

THE WHITTIER FAULT TREND: CROSS SECTIONS, STRUCTURE MAPS, AND WELL TOPS IN THE MAJOR OIL PRODUCING AREA OF THE NORTHEASTERN LOS ANGELES BASIN*

By

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PREFACE

Understanding the deep structure of the Los Angeles basin is critical to the assessment of the seismic hazard as well as the future petroleum potential in one of the most densely populated regions in the United States. In the center of the basin, that deep structure is hardly known because over 6.4 km of Pliocene and younger rocks have buried the rocks that record the early history of the basin. The acquisition of the modern seismic data that might reveal the deep structure has not been feasible in this densely populated area. Fortunately, just 50 km to the east, evidence of the character of the structure of the deep Los Angeles basin is accessible in the outcrops and wells of the Puente Hills area of the northeastern Los Angeles basin (NELAB). There, Miocene and older rocks have been uplifted along the Whittier fault by as much as 4.5 km since ca. 7-8 Ma by N-S shortening that is linked to the development of the San Andreas fault system. Thousands of oil wells have been drilled in the area, some to depths of more than 3 km.

Two recent papers together describe an integrated 3-D analysis of this unique window into the Los Angeles basin with the aim of developing a well-constrained geologic model to help in understanding the structural development and seismicity of the region. Bjorklund and Burke (2002) focus on a huge quantity of surface and subsurface data along the Whittier fault and introduce a three-phase model for the evolution of the active fault. Their model establishes relationships between early rifting and later folding and reverse faulting. Bjorklund, et al. (2002) review the evidence for Miocene extension in the NELAB. In that study, relationships established among volcanic rocks, active faults and mid-crustal structures revealed by P-wave tomography indicate that crustal heterogeneities may localize areas of high seismicity. This publication is a set of newly prepared maps, cross sections and tables that substantially supplement the material presented in the two already published papers. Other topics addressed in this publication include: (1) Sources and quality of data, (2) elaborations on previously published interpretations, and (3) aspects that may warrant further study.

The interpretations in this publication are based on data from a wide range of sources, including a significant body of interpreted data that has been held by oil companies. By making the original data of this publication readily accessible in a digital format, we hope to facilitate additional research that will result in the refinement and the enlargement of the existing database and greater public availability of privately held data.

Abbreviated Figure Captions (1-3)

(Note: Complete captions after **REFERENCES** and with the images.)

Figure 1. Index map of the greater Los Angeles basin.

Figure 2. Shaded relief map of northeastern Los Angeles basin.

Figure 3. Stratigraphic column.

GEOLOGIC SETTING

Since the recognition in the 1960s of the role of plate tectonics in the structural history of the earth, significant progress has been made in understanding the evolution of the California borderland. The tectonic events that embody this evolution in the greater Los Angeles basin are the following (Refer to Figure 1 for the location of the San Andreas fault, the Los Angeles basin and the western Transverse Ranges).

1. Beginning ca. 28 Ma, cessation of Pacific plate subduction in the central and southern California area and the evolution of the San Andreas transform fault system (Atwater, 1998).
2. Uplift of metamorphic core complexes represented in the Los Angeles basin by the Catalina Schist and clockwise rotation of the western Transverse Ranges block by more than 90 degrees since ca. 18 Ma (Luyendyk, 1991, Crouch and Suppe, 1993).
3. Lithospheric extension in the wake of the rotating western Transverse Ranges that resulted in the development of regional detachment surfaces (Crouch and Suppe, 1993).
4. In the Los Angeles basin area, cessation of extension at ca. 7-8 Ma and the onset of north-south compression associated with the San Andreas transform fault system, which has produced about 50 km of shortening across the basin (Argus et al., 1999, Bjorklund et al., 2002).

In the greater Los Angeles basin area, these events have resulted in the northwest-southeast trending right-lateral strike slip faults of the Peninsular Ranges (Palos Verdes, Newport- Inglewood, Elsinore, San Jacinto and San Andreas) and the east-west trending left-lateral oblique slip faults of the western Transverse Ranges (Santa Monica, Hollywood, Raymond, Sierra Madre-Cucamonga) (Figure 1). Metamorphic rocks of an accretionary-wedge complex (ca. 160 Ma), magmatic-arc rocks of the Southern California batholith (ca. 120-95 Ma) and forearc sedimentary rocks (ca. 90-49 Ma?) make up the cores of the

uplifts produced by these faults. The intervening basins have been filled with Miocene and younger sedimentary deposits and volcanic rocks (ca. 16-0 Ma). The sedimentary rocks consist predominantly of turbidites that have been shed from the surrounding uplifts.

The Puente Hills of the northeastern Los Angeles basin are located west and northwest of the Peninsular Ranges and southeast of the Transverse Ranges but are not clearly associated with either geomorphic province ([Figure 1](#) and [Figure 2](#)). This dilemma has led to conflicting interpretations of the structural development of the area. From north to south, the Puente Hills anticline, the Whittier fault, which trends N70°W and cuts the steeply dipping south limb of the anticline along a 40 km strike-length, and the La Habra syncline characterize the structural setting of the Puente Hills ([Figure 2](#)). Basement rocks that underlie the Puente Hills exhibit as much as 14000 feet of vertical separation due to folding and offset along the Whittier fault (cf. Yerkes, 1972, p. 29). Most studies of the Whittier fault have concluded that movement on the Whittier fault has been predominantly right-lateral strike slip, but a consensus has not been reached on the amount of horizontal separation. Estimates of horizontal displacement have ranged from nearly one mile to 25 miles (English, 1926, Hill, 1954, Woodford, 1954, Lamar, 1961, Durham and Yerkes, 1964, Yerkes, 1972, Sage, 1975, Wright, 1991, McCulloh et al., 2000). Offsets of more than about 15 miles would not be compatible with the late Pliocene (2.5 Ma) origin now ascribed to the Elsinore fault (Hull and Nicholson, 1992) and would necessarily be related to a different kinematic regime. Gourley (1975) and Davis et al. (1989) do not require any horizontal displacement on the Whittier fault. One paleoseismic study of excavated trenches concluded that Upper Quaternary channel sandstones had been offset 9-26 m in a right-lateral strike slip sense and estimated the ratio of lateral to vertical slip at 12:1 (Gath et al., 1992). Radiocarbon dates from those trenches indicated that the faulting took place within the past 17,000 years.

