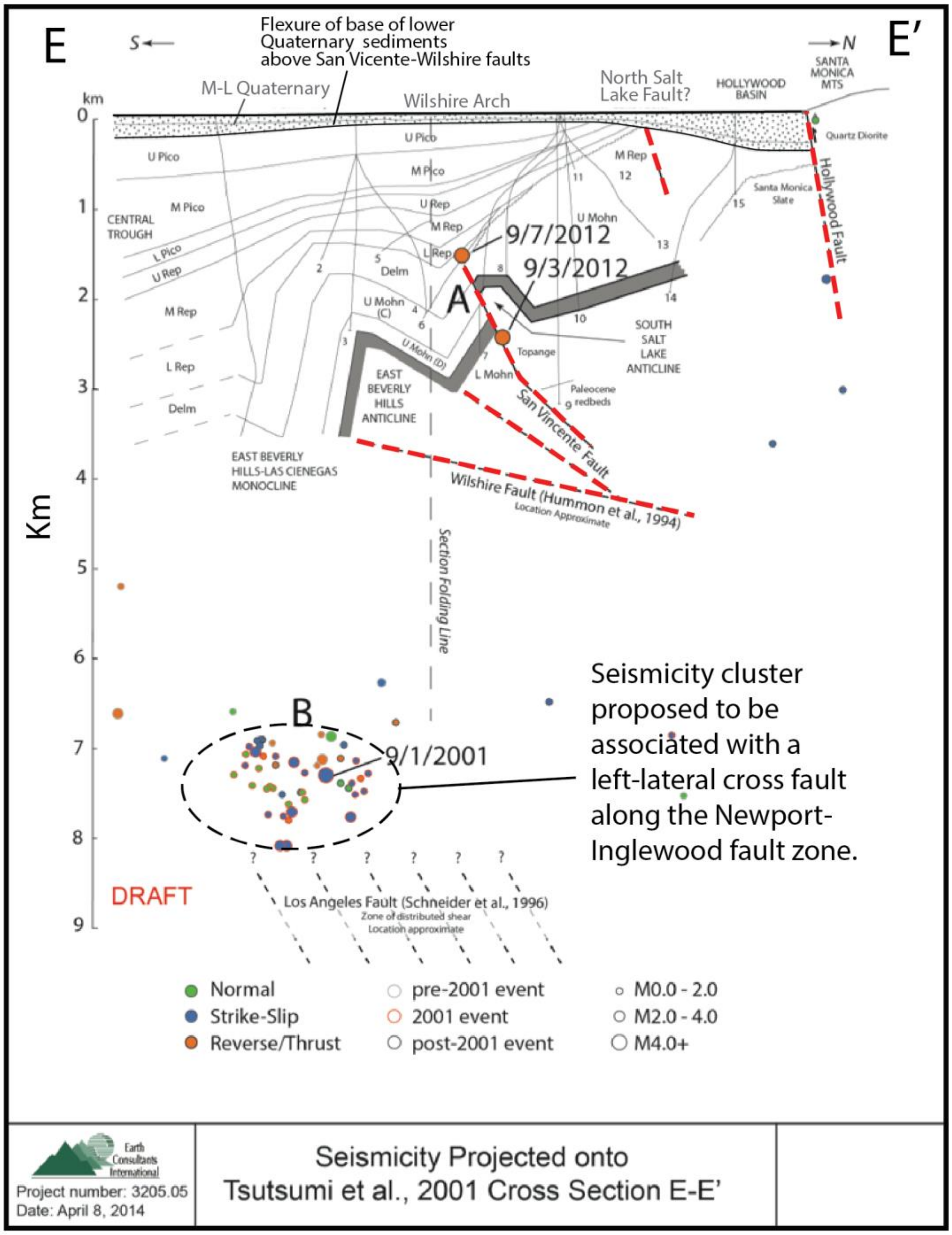
San Vicente Fault

Wright (1991) and Tsutsumi et al. (2001) identify the San Vicente Fault (SVF) as an east-west to northeast trending, north-dipping reverse fault along the boundary between the San Vicente and East Beverly Hills oil fields to the north and south respectively (Figure 7, Figure 8, Plate 3 and Plate 4a). The western end of this fault zone extends into the southern BHUSD (Plate 3). Wright (1991) indicates that the SVF offset and folded oil bearing Miocene sediments but is overlain by unfaulted Pliocene (Repetto age) sediments across an erosional surface. Wright (1991) does not show Holocene age deformation associated with any approximately east-west trending compressional structures in the region of the SVF.

Tsutsumi et al. (2001) indicates that the SVF is a primarily east striking, blind fault extending through the San Vicente and South Salt Lake oil fields. Similar to Wright (1991), Tsutsumi et al. (2001) indicates that the SVF was a normal fault during the Miocene and that the western portion of the SVF was re-activated as a reverse fault during the latest Miocene to early Pliocene (Figure 9). Tsutsumi et al. (2001) extends the SVF to a depth of approximately 1 km and indicates that it displaces latest Miocene to early Pliocene sediments in the west, but only late Miocene sediments toward the east. However, sediments as young as mid-Quaternary overlying the blind SVF are shown to be deformed into a south-dipping monoclonal-arch structure (Figure 8), which is similar to that shown by Hummon et al. (1994). Tsutsumi et al. (2001) indicate that active tectonic shortening is likely occurring south of the SVF associated with the development of the East Beverly Hills-Las Cienegas Monocline along the northeastern side of the Los Angeles Central Trough (Plate 3 and Plate 4a). Although Tsutsumi et al. (2001) indicate that the western SVF likely ceased activity in the Pliocene (~3.6 Ma; Figure 9), deformed mid-Quaternary sediments above the blind fault suggest it may be active. In addition, Earth Consultants International (ECI) evaluated of two relatively small earthquakes occurring on September 7 and 9th, of 2012 in very close proximity to the mapped location of the SVF of Tsutsumi et al. (2001) that suggest that the western SVF may be active (Figure 8). If the SVF is active, it may be accommodating dominantly left-lateral displacement which would tend to not fold sediments as readily as a reverse dip-slip fault.

Wright (1991) indicates that the SVF Fault may exist in the eastern Cheviot Hills near Century City (Plate 3). It seems possible that this fault may coincide with the Santa Monica Fault (S Strand, Branch A and B) of Tsutsumi et al. (2001) shown on their cross section D-D'. If this is the case, then the SVF may extend across the boundary between the Potrero Canyon-Santa Monica Fault Segment and the Hollywood Fault Segment (Figure 2).

Figure 8: Modified Cross Section E-E' of Tsutsumi et al. (2001) showing the locations of the Wilshire, San Vicente, North Salt Lake, and Hollywood Faults. The approximate location of two small earthquakes provided by Earth Consultants International (see Figure 41 for cross section location). These earthquakes may have occurred on the western portion of the San Vicente Fault. Seismic Cluster B (black dashed oval area) with the largest earthquake event representing that of September 1, 2001.



East Beverly Hills-Las Cienegas Monocline and Los Angeles Central Trough

Numerous deep, northward dipping blind thrust faults (ramps), some of which are the same faults but with different names are considered responsible for the development of the East Beverly Hills-Las Cienegas Monocline (EBHLCM) and associated Los Angeles Central Trough (LACT) to the southwest (Plate 3 and Plate 4a). The EBHLCM and LACT trend north-northwest essentially parallel to structures within the Peninsular Ranges (PR). The reverse/thrust faults considered responsible to create the EBHLCM and LACT include the San Vicente (discussed earlier), Wilshire-Las Cienegas, Puente Hills thrusts (numerous fault segments), the Compton-Los Alamitos, and possibly the poorly mapped Los Angeles Fault of Schneider et al. (1996). The San Vicente Fault is considered inactive since the early Pleistocene suggesting the reverse faulting compressional deformation has migrated toward the south as proposed by Tsutsumi et al. (2001). Most if not all of these thrust ramp faults are presumed to connect at depth with the regional, shallow northeast dipping Lower Elysian Park Detachment (décollement) Fault (LEPF; Plate 1 and Plate 2).

The Wilshire Fault occurs below the San Vicente Fault and above the Los Angeles décollement fault (Figure 8) in the northwestern region of the EBHLCM. This is the region of the San Vicente and Las Cienegas Faults shown on Plate 1 and Plate 2. The Wilshire Fault was proposed by Hummon et al. (1994) and Hummon (1994), but may be the same fault as the Las Cienegas Fault (see Dolan et al., 2001), or possibly the northern Puente Hills Thrust segment of Shaw and Shearer (1999). Hummon et al. (1994) identified a 10-35 degree north-dipping, N75E striking blind thrust fault projecting to depths of approximately 2 to 4 km referred to as the Wilshire Fault (Figure 8 and Figure 19). It should be mentioned that Lang (1994) indicate that their Wilshire Fault is the same as the previously recognized 6th Street Fault identified by Lang and Dreessen (1975). Hummon et al. (1994) indicates that movement across the Wilshire Thrust resulted in uplift and associated erosion of the hanging wall rocks leading to the development of the Wilshire Arch (the northern Los Angeles Shelf of Wright, 1991), the northwestern end of the southwest dipping EBHLCM along the northwestern side of the LACT, and a back limb fold associated with the Hollywood basin (Plate 3 and Plate 4a). The Wilshire fault may be the basal “reverse” fault for the overlying, steeply north-dipping San Vicente Fault discussed earlier, and may connect at depth with the proposed Los Angeles Fault (Figure 8 and 19). These findings suggest that a series of stacked reverse and thrust faults occur in the northwestern region of the EBHLCM.