Our 4-D analysis of the available data shows that, although a small component of strike slip separation is required, dip-slip separation has been predominant on the Whittier fault during most of the past 8 My. Our review of previous studies of displacements on the Whittier fault suggests that a strike-slip transport direction has not been unequivocally established because of inherent uncertainties in across-the-fault correlations and poorly constrained piercing points. The amounts of uncertainty could well be as great as the estimated offsets. We have proposed a three-phase evolution of the Whittier fold-fault system (Bjorklund and Burke, 2002). That evolution began with extensional phase volcanism (16-14 Ma) and the formation of the Puente Hills half-graben along a proto-Whittier normal fault (14-8 Ma) and concluded with the compressional inversion of the half-graben to form the present Puente Hills anticline, the through-going Whittier reverse fault system and the La Habra syncline (8-0 Ma). Maximum burial of the hydrocarbon source rocks of the La Vida Member, the formation of oil accumulations in Miocene and Pliocene turbidites and substantial erosion of these strata took place from ca. 3-0 Ma (cf. Mayer, 1991) ([Figure 3](#)).

PURPOSE AND CONTENT

The purpose of this publication is to make available, in an accessible and usable format, a core database on the geology of the northeastern Los Angeles basin ([Figure 1](#) and [Figure 2](#)). The document emphasizes the structural and stratigraphic relationships of the Upper Miocene Puente Formation and the Lower Pliocene Fernando Formation, which are intensely drilled and represent the main oil-productive intervals of the Los Angeles basin ([Figure 3](#)). We hope that this publication may be useful to (1) those engaged in petroleum exploration and development, (2) earth scientists who are conducting research on continental transform fault systems, especially in the field of seismotectonics, and (3) earth science educators. The format of the database is devised to make it suitable for use in classes on structural geology, petroleum geology, and computer applications. Computer projects could range from 3-D analyses on high-performance workstations to the creation of conventional maps and cross sections on personal computers. Additional information to complement the database presented here, including geophysical well logs, topographic maps, oil field maps and satellite images, are available from the [California Department of Conservation](#), the [United States Geological Survey](#) and the Los Angeles Basin Data Repository at California State University Long Beach.

This publication consists of a series of 22 large-scale cross sections of oil fields along the Whittier fault, 10 regional cross sections and 6 structure maps (Refer to [Figure 4](#) for the locations of the cross sections and [Figure 1](#) for the location of the area covered by the maps). The discussion of the maps and cross sections elaborates upon published interpretations of the database (Bjorklund et al., 2002, Bjorklund and Burke, 2002) and emphasizes the sources and the quality of the data, local oil field terminology, and topics that may warrant further study. The various digital formats in which the data are available provide the opportunity for users to modify maps and cross sections and to produce illustrations at any scale.

SOURCES OF DATA

Aera Energy LLC (formerly Shell Oil Company) provided most of the well data for the central area of the study (the Brea-Olinda, Esperanza and Yorba Linda oil fields and vicinity). Nuevo Energy and Union Oil Company supplied well data from Sansinena oil field and the Stearns lease in Brea-Olinda oil field. The Department of Geosciences at Oregon State University provided well data in the East and West Coyote, Montebello, Rideout Heights, and Whittier oil fields. Miscellaneous well data were obtained from the District 1 office (Cypress, California) of the California Division of Oil, Gas, and Geothermal Resources (DOGGR). A preliminary digital well database that contains a single line listing of all of the wells in the study area, including API number, current operator, lease, well number and location by section, township, and range and, in most cases, by latitude and longitude was obtained from the Sacramento office of the DOGGR. The current status of the District 1 digital maps in the Los Angeles basin can be found on the [District 1 website](#). Other well data were compiled from published reports (Shelton, 1955, Yerkes, 1957, Durham and Yerkes, 1964, Yerkes, 1972,

Lang, 1978, Schoellhamer et al., 1981, Herzog, 1998 and McCulloh et al., 2000). The well data are tabulated in the WELL DATA section.

Surface geology interpretations are based on preliminary 7.5 minute series digital geologic maps obtained from the Southern California Areal Mapping Project (SCAMP), a cooperative mapping project between the U.S. Geological Survey and the California Geological Survey, published reports (Durham and Yerkes, 1964, Yerkes, 1972, Schoellhamer et al., 1981 and Gath et al., 1992) and field observations of the author.

A preliminary basemap for this study was compiled from paper copies of DOGGR field maps and regional wildcat maps and reduced to a scale of 1:24000. Parts of the study area have not been surveyed for section, township and range corners, and well locations on maps in those areas are not as accurately located as in other areas. Differences between well locations on operator maps and DOGGR maps are, also, common throughout the area. Finally, the digital well locations do not always match the well locations shown on either the DOGGR maps or the operator maps. For this study, the digital well locations have been used wherever possible. However, in some areas, the well locations in the digital database have been modified to fit the well locations provided by the operators, such as in Esperanza oil field. In that area, section corners on vintage 1950 USGS topographic maps have been relocated by as much as 500 feet with respect to topographic features on 1964 vintage USGS topographic maps. Similar differences exist between the operators' well locations and those in the digital database. Additionally, the cross sections in this study were constructed using a variety of base maps, and the well locations shown on the sections do not always match exactly the well locations on the final basemap; that is, the digital database. In spite of all of the difficulties in determining well locations, errors are estimated not to be greater than about 500 feet, which is about the accuracy of this study.

FORMATS OF FILES

As noted above, a comprehensive version of the Whittier fault study, entitled ***The Whittier Fault Trend in the Major Oil Producing Area of the Northeastern Los Angeles Basin: Interpretation and Data***, is available on CD-ROM. The CD-ROM includes a high-resolution PDF file of the publication, the original high-resolution files from which the figures and plates were created (Arc coverages, Arc shape files, Arc export files, JPEG and Canvas), and PDF files of the two already published reports that this publication supplements (Bjorklund and Burke, 2002, Bjorklund et al., 2002). The CD-ROM may be ordered at the AAPG Online Bookstore (<http://bookstore.aapg.org>) or from Search and Discovery sd@datapages.com.