The usage of the term Las Cienegas Fault has been used for decades within the oil industry (see Wright, 1991). The Las Cienegas Fault located southeast of the BHUSD is a northwest trending, north-dipping blind reverse fault (Plate 1; Plate 2, Figure 1, Figure 7). This fault exhibited normal displacement (normal fault) during the early Miocene to early Pliocene and was reactivated to exhibit reverse faulting between the early Pliocene to the early Pleistocene (see Wright, 991; Schneider et al., 1996 and Tsutsumi et al., 2001; Figure 9). Some publications indicate that reverse activity on the Las Cienegas Fault decreased and likely become inactive by the late Pliocene to early

Pleistocene (Wright, 1991; Schneider et al., 1996; Figure 9). However motion across the San Vicente and Las Cienegas Faults assisted in the initial development of the East Beverly Hills-Las Cienegas Monocline and associated northern Los Angeles Central Trough (LACT) (Plate 3 and Plate 4a; Schneider et al., 1996) and Holocene activity should not be ruled out. Schneider et al. (1996) proposed that an even deeper thrust fault occurs beneath the Las Cienegas Fault they refer to as the Los Angeles Fault, which assists in the development of the LACT. They indicate that the Las Cienegas Fault has become largely inactive as a secondary structure and current activity is dominantly occurring on the Los Angeles Fault at depth. It is possible that the proposed Los Angeles Fault is simply a deep thrust ramp emanating upwards from the regional Lower Elysian Park Fault (Plate 1 and Plate 2). Dolan et al. (2001) evaluating data regarding activity and slip rate of the Las Cienegas (Los Angeles) Fault System suggest that the fault may be active but that its slip rate may have diminished in the late Quaternary. Regardless of the fault names and exact locations, the data indicate the strong likelihood that active reverse-thrust faults are responsible for the development of the EBHLCM and LACT.

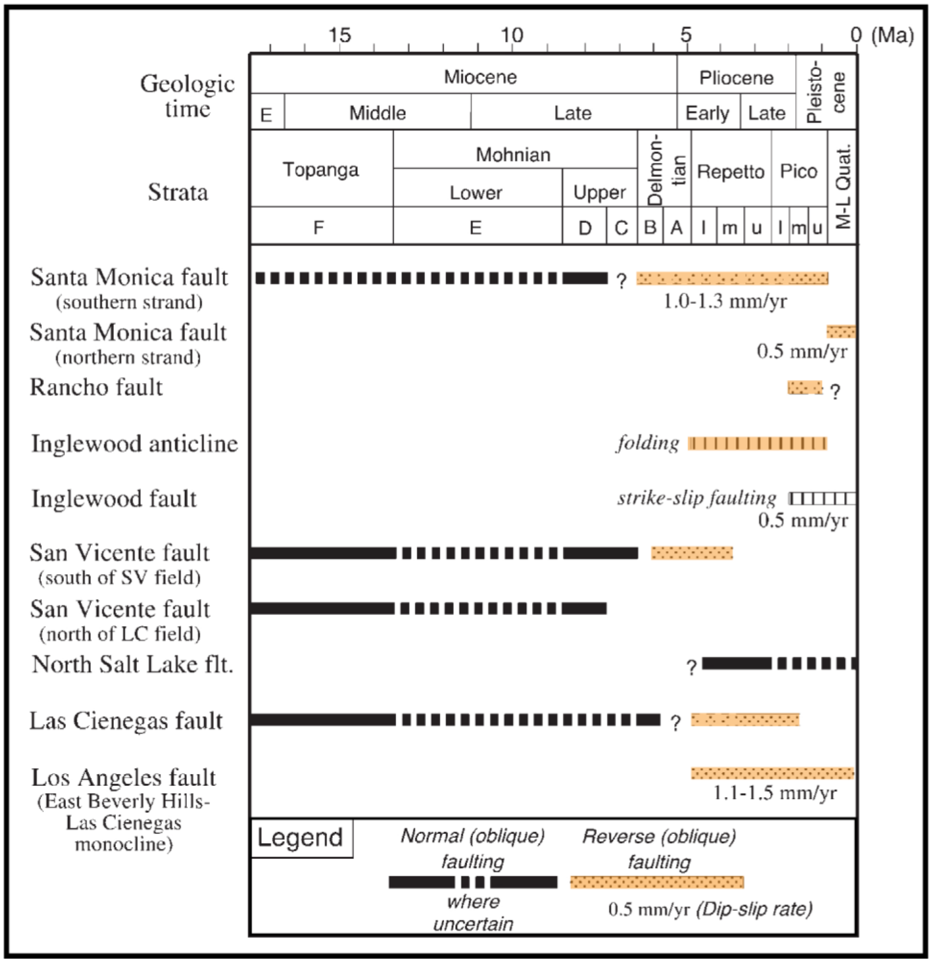
The detailed study by Shaw and Shearer (1999) identify various faults segments associated with the north-northeast dipping Puente Hills Thrusts along the northeastern edge of the LACT (Plate 1 and Plate 2). Shaw et al. (2002) indicates that the Puente Hills Blind-Thrust likely produced the Whittier Narrows (Mw = 6.0) earthquake and determined Quaternary slip rate across the fault zone of 0.62 to 1.28 mm/yr. Argus et al. (2005) evaluated Global Positioning system (GPS) geodesy and synthetic aperture radar (SAR) data throughout southern California. They determined that the region of Los Angeles in the vicinity of the Puente Hills Thrusts exhibit relatively high contractional strain rates relative to the southwest and northeast. These findings are consistent with development of the LACT and suggest that the faults and folds are active (also see Shaw et al., 2002).

The Compton-Los Alamitos Fault is located northwest of the Newport-Inglewood Fault Zone and southeast of the Puente Hills Thrust System (Plate 1 and Plate 2). Based on work by Wright (1991) and Yeats and Verdugo (2010), this fault dips toward the southwest and occurs along the southwestern edge of the LACT. Yeats and Verdugo (2010) suggest that the northwestern end of the Compton Thrust may connect with the Newport-Inglewood Fault Zone immediately southeast of the Baldwin Hills. They postulate that the Compton-Los Alamitos Fault is a reverse fault related to the Newport-Inglewood Fault Zone, analogous to numerous reverse faults identified along the western and eastern sides of the northern Newport-Inglewood Fault Zone. In contrast, their Compton-Los Alamitos Fault appears to be in the approximate location of an axial plane of a fault bend fold associated with a change in dip of the underlying Compton Thrust shown by Shaw and Suppe (1996), and Leon et al. (2009). The Compton-Los Alamitos Fault may connect with a bend in the relatively shallow dipping Compton Thrust which Shaw and Suppe (1996) show occurring at depths of approximately 5 km near Palos Verdes, to 10 km east of the Newport-Inglewood Fault (Plate 1 and Plate 2).

Many of the fault zones discussed in this section may connect at depth with the regional Lower Elysian Park Thrust (LEPT, detachment fault) which may reside at a depth of approximately 10 km, and extend offshore (Plate 1 and Plate 2; see Figure 47). The LEPT may be seismogenic; hence capable of producing earthquakes. For example, based on depths of historical seismicity, Richards-Dinger, and Shearer (2000) determined a seismogenic depth (depth that produce earthquakes) of approximately 15 to 20 km in the southern California region. In addition, Dolan et al. (1995) extends the LEPT in the region underlying the Puente Thrusts in the northeast to the Compton Thrust in the southwest as a potential seismic source. Although a regional detachment-décollement fault has not produced a major earthquake in historical times, the possibility that they are seismogenic should be considered in seismic hazard assessments.

It is difficult to assess which of these fault systems should be considered part of the Western Transverse Ranges (WTR) or the Peninsular Ranges (PR) tectonic terrains. The likely active Santa Monica Thrust under the Santa Ana Mountains trends approximately east-west, placing it within the WTR and north of the TRSBLL. The San Vicente Fault Zone (SVF) due to its northern location, and approximately east-west strike is likely associated with the WTR, and is located south of the TRSBLL. The SVF is considered inactive based on evaluation of non-folded Quaternary sediments overlying the fault, but it is possible that the western end of the SVF is active as an oblique left-lateral reverse fault. This portion of the fault zone is under the southern region of BHUSD. Shaw et al. (2002) indicate that the Puente Hills Blind Thrust System could be considered the southernmost reverse faults associated with the WTR. However, it is generally understood that the regional Lower Elysian Park Detachment Fault, which underlies the Puente Hills Thrust Fault is likely more associated with the PR compared to the WTR.

Figure 9. Estimated style and age of faulting along the Santa Monica (Potrero Canyon) Fault and Hollywood Fault segments by Tsutsumi et al. (2001).



4.0 Evaluation of net surface uplift and subsidence rates vs. fault activity

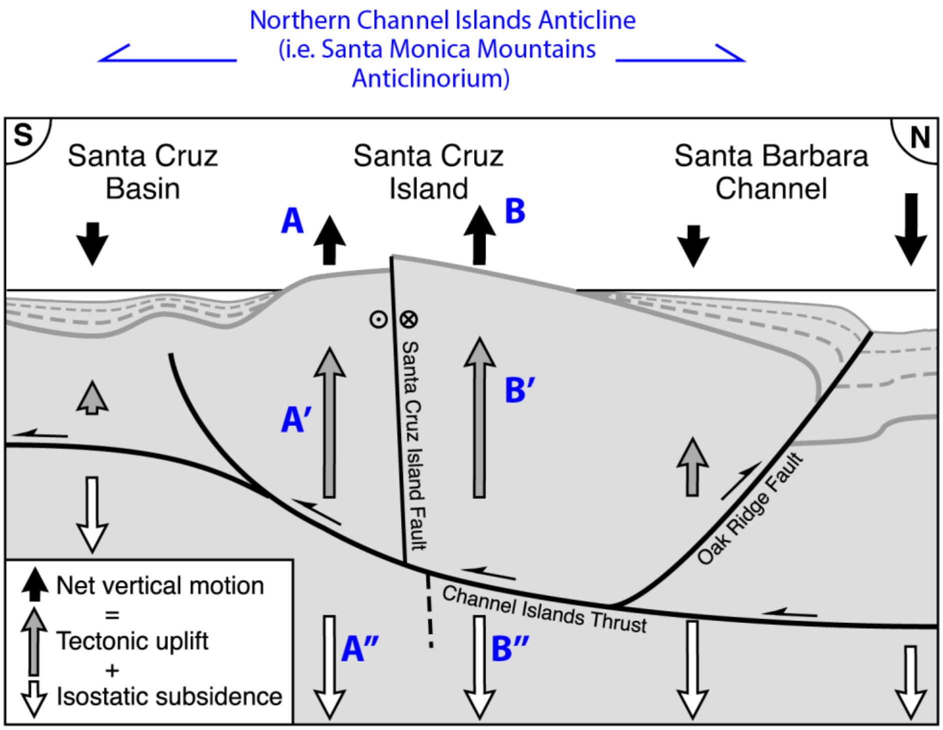
Sorlien et al. (2006, 2013) indicate that if deep displacement on the low-angle Santa Monica Bay Fault diminishes up-dip (toward the south) then it creates a broad forelimb in the hanging wall. That tilting may be the result of blind thrust displacement on the underlying Santa Monica Bay Fault (Sorlien et al., 2006, 2013). Tilting associated with a deep thrust allows for uplift of “mountains” and subsidence to the south on the southern limb of the “fold” (Sorlien et al., 2006). This style of tilting (folding) occurs south of the TRSBLL (i.e. Dume-Potrero Canyon-Santa Monica Boulevard Faults) similar to that proposed by Davis et al. (1989) south of the Hollywood Fault. Sorlien et al. (2006) however indicate that the Santa Monica Bay Fault appears to scarcely deform post Miocene strata south of the Dume-Santa Monica Fault system (south of the TRSBLL) but may be active at depth directly beneath the Santa Monica-Dume Fault. This report concludes that similar tilting has occurred south of the Potrero Canyon-