The original files from which the maps for this study have been created are ARC/INFO coverages in the Universal Transverse Mercator coordinate system (Zone 11, NAD 27). These files are included in the CD-ROM Covers directory as ARC export interchange files (.e00 filename extensions) and as standard ARC

coverages. The coverages are also available as Arc shape files in the CD-ROM Shapes directory. A freeware copy of ARCEXPLORER, which has been included in the CD-ROM Arcexpl2 directory, can be used to view the shape files and coverages. The export interchange files can be converted to coverages at ARC with the command IMPORT COVER <INTERCHANGE FILE NAME> <OUTPUT COVERAGE NAME>. In ARC/INFO, xyz files can be generated from the coverages and used in applications to create 3-D images and to carry out structural analyses. Maps that have been created from the coverages for this publication are included in the CD-ROM Plates directory as JPEG images. A symbol set, alcgeol.mrk, created by the USGS to render oriented geologic structure symbols, such as strike and dip symbols, is included in the Covers directory (See Alacarte for additional information on specialized geologic symbol sets.). The content or theme of each file can be determined by referring to the following explanations of file name abbreviations.

dogwell = California Division of Oil and Gas single line listing of well information for all wells in the study area.

nb = north fault block or hanging wall block of the Whittier fault.

sb = south fault block or footwall block of the Whittier fault.

sections = index map showing locations of cross sections in figures.

tps = top of Soquel Member of Puente Formation.

tpsc = top of Sycamore Canyon Member of Puente Formation (base of Lower Fernando Member).

oc = outcrop

well = map showing surface locations of wells.

top(s) = map showing locations of the elevations in the wellbore, which will be different from the surface well locations for directionally drilled wells.

wf = Whittier fault

protowf = proto-Whittier fault

flt = fault

The original files of the cross sections were created on a PC using Canvas5 and are in the CD-ROM Canvas directory. Tables in Excel format are in the CD-ROM Tables directory. An Arc grid export interchange file of the northeastern Los Angeles basin, which is a mosaic of 11 USGS 10 meter, 7.5 minute Digital Elevation Models (DEMs), is in the CD-ROM Dem directory.

CROSS SECTIONS IN BREA-OLINDA, YORBA LINDA, AND ESPERANZA OIL FIELDS

Figure Captions (4-26)

(Note: Complete caption of Figure 4 after **REFERENCES** and with the image.)

Figure 4. Index map of cross sections.

Figure 5. Cross section of Sansinena oil field, East Area.

Figure 6. Cross section (a) of Brea-Olinda oil field, west Puente lease.

Figure 7. Cross section (b) of Brea-Olinda oil field, west Puente lease.

Figure 8. Cross section (a) of Brea-Olinda oil field, east Puente lease.

Figure 9. Cross section (b) of Brea-Olinda oil field, east Puente lease.

Figure 10. Cross section of Brea-Olinda oil field, Naranjal, Orange, and Rowland leases.

Figure 11. Cross section of Brea-Olinda oil field, Brea, Pico, and Grazide leases.

Figure 12. Cross section of Brea-Olinda oil field, west Stearns and Menchego leases.

Figure 13. Cross section (a) of Brea-Olinda oil field, central Stearns and Tonner leases.

Figure 14. Cross section (b) of Brea-Olinda oil field, central Stearns and Tonner leases.

Figure 15. Cross section (c) of Brea-Olinda oil field, central Stearns and Tonner leases.

Figure 16. Cross section of Brea-Olinda oil field, Naranjal and east Stearns leases.

Figure 17. Cross section of Brea-Olinda oil field, 100-acre, Columbia, and Olinda leases.

Figure 18. Cross section of Brea-Olinda oil field, Olinda and Olinda Fee 2, 3, and 4 leases.

Figure 19. Cross section of Yorba Linda and Brea-Olinda oil fields, Olinda Fee 1 and 4 leases.

Figure 20. Cross section of Yorba Linda oil field, Olinda Fee 1 and 4 leases.

Figure 21. Cross section (a) of Yorba Linda oil field, Olinda Fee 4 lease.

Figure 22. Cross section (b) of Yorba Linda oil field, Olinda Fee 4 lease.

Figure 23. Cross section (c) of Yorba Linda oil field, Olinda Fee 4 lease.

Figure 24. Cross section of Esperanza oil field, Dometal lease.

Figure 25. Longitudinal cross section of Yorba Linda oil field, Olinda Fee 4 lease.

Figure 26. Longitudinal cross section of East Yorba Linda oil field.

Description

Twenty-two cross sections along the 8 mile central segment of the Whittier fault system form the core dataset for the study (Figure 4, Figures 5-26). The cross sections consist of scanned images of wellbore locations, geophysical log curves (a spontaneous potential or gamma ray and resistivity curve), maximum bedding dips from core and dipmeter data (not corrected for strike of sections), paleontological data (see Wissler, 1943, Blake, 1991 and Barron and Isaacs,

2001 for discussions of microfaunal divisions), and local correlations established by Shell Oil Company geologists during the development of the fields. Because the quality of the reproductions of the original cross sections was variable, curves and annotations that are not legible on the original cross sections are not legible on the scanned images. Interpretations of faults, the top of the Sycamore Canyon member of the Puente Formation (near the top of the Miocene) and the top the Soquel member of the Puente Formation (approximately the top of microfaunal division D) have been modified in this study and are shown on the cross sections by heavier lines. Red arrows mark the locations of paleontological data in wellbores. Dashed green lines and polygons show the locations of oil sandstones and original oil-water contacts.

Puente Hills Area of the Northwest Brea-Olinda Oil Field

Along this segment of the Whittier fault, the contacts between Pliocene and Miocene strata and Delmontian and Mohnian strata are not well established. Shell Oil Company has placed the base of the Pliocene within the siltstone interval between the top of the Miocene upper "B" sands and the base of the Pliocene "A" sands (operator terminology). In Sansinena oil field, which adjoins Brea-Olinda oil field on the northwest ([Figure 4](#) and [Figure 5](#)), Union Oil Company placed the base of the Pliocene at the top of the upper "B" sands. Data are not available for this study to resolve the issue, which results in a maximum structural difference between the two interpretations of about 500 feet locally. In Brea Olinda oil field, the base of the Lower Fernando structure map and cross sections in this publication reflect the Shell Oil Company correlations. The base of the Delmontian Sycamore Canyon Member is located within a thick section of conglomeratic sandstones. Sandstone units in the Yorba Member, such as the "C-2" sand ([Figure 9](#)), are indistinguishable, based on lithologic characteristics, from those in the Sycamore Canyon Member, and paleontologic data in this dominantly sandstone interval are sparse. Within the Upper Miocene section, the top of the Soquel Member is the best horizon for regional correlation.

The correlations locally of individual sandstone units are well defined by hundreds of closely spaced wells. In the footwall block of the Whittier fault, steeply south-dipping, channel-shaped, Lower Pliocene and Upper Miocene sandstone units pinchout updip, generally more than 2000 feet from the main Whittier fault. On [Figure 9](#), updip from the sandstone pinchouts, paleontological data show that the Yorba Member underlies the Lower Fernando Member, which demonstrates the absence updip of strata equivalent to the Sycamore Canyon Member and is the best evidence in the study area for the early growth of the Whittier fault. The structural and stratigraphic details of isolated sandstone units within a fault slice near the Whittier fault, termed "D" sands and Ballard sands by the operator, are not as well known. The correlation of these sandstones with the downdip Soquel sandstone has been established by using paleontological data and bedding dips from cores and dipmeters ([Figure 8](#) and [Figure 9](#)).

The Whittier fault has been intersected by numerous wellbores in northwest Brea-Olinda and is well defined at shallow depths. However, the surface trace of

the fault is usually covered by colluvium and only approximately located. Wells drilled from the hanging wall block penetrate La Vida strata juxtaposed against Fernando strata in the footwall block ([Figure 6](#)). Several wellbores, directionally-drilled from the footwall block, cross the Whittier fault from Soquel sandstone or Division D strata into lower La Vida strata or metavolcanic basement rocks in the hanging wall block at depths between 3000 and 6000 feet (cf. [Figure 6](#) and [Figure 7](#)). Yerkes (1972) places the Whittier fault trace along the southern boundary of a fault-bounded slice of Yorba siltstone. Previous workers (Shell Oil Company proprietary reports) have suggested that a large landslide of La Vida strata covers the Whittier fault in this area ([Figures 6, 7, and 8](#)). The evidence for this interpretation includes the presence of La Vida and Yorba siltstones at shallow depths in wellbores and south of the projected location of the Whittier fault based on well data. Either the dip of the Whittier fault flattens considerably near the surface or landslide deposits cover the fault trace. The landslide interpretation has been preferred for this study because of (1) the lack of evidence of flattening on the Whittier fault to the northwest and southeast; (2) the presence of numerous recent landslides of La Vida throughout the Puente Hills (Durham and Yerkes, 1962, Yerkes, 1972 and Tan et al., 1984); and (3) the compatibility of a large landslide interpretation with surface features. The surface trace of the Whittier fault mapped by Yerkes (1972) would approximately locate the toe of the landslide. Valleys at higher elevations in the Puente Hills are reasonably oriented to have formed along a scarp at the head of the landslide. Small normal faults, numerous small folds, and an apparently partially covered diabase sill further characterize the landslide area. The possible areal extent of the landslide block is shown on [Figure 4](#).

Brea and Tonner Canyon Areas of Central Brea-Olinda Oil Field

The Tonner and Menchego faults (operator terminology) are the dominant structural features of the central area of the Brea-Olinda oil field. The faults have been intersected by wellbores in which microfaunal data and log correlations indicate the presence of repeated sections ([Figure 12](#) and [Figure 14](#)). In many cases, the repeated sections are within a predominantly siltstone interval and could not have been identified without the use of paleontological data. In other cases, sandstone strata appear to have been fault-truncated but, in the absence of paleontological data, could also have been interpreted to have pinched out. The presence of the Tonner fault is most clearly indicated by the microfaunal evidence of the Soquel Member in several wells at shallow depths and by the coincidence of the upward projection of the fault with a mapped surface fault (cf. Tan et al., 1984 and [Figure 13](#)). A conglomeratic sandstone on the north side of that fault in Tonner Canyon has been mapped as the Lower Fernando Member by Tan et al. (1984) and as the La Habra Formation by Durham and Yerkes (1972). These interpretations are not compatible with the presence of foraminifera of Division D age at a depth of about 500 feet in the Mobil Tonner 24 well just north of the fault ([Figure 14](#)). The sandstone is inferred to be part of the Yorba Member based on the presence of conglomeratic sandstones in the Yorba

Member in the subsurface. Thick sandstones in the Yorba Member are not common in outcrops but are common in the subsurface. The Menchego fault does not appear to reach the surface and possibly does not penetrate the Upper Fernando Member. The Menchego and Tonner faults, as well as sand pinchouts, provide critical updip and lateral closure for oil accumulations in the turbidite channel sandstones of the Sycamore Canyon Member.

The relationship of the Tonner and Menchego faults to the proto-Whittier fault (See Bjorklund and Burke, 2000) for a discussion of the proto-Whittier fault), which is critically important in understanding the evolution of the Whittier fault system, is well defined by surface and well data in this area. A diabase unit crops out for a distance of about 3000 feet just north of Brea Canyon, and its south contact, which is covered by alluvial deposits, marks the location of the proto-Whittier fault (cf. Yerkes) ([Figure 11](#)). Tan et al. (1984) extend the proto-Whittier fault trace about 8000 feet to the southeast with decreasing throw, showing the La Vida siltstone on the north in fault contact with the Soquel sandstone on the south. Farther to the southeast, the contact between the La Vida and Soquel Members has been interpreted to be depositional, and the subsurface location of the proto-Whittier fault has been inferred from surface folding and several thousand feet of separation of lower La Vida strata. The relationships shown on [Figure 23](#) and nearby cross sections establish that uplift of the north block of the Whittier fault system has been formed by (1) inversion of the Whittier half-graben that has been accommodated by displacement on the Menchego and Tonner faults, with dips approximately the same as the inferred dip of the Whittier fault in the basement, (2) by displacement on the proto-Whittier fault and (3) by folding (Bjorklund and Burke, 2002). The southernmost, throughgoing fault at the surface in this area, which is the Tonner fault, has been mapped as the Whittier fault in this publication.

Carbon Canyon Area of Southeast Brea-Olinda Oil Field and Yorba Linda and Esperanza Oil Fields

The Lower Fernando Member is unusually thick in the Carbon Canyon area due to the presence of a lower interval of conglomeratic sandstones, termed "A" sands by the operator ([Figure 19](#) and [Figure 20](#)), that are not present in the outcrops farther to the east. Isolated outcrops within the Carbon Canyon floodplain have been identified by Durham and Yerkes (1962) and Tan et al. (1984) as the Sycamore Canyon Member but probably correlate with the Lower Pliocene "A" sands. On the maps and cross sections in this publication, the location of the base of the Lower Fernando Member below the alluvial cover as interpreted by Tan et al. (1984) and Durham and Yerkes (1962) has been modified to reflect the presence of the "A" sands.