Santa Monica Boulevard Faults that resulted in erosion of the Santa Monica Arch (Figure 29, Figure 30 and Figure 33). The Santa Monica Arch is considered correlative in terms of development to the Wilshire Arch proposed by Hummon et al. (1994) east of the Newport-Inglewood Fault (Figure 19). In this model, the volume of sediments in the region of the Santa Monica Arch were uplifted, folded and tilted similar to folding south of the Santa Monica Mountains immediately east of the Newport-Inglewood Fault proposed by Davis et al. (1989).

Net uplift rates in regions exhibiting compression can be much less than that predicted by fault slip rates alone. Pinter et al. (2003) evaluating structures in the Channel Islands determined that if tectonic isostatic subsidence is occurring, that uplift rates determined from uplifted terraces can lead to fault slip rate errors of an order of magnitude (also, Sorlien et al. 2013). Thermal contraction of the crust after Miocene extreme extension and volcanism also contributes to the regional subsidence of Los Angeles and Santa Monica Basins (Mayer, 1991; Sorlien et al 2013; Nicholson et al. 1994; Atwater 1998). Pinter et al. (2003) determined that surface uplift (net uplift) is the difference between the upward tectonic driving force and the downward isostatic vector at any given point. In addition, they suggest that when isostatic subsidence is occurring, that net vertical motion above a thrust ramp is typically positive leading to the development of “mountains”, but that it is occurring at rates substantially less than the tectonic driving force (i.e. fault slip rates). These concepts are illustrated in Figure 10 that shows the vector for net uplift of Santa Cruz Island (blue A and B) is the difference of the actual tectonic uplift (blue A’ and B’) and local subsidence (blue A” and B”). This is a key process to convolve into uplift estimates provided from marine terraces (see Figure 2). In other words, if isostatic and thermal subsidence is occurring, relatively small estimates of uplift rates acquired from marine terraces may be an order of magnitude less that the actual tectonic uplift rates; which leads to an underestimate of fault slip rates at depth, which leads to underestimating local seismic hazards.

Pinter et al. (2003) also indicate however, that if the mass of eroded material from the uplifted area (i.e. mountains) is equal to the tectonic uplift rate, that this represents a “steady-state topography” indicating that net isostatic response is zero. In this case, the magnitude of vertical uplift (i.e. blue A’ and B’ in Figure 38) essentially equals the vector magnitude of isostatic subsidence (i.e. blue A” and B” in Figure 10). As Pinter et al. (2003) point out, this is likely the case for the Santa Monica Mountains near the City of Santa Monica based on findings by Meigs et al. (1999) estimating that the rate of mass removal from the Santa Monica Mountains is about equal to the tectonic uplift rate. This is a very important finding in terms of estimating seismic hazards associated with deep thrust ramps not only in the region of the City of Santa Monica, but also along the entire region south of the Santa Monica Mountains. This is because deep thrust ramps associated with the WTR has been identified south of the Hollywood Fault Segment (Figure 2). Some of these faults include: the Wilshire Fault (Hummon et al., 1994), the Los Angeles Fault (Schneider et al., 1996), and the Puente Hills Blind-Thrust (Shaw et al., 2002).

Figure 10: Modified schematic illustration from Pinter et al. (2003) of the components of vertical motion for the development of the Northern Channel Islands anticline, which is the western extension of the Santa Monica Mountains Anticlinorium of Davis and Namson (1989). The figure demonstrates that the net vertical uplift of the anticline (Blue A and B) is the difference of fault vertical uplift (blue A' and B') and isostatic subsidence (blue A" and B"). In the region of the Channel Islands, mass removal due to erosion is substantially less than the rate of tectonic uplift, which leads to net uplift. However, the vertical component of net uplift (blue A and B) is much less than would be estimated purely on fault slip rates alone.



Schematic illustration of the components of vertical motion on the NCI anticline. The surface topography rises at a rate equal to the tectonic driving force at any given point (slip rate on thrust fault times sine of fault dip) less the rate of isostatic subsidence. The uplift is local but the flexural isostatic response occurs over a broader area, with the result that net surface uplift is positive near the crest of the structure, but subsidence occurs on the flanks. North of the Oak Ridge fault, subsidence jumps up in rate because of the disappearance of uplift on the footwall of the thrust and because of the contribution from additional sediment loading in the basin.

APPENDIX B

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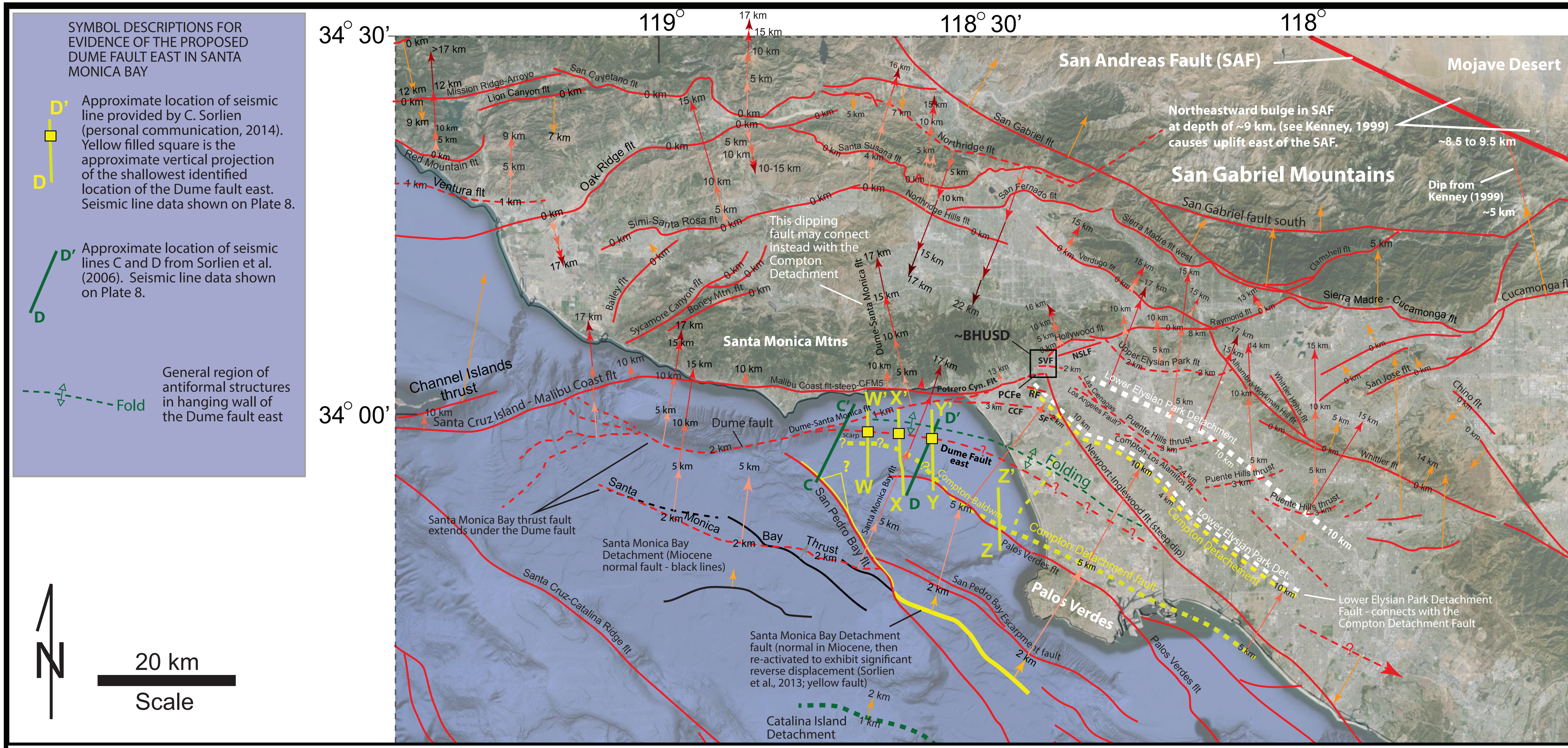


15 km
10 km
5 km
0 km
2 km

Depths of fault planes shown utilizing depth designation arrows in kilometers (km)

Fault. Solid line if the fault is believed to extend to depths shallower than 2 km.

Dashed lined faults are believed to not extend to depths shallower than approximately 1 to 2 km (depths of shallowest depth of the fault often provided on red dash line). Map location of blind faults are projected vertically upward from their shallowest mapped location. Note: The Lower Elysian Park Detachment and Catalina Detachment faults are shown as white, and other Miocene normal detachment faults are shown as black unless described differently.

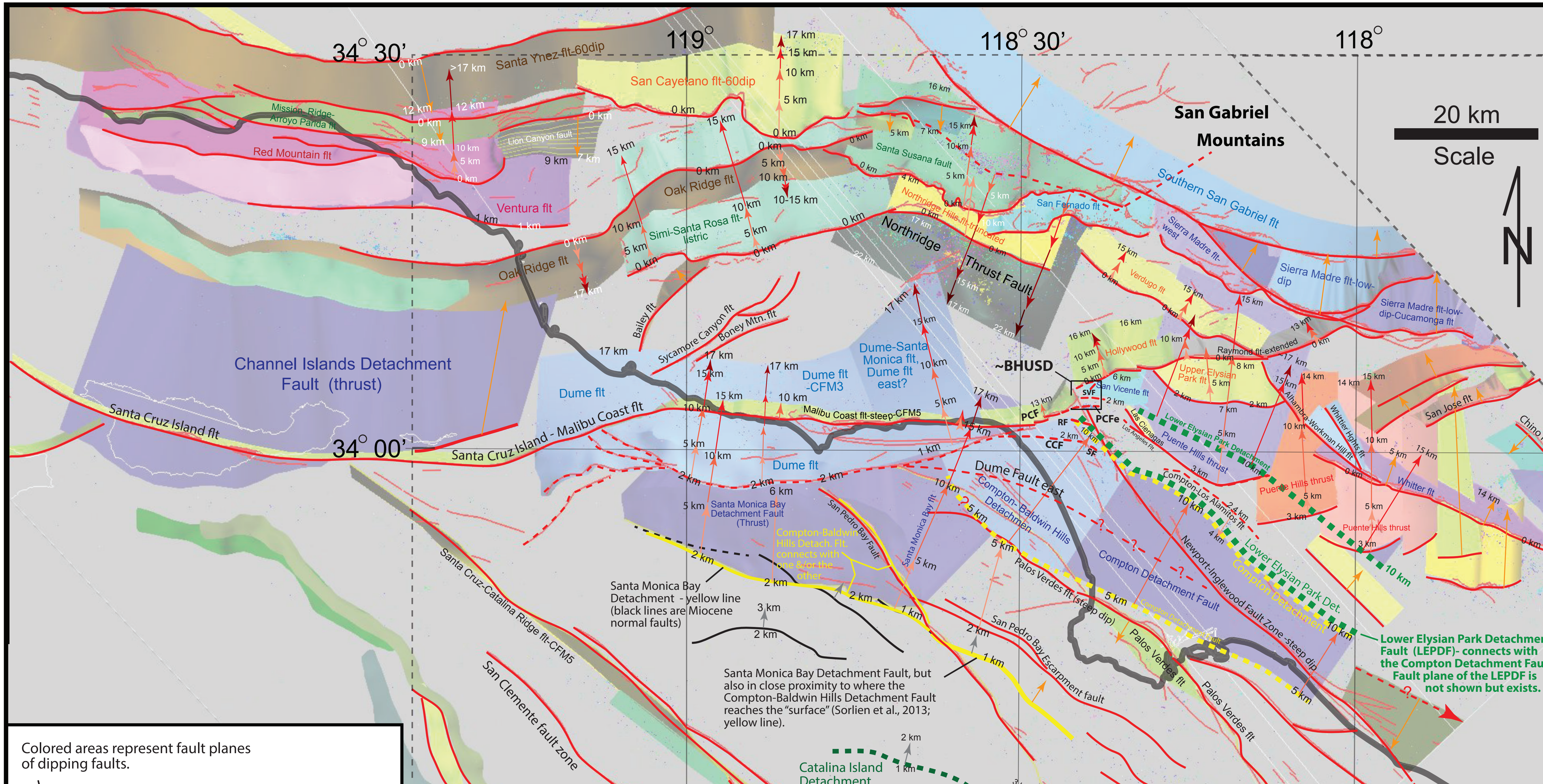
Approximate depth of fault color designations. Arrow direction ~ dip of fault (accuracy of a km or two)

>/= 17 km
15 km
10 km
5 km
0 km

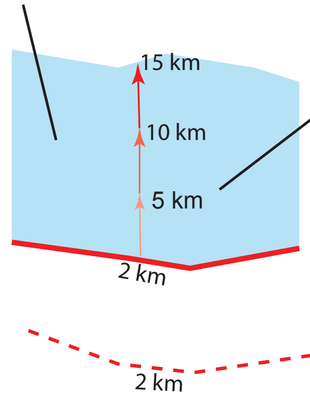
Notes: The Lower Elysian Park Detachment Fault (white dashed line) underlies all segments of the Puente Hills thrust faults (note 10 km depth for the Lower Elysian Park Detachment Fault vs ~3 km depth for the Puente Hills thrust fault segments). The Lower Elysian Park Detachment Fault connects with the Compton Detachment Fault (yellow line), which continues southwestwardto reach the "surface" west of Palos Verdes (solid yellow line).

Fault map modified from data obtained from Christopher Sorlien (personal communication, 2014, Sorlien et al., 2013) that provided the fault base map, fault names, and version of the Community Fault Model (CFM), dip directions, and depths. Exceptions include((i,e. faults that were added) the North Salt Lake Fault (**NSLF**), Potrero Canyon Fault (**PCF**), Potrero Canyon Fault east (**PCFe**), San Vicente Fault (**SVF**), Culver City Fault (**CCF**), Rancho Fault (**RF**); Sentous Fault (**SF**) and Compton -Los Alamitos Fault. The **Dume Fault east** proposed by M. Kenney and C. Sorlien.

Kenney GeoScience	CLIENT: BEVERLY HILLS UNIFIED SCHOOL DISTRICT	Job No. 723-11
	FAULT MAP OF WESTERN SOUTHERN CALIFORNIA AND OFFSHORE AREA INCLUDING DATA FOR PROPOSED DUME FAULT EAST IN SANTA MONICA BAY	Date: March 30, 2016 Drafted by: CS & MDK
		PLATE 1



Colored areas represent fault planes of dipping faults.

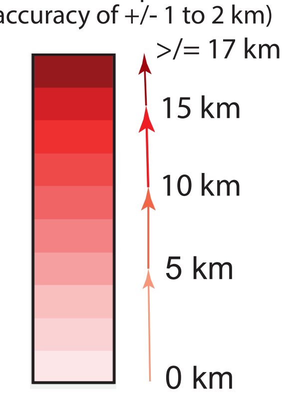


Depths of fault planes shown utilizing depth designation arrows in kilometers (km)

Fault. Solid line if the fault is believed to extend to within 1 kilometer of the surface.

Dashed lined faults are believed to not extend to depths shallower than approximately 1 to 2 km (depths of shallowest depth of the fault often provided on red dash line). Map location of blind faults are projected vertically upward from their shallowest mapped location. Note: The Lower Elysian Park fault and Catalina Detachment faults are shown as green. Compton and Compton-Baldwin Hills Detachment is shown as yellow.

Approximate depth of fault color designations. Arrow direction ~ dip of fault (accuracy of +/- 1 to 2 km)



Notes: See notes on Plate 1.

Note: Most fault locations are from the various version of the California Fault Model (CFM). Some faults in the proximity of the BHUSD are added based on the findings in this report.

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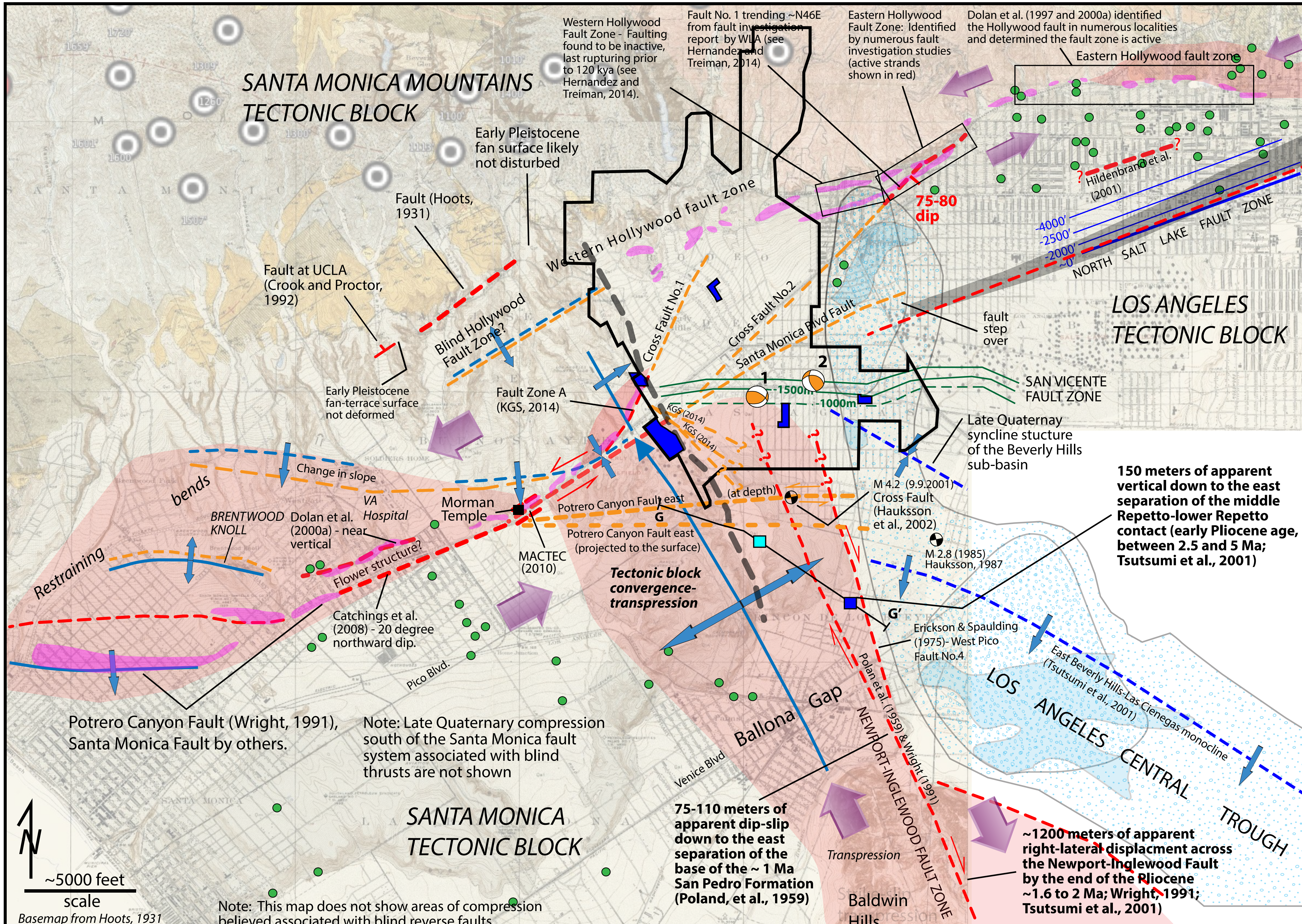
DEEP DETACHMENT AND THRUST RAMP FAULT MAP OF WESTERN TRANSVERSE RANGES AND NORTHERN PENINSULAR RANGES