About 1300 feet northwest of [Figure 17](#) along the strike of the Whittier (Tonner) fault, trenching was conducted to look for evidence of recent movement on the Whittier fault near Olinda Creek (Gath et al., 1992) (See Bjorklund and Burke, 2002 for additional discussion of the trenching). Although the conclusions of the study on fault kinematics are not convincing, the trenches established a dip on

the Whittier fault of about 25 degrees to a depth of 10 feet. The Tonner fault , which has a north dip of 55 degrees in the subsurface, or a related splay fault may flatten at the surface in this area.

Between Brea-Olinda and Esperanza oil fields, well data near the Whittier fault are widely spaced. Two wells intersected the fault at about 2000 feet and several deeper wells that did not intersect the fault limit its maximum possible dip (Figures 19, 20, 21, 22, and 23). With one exception, the surface contact along this segment of the Whittier fault for this study is the contact mapped by Tan et al. (1984). In the vicinity of Figure 22 and Figure 23, Tan et al. (1984) show the La Vida Member in the north block of the Whittier fault in contact with the Yorba Member on south. Surface paleontologic data indicate that the age of the unit mapped as the Yorba Member is Division D in age and instead correlates with the Soquel Member. On this basis, the surface contact of the Whittier fault has been placed at the south contact of that unit, which is the contact with the Sycamore Canyon Member.

Outcrops in the area of Esperanza have been highly deformed in the core of the La Habra syncline. Tan et al. (1984) interpreted the relationships of outcrops of the Sycamore Canyon and Yorba Members in this area to reflect tight folding. Durham and Yerkes (1964) instead invoked a complex pattern of faults to explain the outcrop distribution. The well data in Esperanza field are no easier to interpret, but the simplest interpretation is one in which the deformation has been accommodated mainly by flexural slip and not by faulting (Figure 24). This interpretation is based on abundant dipmeter and paleontologic data. The deformational style is compatible with the likely mechanical properties of the uniform section of the relatively thin, alternating sandstone and siltstone beds that characterize the Sycamore Canyon and Yorba Members in the area. A similar deformational style is present at Whittier oil field along the northwestern segment of the Whittier fault in a similar thin-bedded section (footwall structure in Figure 34). In contrast, the equivalent strata in Brea-Olinda oil field are dominated by thick intervals of stacked, unfaulted, conglomeratic, turbidite-channel sandstones that exhibit homoclinal dips on the north limb of the La Habra syncline.

Figure 25 and Figure 26, extending from Yorba Linda oil field to Esperanza oil field, intersect Figures 19, 20, 21, 22, 23, and 24 and establish a western plunge along the axis of the La Habra syncline of about 12 degrees. Conglomerates in the Upper Fernando in Yorba Linda oil field produce heavy oil (12- 14°API) by steam stimulation. Lying immediately below strata of the La Habra Formation, the Upper Conglomerate (operator terminology) is the youngest oil-productive reservoir in the NELAB, producing heavy oil from a depth of about 600 feet (Figure 25).

REGIONAL CROSS SECTIONS

Abbreviated Figure Captions (27-36)

(Note: Complete captions after **REFERENCES** and with full-scale images.)

Figure 27. Cross section of Santa Ana Canyon and the southeast segment of the Whittier fault.

Figure 28. Cross section of Kraemer oil field, Esperanza oil field, and the Chino Hills.

Figure 29. Cross section of Richfield oil field, Yorba Linda oil field, and the Chino Hills.

Figure 30. Cross section of Brea-Olinda oil field and the central segment of the Whittier fault.

Figure 31. Cross section of East Coyote oil field, Brea-Olinda oil field, and the Puente Hills.

Figure 32. Cross section of La Mirada oil field, Leffingwell and Sansinena oil fields, and the Puente Hills.

Figure 33. Cross section of Leffingwell oil field, Whittier oil field, and the Puente Hills

Figure 34. Cross section of Whittier oil field, Turnbull oil field, and the northwest segment of Whittier fault.

Figure 35. Longitudinal cross section of Montebello oil field, Whittier Narrows, Puente and Chino Hills, and Chino fault.

Figure 36. Cross section of Anaheim nose, East Coyote oil field, Brea-Olinda oil field, and Puente Hills.

Description

Ten regional cross sections have been constructed to provide a wider, 3-D perspective within which to view the structural interpretation of the Whittier fault and to insure that the structural contour maps are reasonable and consistent across the study area (Figures 27, 28, 29, 30, 31, 32, 33, 34, 35, and 36). See Figure 4 for the locations of the cross sections. Figures 27, 28, 29, 30, 31, 32, 33, 34, 35, and 36 together with the oil field cross sections above complete a grid of cross sections that covers the Puente and Chino Hills and most of the oil fields along the south flank of the La Habra syncline. The structural and stratigraphic interpretations south of the La Habra syncline are based on limited well data and, in some cases, have been modified from published reports. They are not comprehensive analyses. Except at the ends of the Whittier fault (Figure 27, Figure 33, and Figure 35), the cross sections have been balanced with respect to bed length and area in the vicinity of the Whittier fault, but only the sections along the central segment of the fault are well constrained (See Bjorklund and Burke, 2002, Fig. 12, Appendix A, for a discussion of balancing methodology). Figure 35 extends across the Puente Hills eastward from Whittier Narrows to the Chino fault, and Figure 36 extends from the Puente Hills southward to the Anaheim nose. Both of these cross sections incorporate P-wave seismic tomographic data (Zhou, 1994,) and extend to depths of 50,000 feet (See Bjorklund, et al., 2002 for additional discussion). Figure 27, Figure 30, and Figure 34 are representative of

the central, southeast and northwest segments of the Whittier fault, respectively (See Bjorklund and Burke, 2002 for additional discussion.)

STRUCTURE MAPS

Plate Captions (1-6)

Plate 1. Structure map on the top of the Sycamore Canyon Member (hanging wall block). Numbers shown on cross section lines are figure numbers. Quaternary undivided (Qu), Sycamore Canyon Member (Tp_{sc}).

Plate 2. Structure map on the top of the Sycamore Canyon Member (footwall block). Numbers shown on cross section lines are figure numbers. Quaternary undivided (Qu), Sycamore Canyon Member (Tp_{sc}).