Job No. 723-11

Date: March 30, 2016

Drafted by: CS & MDK

PLATE 2



SYMBOL DESCRIPTIONS

- Approximate location of published fault in the near surface
- Approximate location of postulated fault in the near surface
- Approximate location of the West Beverly Hills Lineament
- -2000' 0' — Approximate location of structure contours for the North Salt Lake Fault from Hummon (1994). Depth in feet below the surface.
- Approximate region of historical subsidence proposed to be associated with the North Salt Lake Fault (Hill et al., 1979).
- -1500m -1000m — Approximate location of structure contours of the western end of the blind San Vicente Fault (Tsutsumi et al. 2001).
- Approximate location of geomorphic "fault" scarps of Dolan and Sieh (1992) along the Santa Monica and Hollywood fault zones
- G G' — Approximate location of Tstusumi et al. (2001) Cross Section G-G'. Dark blue box indicates ~vertical projection of their Newport-Inglewood Faut; cyan box indicates their surface projection of Newport-Inglewood fault to the West Beverly Hills Lineament.
- Late Quaternary anticlinal structure. Arrow on fold axis indicates plunge direction. Dashed fold axis indicates likely not active during late Pleistocene
- Late Quaternary monoclinal structure
- Approximate epicenter location of historical earthquake focal mechanism. Magnitude, year of event and data source provided.
- 2 — Approximate epicenter location of historical earthquake. Event 1 occurred on 9.7.2012, Mw 3.4 at 1.5 km depth. Event 2 occurred on 9.3.2012, Mw 3.2 at 2.4 km depth. Depth evaluation by ECI (personal com.) of these events shows that they are located on the San Vicente Fault of Tsutsumi et al. (2001)
- Generalized movement direction of tectonic block bounded by fault zones
- Generalized regions of Quaternary uplift. Not all of these regions remain active.
- Approximate limits of the Beverly Hills Unified School District (City of Beverly Hills)
- Approximate location of school in the Beverly Hills Unified School District

Mendenhal, 1905 Groundwater data (WSIP Report No. 139)

- Region of pumping near surface groundwater (saturated)
- Region of artesian wells in 1905
- Approximate region of original artesian wells.
- Location of pumping plants in 1905

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CLIENT:
BEVERLY HILLS UNIFIED SCHOOL DISTRICT

NEAR SURFACE QUATERNARY TECTONIC MAP OF THE NORTHWESTERN LOS ANGELES BASIN

Job No. 723-11
Date: March 30, 2016
Drafted by: MDK

PLATE 3

FAULT ACTIVITY COLOR DESIGNATIONS

Fault zone or near surface fold structure known to be or considered Active based on existing data (Holocene activity).

Blind compressional fault (thrust ramp) that deforms mid Quaternary sedimnts likely less than 1 Ma, and is "Potentially Active", but designated as Active in this report for seismic hazard evaluation purposes.

Fault zone that was likely active in the Quaternary, but Holocene activity unknown (Potentially Active) .

Fault zone that is likely Inactive based on the existing data. For near surface faults, this indicates evidence exists demonstrating no surface rupture has occurred during the Holocene, and for blind faults that the existing data suggests the fault has not been Active of over 1 million years.

Approximate fault location at depth or at the surface from the Community Fault Model (Plesch et al, 2007), or Green et al. (1975) extending from offshore to the Santa Monica area. Activity color designations apply.

Fault Symbols:

U - side that went up - apparent displacement across fault

D - side that went down - apparent displacement across fault

Barb points down dip on faults exhibiting apparent reverse displacement

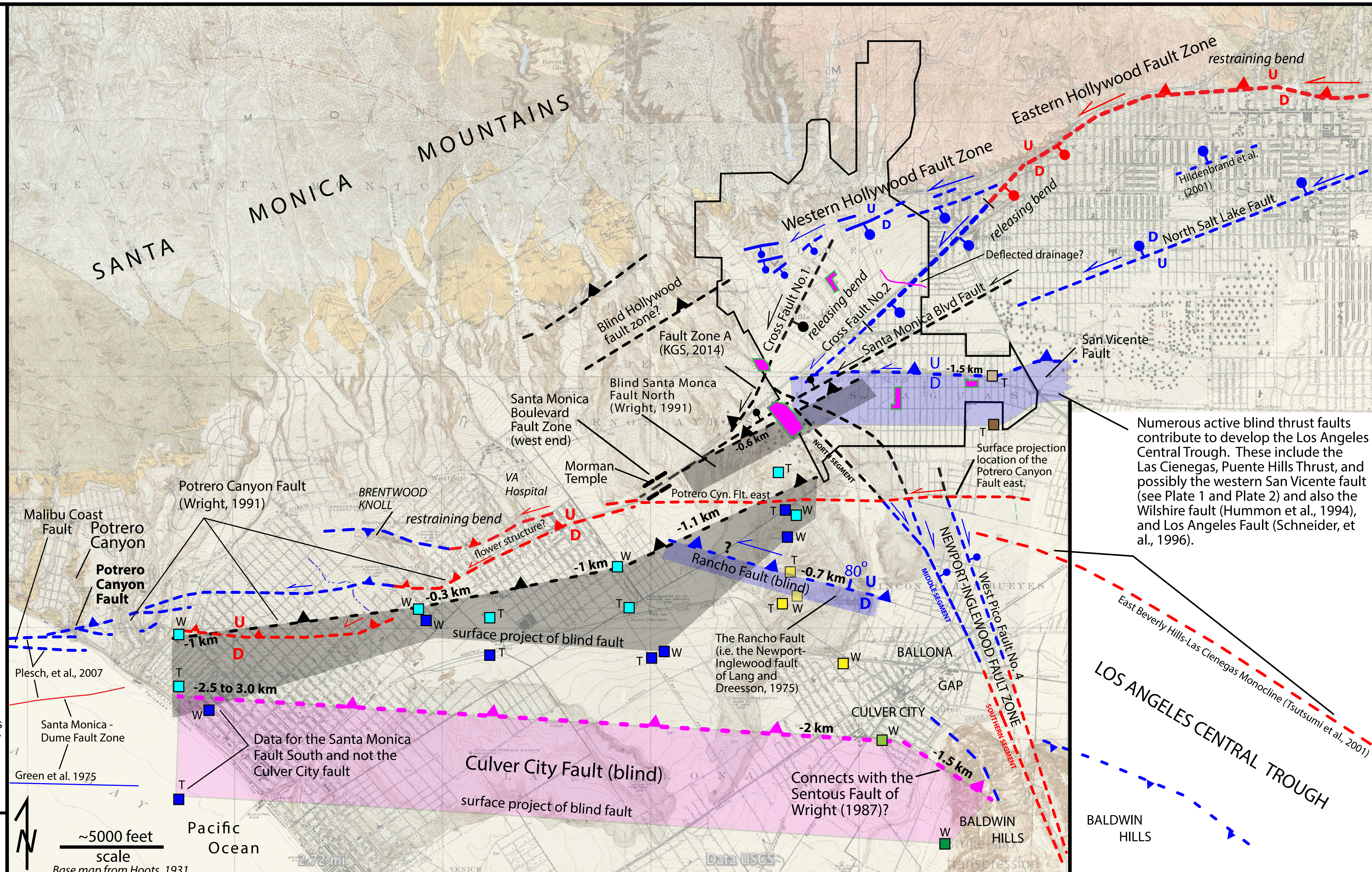
Ball points down dip on faults exhibiting apparent normal displacement

Arrow indicates motion of strike-slip displacement.