Plate 3. Structure map on the top of the Soquel Member (hanging wall block). Numbers shown on cross section lines are figure numbers. Quaternary undivided (Qu), Soquel Member (Tp_s), Yorba member (Tp_y).

Plate 4. Structure map on the top of the Soquel Member (footwall block). Numbers shown on cross section lines are figure numbers. Quaternary undivided (Qu), Soquel Member (Tp_s).

Plate 5. Structure map of the Whittier fault. Numbers shown on cross section lines are figure numbers.

Plate 6. Structure map of the proto-Whittier fault. Numbers shown on cross section lines are figure numbers. Quaternary undivided (Qu), Soquel Member (Tp_s).

Description

The absence of any single lithologic unit that can be correlated continuously across the study area and the lithologic similarities of many of the rock units create difficulties in the construction of area-wide structure maps and a dependence on paleontologic data to establish correlations. In practice, boundaries of formation members have been extended from areas with paleontologic data on the basis of lithologic characteristics. The highest quality well data are assumed to be those data that have been obtained from the operators. For example, the well data from Aera Energy in Brea-Olinda oil field have been used, in most cases, in preference over published data. Errors in well correlations are believed to be generally less than 500 feet, although, in a few cases, errors in exploratory wells and deep field wells could be greater. Because of the contrasting lithologies of units on opposite sides of the Whittier fault, interpretations of fault boundaries are usually reliable.

To avoid overlap of structural contours, the structure contour maps on the top of the Sycamore Canyon Member and the top of the Soquel Member are shown on separate maps of the hanging wall and footwall blocks of the Whittier fault (Plates 1, 2, 3, and 4). For small reverse faults within the footwall block, only the hanging

wall cutoffs have been shown on the maps. Both the hanging wall and footwall cutoffs are shown for the larger normal faults in the hanging wall block. The Sycamore Canyon structure map of the footwall block ([Plate 2](#)), which is based on more well data than the Soquel structure map of the footwall block ([Plate 4](#)), has been used to estimate the depths to the Soquel Member in areas of no well control. Estimates of the depths to the top of the Soquel Member and the top of the Sycamore Canyon Member in the axial area of the La Habra syncline are based on projections from wells on the flanks of the structure. Due to erosion, the top of the Sycamore Canyon Member can only be reliably mapped over the northwest part of the hanging wall block of the Whittier fault ([Plate 1](#)). Although the top of the Soquel Member has been eroded over the crest area of the Puente Hills anticline in the hanging wall block, the lower part of the Soquel Member is present in scattered outcrops, and a restored elevation of the top of the Soquel Member can be reliably estimated in those areas ([Plate 3](#)). In areas of closely spaced wells, all well data are not shown on the structure maps to avoid overprinting.

The Whittier fault has been mapped as a continuous fault from the Santa Ana Canyon to the Whittier Narrows (Durham and Yerkes, 1964, Yerkes, 1972 and Tan, et al., 1984) ([Plate 5](#)). The southeasternmost outcrop of the Whittier fault is located at Bee Canyon, north of the Santa Ana River (Tan et al., 1984). Southeast of that point, the Whittier fault is covered by alluvium (See Bjorklund and Burke, 2002 for additional discussion of this area). Between Brea-Olinda oil field and the Santa Ana Canyon, Durham and Yerkes (1964) have mapped several faults associated with the Whittier fault system, whereas Tan et al., (1984) have mapped a single, through-going trace. The single trace interpretation has been adopted in this study, because well data do not require multiple fault traces. In the Brea Canyon area of Brea-Olinda oil field, the proto-Whittier fault and the Tonner fault crop out ([Plate 6](#)). The Tonner fault has been mapped as the active segment of the Whittier fault in this area because of its continuity and the results of a trench study across it that reported offsets of strata dated at about 15,000 years before the present (Gath et al., 1992). Northwest of Brea-Olinda oil field, a possible paleo-landslide may obscure the location of the Whittier (See [Figure 4](#) and the Puente Hills area discussion above). At Whittier oil field, three faults have been mapped at the surface over a distance of 11,000 feet (Yerkes, 1972). The northernmost of the three faults, which has a well-defined trace and appears to be continuous across the field, has been mapped in this study as the Whittier fault. The northwesternmost outcrop of the Whittier fault is located north of the city of Whittier in Turnbull Canyon (Yerkes, 1972). From that point northwest to the Whittier Narrows, the Whittier fault is covered by alluvium, but its location can be mapped using subsurface data ([Plate 5](#)). At the Whittier Narrows, the points at which the structure maps on the top of the Sycamore Canyon Member and the top of the Soquel Member do not require fault separation define the northwest tip line of the Whittier fault. The nature of the relationship between the terrace-like linear features in the eastern Montebello Hills, which have been attributed to possible faulting (Treiman, 1991), and the

Whittier fault is beyond the scope of this study (See Bjorklund and Burke, 2002 for additional discussion).

WELL DATA

Table Captions (1-9)

Table 1. Wells in hanging wall block with elevations of base Fernando.

Table 2. Wells in footwall block with elevations of base Fernando.

Table 3. Wells in hanging wall block with elevations of top Soquel.

Table 4. Wells in footwall block with elevations top Soquel.

Table 5. Wells with elevations of Whittier fault.

Table 6. Wells with elevations of proto-Whittier fault.

Table 7. All wells with elevations of base Fernando, top Soquel and faults.

Table 8. All wells in study area.

Table 9. Well status codes for wells contained in the database.

Description

Tables 1, 2, 3, 4, 5, and 6 show the wells used in the construction of the six structure contour maps (Plates 1, 2, 3, 4, 5, and 6), including the elevations of the contoured horizons in the wells. The well coordinates included in the tables are the bottom hole locations of the horizons in the wellbores. For directionally drilled wells, these coordinates will differ from the surface locations of the wells. Table 7 is combined list of all wells for which elevations of the top of the Sycamore Canyon Member, the top of the Soquel Member, the proto-Whittier fault and the Whittier fault have been compiled. Table 8 is a list of the nearly 8,000 wells in the study area that are in the DOGGR District 1 preliminary digital well database (last updated for this publication in August 2000). The well coordinates included in these tables are the surface locations for most of the wells, but well coordinates have not yet been determined by the DOGGR for all of the wells. Table 9 is a list of the meanings of the DOGGR well status codes (status column in the tables).