BHUSD

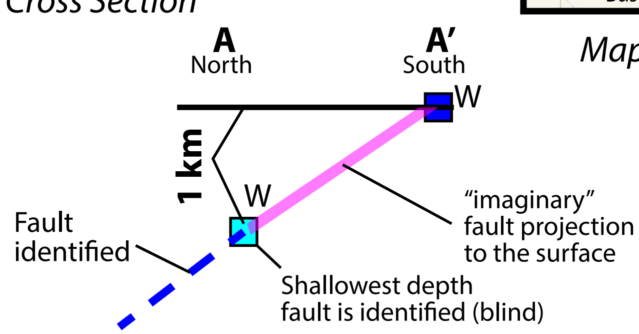
Approximate limits of the Beverly Hills Unified School District (City of Beverly Hills)

Approximate location of school in the Beverly Hills Unified School District

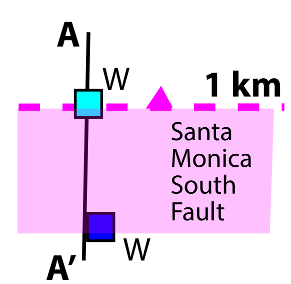


SYMBOL DESCRIPTIONS FOR BLIND FAULTS

Cross Section

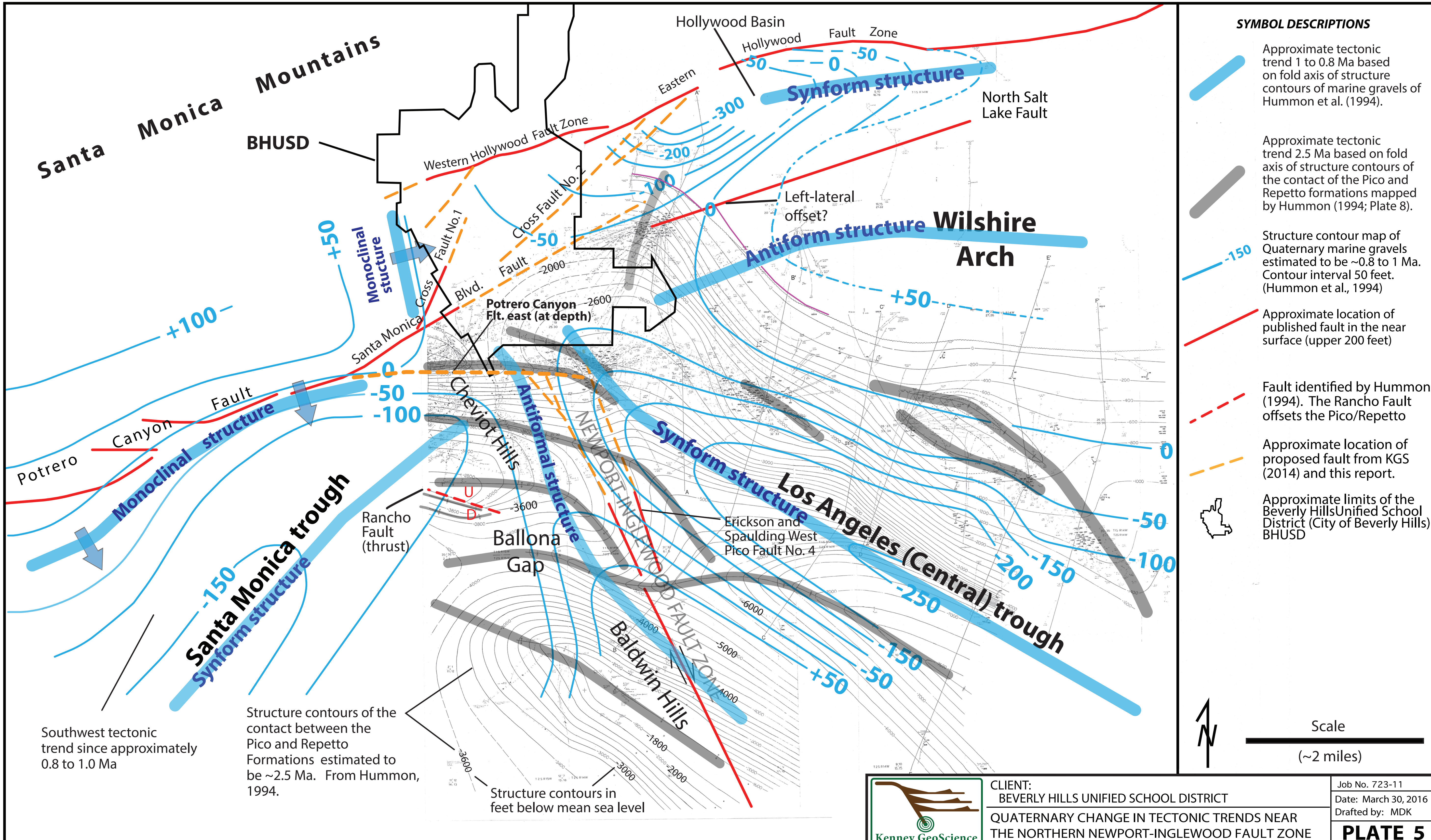


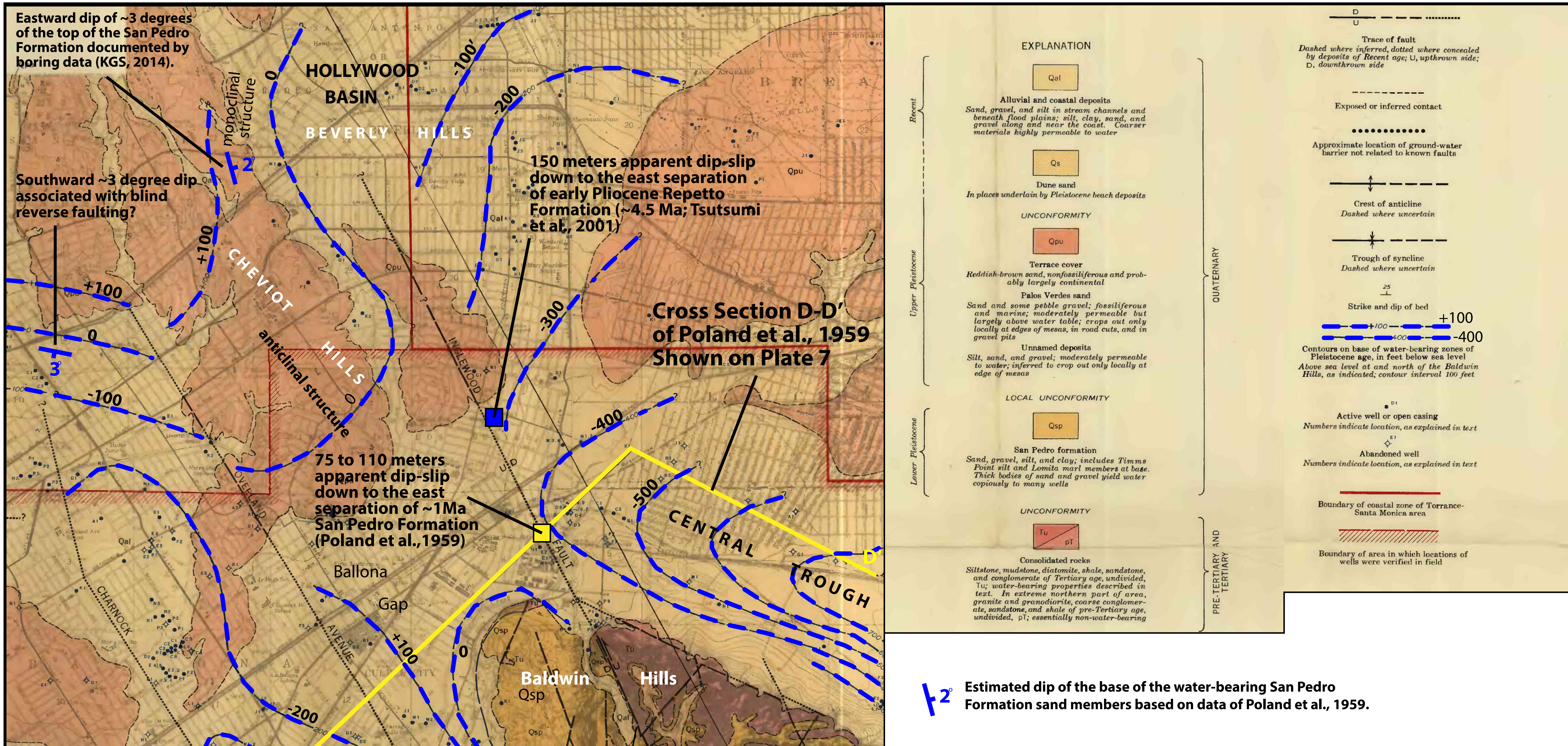
Map View



Blind thrust (reverse) fault projection from shallowest known location of the fault to the surface (hence, imaginary). Dashed line indicates the vertical surface projection of the shallowest depth that blind fault is known to exist. Hence, the shaded areas represent an "imaginary" fault extended through the upper most crust to the surface utilizing an approximate dip as that identified in published cross sections (see cross section diagram to the left). Ligher shaded squares represent location of shallowest depth of a blind fault identified by Wright (W, 1991) or Tsustsumi et al. (T, 2001) on their cross sections. Darker shaded square represents the surface project of the blind faults to the surface utilizing the dip of the fault they show.

Kenney GeoScience	CLIENT: BEVERLY HILLS UNIFIED SCHOOL DISTRICT	Job No. 723-11 Date: March 30, 2016 Drafted by: MDK
	FAULT ACTIVITY DESIGNATION MAP OF THE NORTHWESTERN LOS ANGELES BASIN	PLATE 4


Santa Monica Mountains
BHUSD
Hollywood Basin
Hollywood Fault Zone
Eastern
Western Hollywood Fault Zone
Synform structure
North Salt Lake Fault
Cross Fault No.2
Cross Fault No.1
Monoclinal stucture
Left-lateral offset?
Antiform structure
Wilshire Arch
Santa Monica Blvd. Fault
Potrero Canyon Flt. east (at depth)
Potrero Canyon Fault
Monoclinal structure
Cheviot Hills
Antiformal structure
NEWPORT-INGLEWOOD FAULT ZONE
Synform structure
Los Angeles (Central) trough
Santa Monica trough
Synform structure
Rancho Fault (thrust)
Ballona Gap
Erickson and Spaulding West Pico Fault No. 4
Baldwin Hills
Southwest tectonic trend since approximately 0.8 to 1.0 Ma
Structure contours of the contact between the Pico and Repetto Formations estimated to be ~2.5 Ma. From Hummon, 1994.
Structure contours in feet below mean sea level
SYMBOL DESCRIPTIONS
Approximate tectonic trend 1 to 0.8 Ma based on fold axis of structure contours of marine gravels of Hummon et al. (1994).
Approximate tectonic trend 2.5 Ma based on fold axis of structure contours of the contact between the Pico and Repetto formations mapped by Hummon (1994; Plate 8).
Structure contour map of Quaternary marine gravels estimated to be ~0.8 to 1 Ma. Contour interval 50 feet. (Hummon et al., 1994)
Approximate location of published fault in the near surface (upper 200 feet)
Fault identified by Hummon (1994). The Rancho Fault offsets the Pico/Repetto
Approximate location of proposed fault from KGS (2014) and this report.
Approximate limits of the Beverly HillsUnified School District (City of Beverly Hills) BHUSD
Scale
(~2 miles)
Kenney GeoScience
CLIENT:
BEVERLY HILLS UNIFIED SCHOOL DISTRICT
QUATERNARY CHANGE IN TECTONIC TRENDS NEAR THE NORTHERN NEWPORT-INGLEWOOD FAULT ZONE
Job No. 723-11
Date: March 30, 2016
Drafted by: MDK
PLATE 5



2° Estimated dip of the base of the water-bearing San Pedro Formation sand members based on data of Poland et al., 1959.