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COMPLETE FIGURE CAPTIONS ACCOMPANYING IMAGES

Figure 1. Index map of the Los Angeles basin and surrounding uplifts. Red dashed rectangle shows the area covered by the maps in this document (See Figure 2 for shaded relief map of area.). Northeastern Los Angeles basin (NELAB), Chino fault (CF), Elysian Park Anticline (EPA), Palos Verdes Hills (PVH), San Gabriel Valley (SGV), San Jacinto Valley (SJV), San Jose Hills (SJH), Santa Ana Mountain Boundary Fault (SAMBF).

Figure 2. Shaded relief map of the northeastern Los Angeles basin (Mosaic of 11 USGS 10 meter 7.5 minute Digital Elevation Models (DEMs) with 3x vertical exaggeration). Chino fault (CF), Rio Hondo (RH), San Gabriel river (SGR), San Jose Hills (SJH), Santa Ana Mountains (SAM), Santa Ana river (SAR), Whittier Heights fault (WHF), Workman Hills fault (WoHF).

Figure 3. Stratigraphic column. Green bar shows oil source rock interval. MAX (m) indicates approximate maximum thickness of a unit in meters in the study area. Cenozoic ages from Turner (1970), Blake (1991), Berggren et al. (1995), McCulloh et al. (2000), Barron and Isaacs (2001). Mesozoic ages from Larson, et al. (1958), Imlay (1964), Banks and Silver (1966) Fife et al. (1967). Divisions A through F are benthic foraminiferal divisions from Wissler (1943) with ages of division boundaries from Blake (1991) and Barron and Isaacs (2001). Time of maximum subsidence of Los Angeles basin from Ingersoll and Rumelhart (1999, Fig. 3).

Figure 4. Index map of cross sections. Oil fields are Chino-Soquel (CS), Brea-Olinda (BO), East Coyote (EC), East Los Angeles (ELA), Esperanza (E), Kraemer (Kr), Mahala (Ma), Montebello (Mo), North Whittier Heights (NWH),

Olive (O), Richfield (RI), Rideout Heights (RO), Sansinena (Sa), Santa Fe Springs (SF), Turnbull (T), West Coyote (WC), Whittier (W) and Yorba Linda (YL). Numbers accompanying cross section lines are figure numbers.

Figure 5. Cross section of Sansinena oil field, East Area

Figure 6. Cross section (a) of Brea-Olinda oil field, west Puente lease.

Figure 7. Cross section (b) of Brea-Olinda oil field, west Puente lease.

Figure 8. Cross section (a) of Brea-Olinda oil field, east Puente lease.

Figure 9. Cross section (b) of Brea-Olinda oil field, east Puente lease.

Figure 10. Cross section of Brea-Olinda oil field, Naranjal, Orange, and Rowland leases.

Figure 11. Cross section of Brea-Olinda oil field, Brea, Pico, and Graziade leases.

Figure 12. Cross section of Brea-Olinda oil field, west Stearns and Menchego leases.

Figure 13. Cross section (a) of Brea-Olinda oil field, central Stearns and Tonner leases.

Figure 14. Cross section (b) of Brea-Olinda oil field, central Stearns and Tonner leases.

Figure 15. Cross section (c) of Brea-Olinda oil field, central Stearns and Tonner leases.

Figure 16. Cross section of Brea-Olinda oil field, Naranjal and east Stearns leases.

Figure 17. Cross section of Brea-Olinda oil field, 100-acre, Columbia, and Olinda leases.

Figure 18. Cross section of Brea-Olinda oil field, Olinda and Olinda Fee 2, 3, and 4 leases.

Figure 19. Cross section of Yorba Linda and Brea-Olinda oil fields, Olinda Fee 1 and 4 leases.

Figure 20. Cross section of Yorba Linda oil field, Olinda Fee 1 and 4 leases.

Figure 21. Cross section (a) of Yorba Linda oil field, Olinda Fee 4 lease.

Figure 22. Cross section (b) of Yorba Linda oil field, Olinda Fee 4 lease.

Figure 23. Cross section (c) of Yorba Linda oil field, Olinda Fee 4 lease.

Figure 24. Cross section of Esperanza oil field, Dometal lease.

Figure 25. Longitudinal cross section of Yorba Linda oil field, Olinda Fee 4 lease.

Figure 26. Longitudinal cross section of East Yorba Linda oil field.

Figure 27. Southeastern segment of the Whittier fault across Santa Ana Canyon. Interpretation of hanging-wall block of Santa Ana Mountain Boundary Fault (footwall block of Whittier fault) is based mainly on surface mapping of Durham and Yerkes (1964) and Schoellhamer et al. (1981) and wells not on section. Interpretation of hanging-wall block of Whittier fault below well depths is based

on the thickness of the Cretaceous sequence in Prado Petroleum Government No. 165-1 well (Lang, 1978), located 3.3 km southeast of the section line, and the extrapolation of outcrop data from the Santa Ana Mountains. The base of the Lower Fernando Member is approximately located with unpublished microfaunal data (Aera Energy LLC) from Grayco Oil Grayco No. 1 well.

Figure 28. Kraemer oil field to Esperanza oil field and the Chino Hills. This section is the best illustration in the area of the striking differences in thickness between the La Vida Member on the north and south sides of Whittier fault; these are inferred to indicate Miocene rifting (Bjorklund and Burke, 2002).

Approximately one mile north of the Whittier fault, the Shell Wright 73-18 well penetrated over 4000 feet of La Vida siltstone, rift deposits, and diabase. Nearly 1500 feet of that interval is the Diamond Bar sandstone, which is not present south of the Whittier fault. The equivalent interval approximately one mile south of the Whittier fault in the Texaco Travis 1 well, which is located 3000 feet southeast of this section, is 1510 feet thick and contains no significant sandstone units or diabase. Even if the La Vida Member were somewhat thicker northwest of the Travis well and if the La Vida Member were repeated by unrecognized faults in the Wright well, the conclusion that rift deposition north of the Whittier fault must account for the differences in thickness seems inescapable. The structural features associated with the hanging wall and footwall blocks of the Whittier fault are similar to those found at Brea-Olinda oil field; that is, steeply dipping, faulted forelimb beds and gently dipping backlimb beds. However, at Esperanza, the structural interpretation of the basement block is largely conceptual because of the lack of deep wells and has been derived from constraints imposed by bed length and area assumptions (See Bjorklund and Burke, 2002, Fig. 12, Appendix A, for a discussion of balancing methodology). Any structural interpretation must account for 5000 feet of uplift of the north block of the Whittier fault. The interpretation of the stratigraphic units below the Vaqueros and Sespe Formations are based on USGS cross sections in the Santa Ana Mountains (Schoellhamer et al., 1981). The Pleasants sandstone is inferred not be present. The Schulz Ranch sandstone and the Silverado Formation have been interpreted to be thinner than the closest subsurface control, which is in the Texas Company Irvine NCT-1 No. 1 well to the southeast. See Figure 24 for details on the Esperanza oil field.