0 1 2

Scale (miles)

N

1200 meters right-lateral separation by the end of the Pliocene (Wright, 1991, Tsutsumi et al., 2001).

Geologic-Hydrologic map (Plate 1) from Poland et al., 1959

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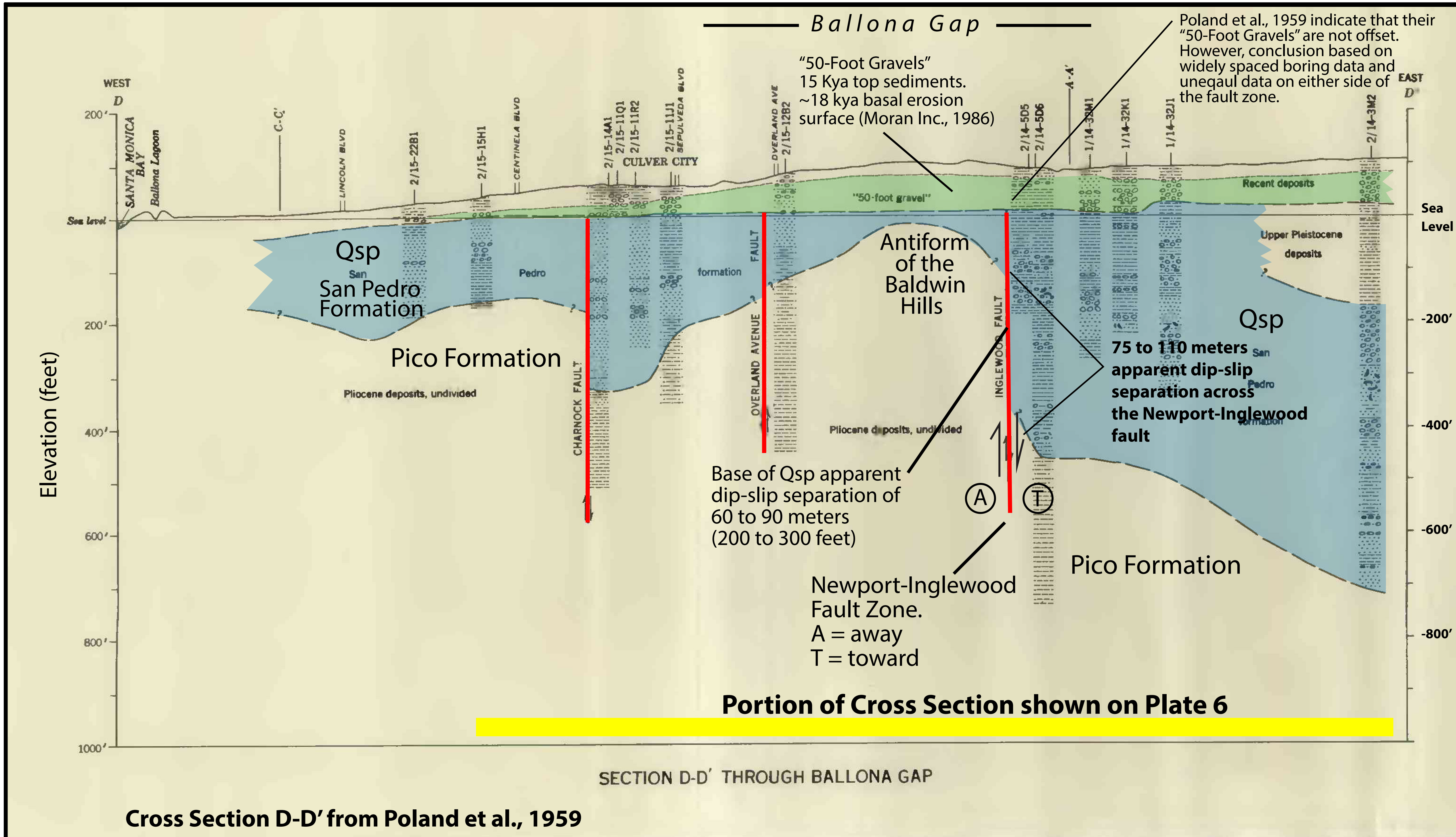
	GEOLOGIC MAP AND APPROXIMATE BASE OF THE FRESH WATER-BEARING SAN PEDRO FORMATION SAND MEMBER IN THE BALLONA GAP REGION FROM POLAND ET AL., 1959	Date: March 30, 2016 Drafted by: MDK
		PLATE 6



0 1 2 3

Horizontal scale (miles)
Vertical scale = 20X Horizontal

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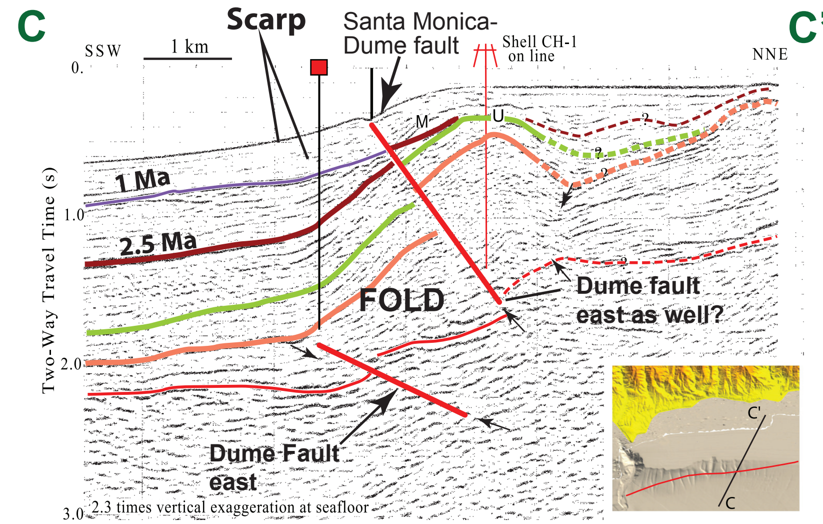
GEOLOGIC CROSS SECTION D-D' IN THE BALLONA GAP FROM POLAND ET AL., 1959

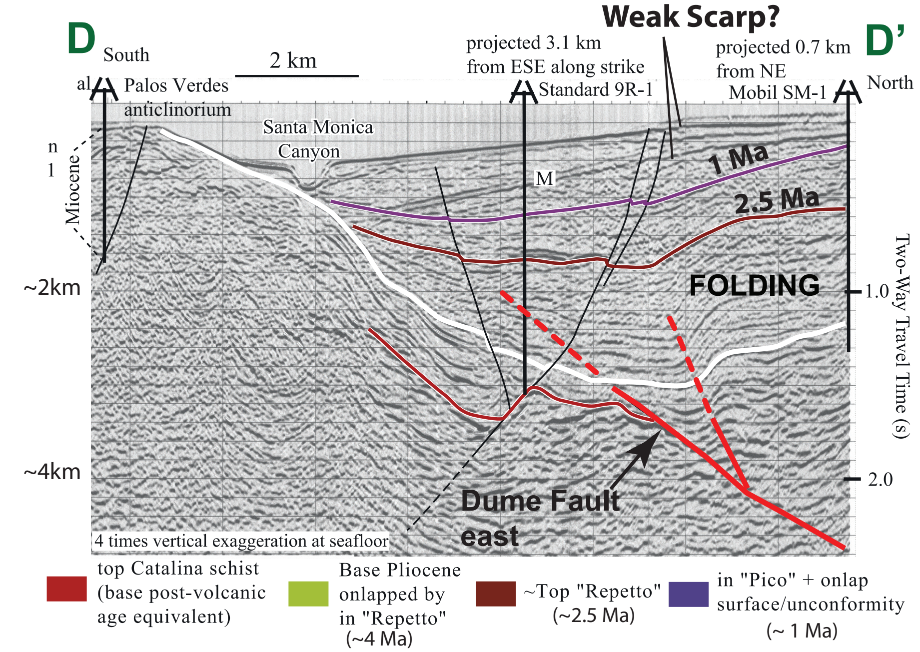
Job No. 723-11

Date: March 30, 2016
Drafted by: MDK

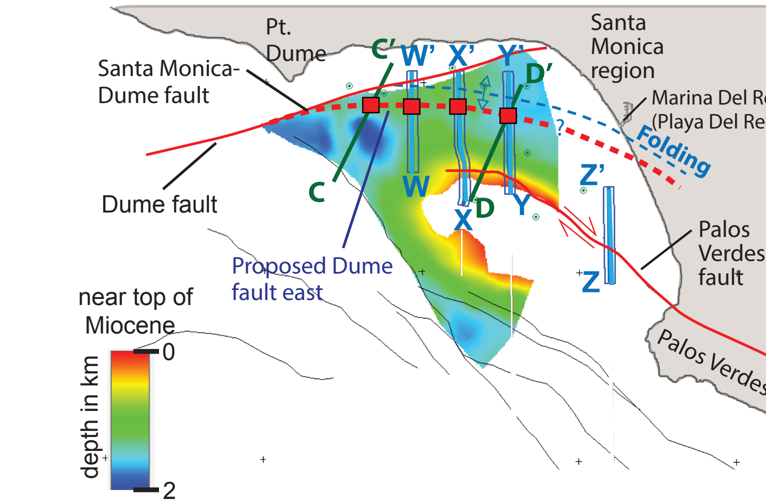
PLATE 7



Modified from Sorlien et al. (2006)

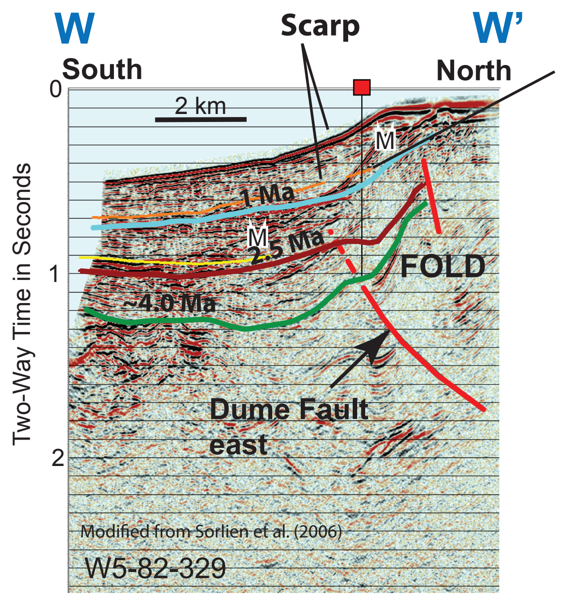


Vertical exaggeration:
Seismic Profiles **C** and **D**: 2.3x vertical exaggeration at seafloor

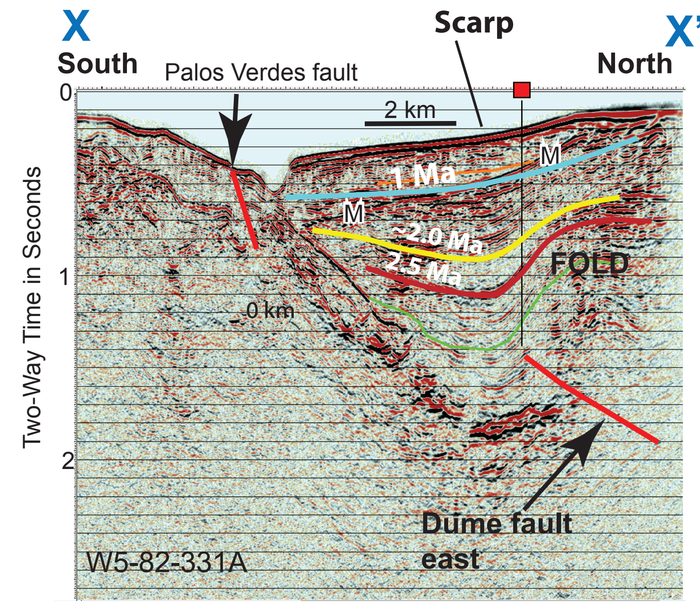


Vertical projection location of the Dume Fault east on Cross Sections

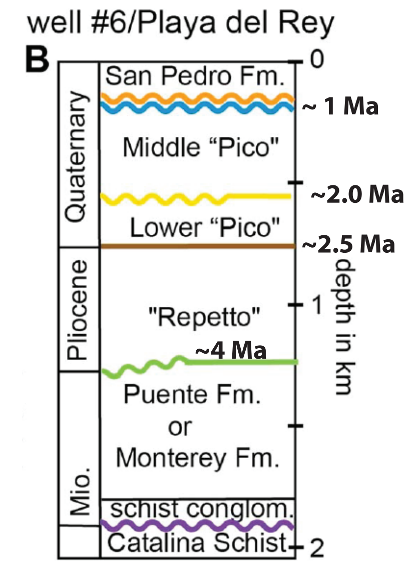
Seismic line locations **W**, **X**, **Y** and **Z** from C. Sorlien (personal communication, 2014), and **C** and **D** from Sorlien et al. (2006).

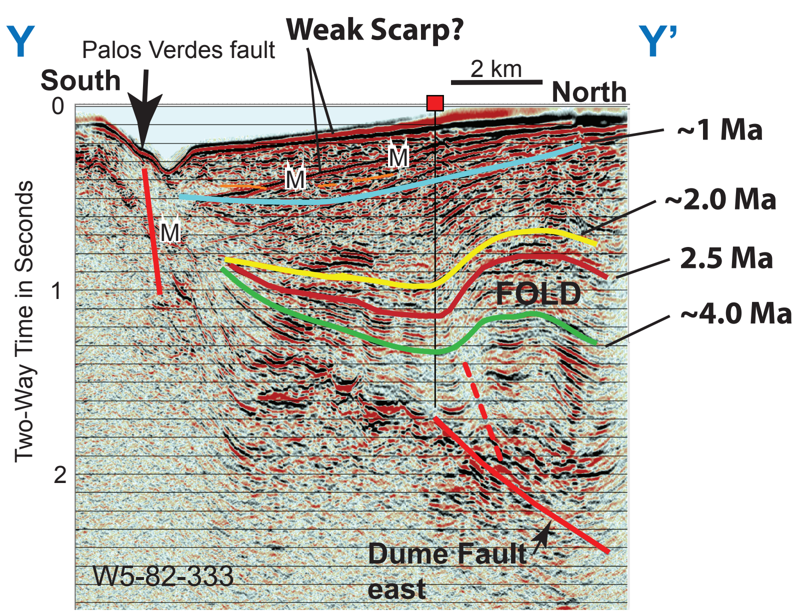


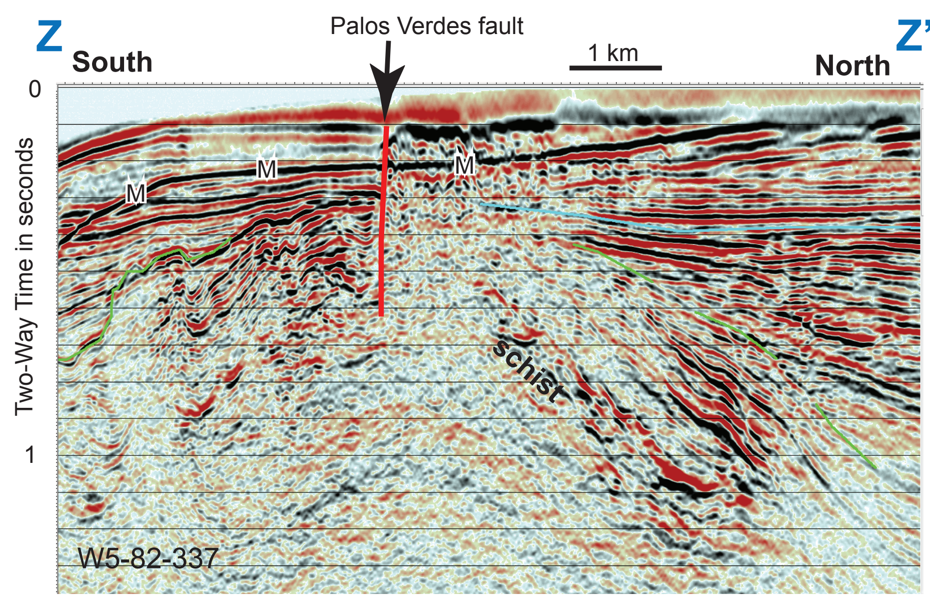
~1Ma sediments deformed, and likely younger as well.



Stratigraphy for Seismic Lines (profiles) W through Z'

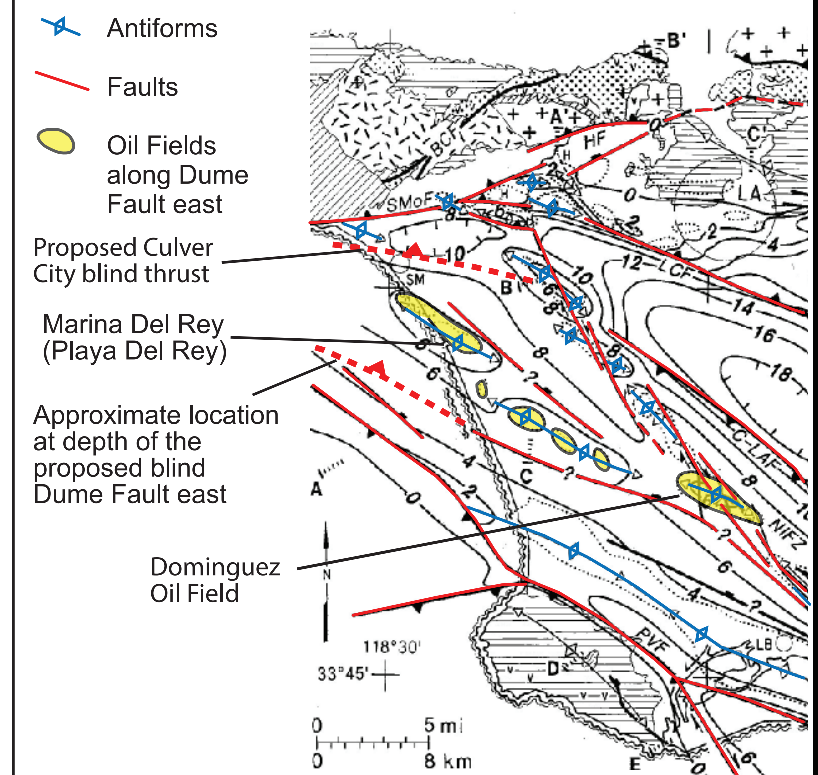






Dume Fault east occurs north of seismic line Z-Z'

Vertical exaggeration:
Sections **W** through **Z**: 4x vertical exaggeration at 2 km interval velocity (~vel in Pliocene)



Modified Figure 9 from Wright (1991) - Base of the Repetto Formation (early Pliocene ~4.5 ma). Structure contour depths in 1000 feet below sea level.

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EVIDENCE FOR THE PROPOSED DUME FAULT EAST IN SANTA MONICA BAY AND EXTENDING ONSHORE
Job No. 723-11
Date: March 30, 2016
Drafted by: CS & MDK
PLATE 8