Figure 29. Richfield oil field to Yorba Linda oil field and the Chino Hills. Although wells along this segment of the Whittier fault are sparse, the structure of the footwall block near the fault is well delineated on this cross section by surface mapping and dip and paleontological data in several wells. In the hanging wall block, the Union Gaines 1 well penetrated a thick section of the La Vida Member that contains sandstone, siltstone and diabase in the lower part, which are characteristic of the strata in the inverted half-graben immediately north of the Whittier fault. In the Gaines well, Durham and Yerkes (1964) included the Diamond Bar sandstones in the Topanga Formation. This correlation results in a top of the Topanga Formation that is structurally too high to be a reasonable possibility when compared with surrounding wells (See Bjorklund and Burke, 2002, section 1.3.3.1 for a discussion of the Diamond Bar sandstone correlation

problem.). In this publication, the base of the Diamond Bar sandstone (base of La Vida Member in this area) in the Gaines well has been picked at a depth of 5860 feet, the top of a volcanic unit. The top of the Topanga Formation is picked at the base of the volcanic unit. An alternative interpretation for the top of the Topanga Formation is the top of the sandstone bed overlying the volcanic unit. However, volcanic rocks in this area commonly overlie the Topanga Formation but are not known to occur within it. See [Figure 20](#) for a large-scale cross section of the vicinity of the Whittier fault.

[Figure 30](#). Central segment of the Whittier fault across Brea-Olinda oil field. Correlations modified from Durham and Yerkes (1962). Yeats and Beall (1991) and unpublished data from Aera Energy LLC (formerly Shell Oil Company). Interpretation of footwall block of the Whittier fault is based on data from Chevron Murphy-Coyote No. 373 in West Coyote oil field (West and Redin, 1990, McCulloh et al., 2000) and Prado Petroleum government 165-1 east of the Chino fault and the extrapolation of outcrop data from the Santa Ana Mountains (Schoellhamer et al., 1981). Yellow units within Sycamore Canyon and Yorba members represent oil-productive, turbidite fan-channel sandstones. Sycamore Canyon member (Tpsc, Yorba Member (Tpy). See [Figure 13](#) for large-scale corss section of the vicinity of the Whittier fault.

[Figure 31](#). East Coyote oil field to Brea-Olinda oil field and the Puente Hills. This cross section shows the most prolific oil-producing section along the Whittier fault, which is located in the footwall block, and the only oil-producing section north of the fault, which is located on the crest of the hanging wall block at the structurally highest part of the Puente Hills anticline. Underlying the Puente A lease in the hanging wall block, oil has been produced from fractured La Vida siltstone, Topanga sandstone and basement metavolcanic rocks (e.g. Puente A-3 and A-6). The metavolcanic rocks have been correlated with the Santiago Peak Volcanics and interpreted to be a pendant in granite and granodiorite batholithic rocks (Yerkes, 1972). This is the only known oil accumulation in these intervals in the northeastern Los Angeles basin. Abundant well and surface data constrain structural relationships. Bedding dips in the La Vida siltstone in the hanging wall block range from 30 to 60 degrees, indicating substantial rotation of the block during uplift. Numerous wells, several of which penetrated definitive contacts of metavolcanic basement rocks against sedimentary rocks, define the location of the Whittier fault from sea level to a depth of more than 7000 feet. See [Figure 9](#) for a larger-scale cross section of the vicinity of the Whittier fault.

[Figure 32](#). La Mirada oil field to Leffingwell and Sansinena oil fields and the Puente Hills. The interpretation shown on this cross section has been modified from Yerkes (1972) and West and Redin (1991). The Coyote Hills fault, proposed by Shaw and Shearer (1999), has been added as a possible alternative interpretation of the Norwalk fault (?). The simplified interpretation of Sansinena field is based mainly on data provided by Nuevo Energy Company and Union Oil Company and a published report by Woodward (1958). The tightly folded anticline in the footwall block has been established by well data at the top of the Soquel Member. The anticline has also been mapped at the surface in the Upper

Fernando Member and named the Sansinena nose by the operator (unpublished map, Hoots and Kinney, 1939). Sansinena 3B48 has been projected to show stratigraphy only and does not reflect the subsea position of the well. The details of the structure and stratigraphy in the core of the footwall anticline below the top of the Soquel sandstone are largely schematic. The basement geometry of the Whittier fault satisfies constraints for conserving bed length and area during deformation but is not a unique interpretation. The kinematic problem of inverting and rotating a half-graben to produce the Sansinena structure has not been completely resolved. The interpretation of Leffingwell oil field that has been depicted on this cross section is speculative. A conglomeratic sandstone nearly 800 feet thick in the Hathaway Woodward Community K-1 well, which is absent in the Standard German Community 1 well just 1400 feet to the south, had been correlated with the Soquel Member, and a volcanic unit in both wells had been interpreted to dip about 40 degrees north (Yerkes, 1972, Section D-D', Plate 2). The overlying Yorba Member and younger strata were shown to be horizontal and undeformed. This interpretation requires the development of a compressive structure between ca. 14 Ma and 8 Ma, which would not be likely in a region that was undergoing extension during that time period. The interpretation shown on this cross section separates the German Community and Woodward Community wells with a graben-forming normal fault that dips north. The conglomeratic sandstone would then correlate with the lower La Vida and represent a rift deposit in a small half-graben (cf. Bjorklund and Burke, 2002). Further investigation of the Leffingwell field area is beyond the scope of this study, but data may be available in the West Coyote oil field area to evaluate the viability of a half-graben interpretation.

Figure 33. Leffingwell oil field to Whittier oil field and the Puente Hills. This section is located near the point at which the strike of the Whittier fault changes from N70W to nearly due north (Figure 4). Although only three wells, Union Puente Farms 1 and Shell Pellissier 1 and Bartolo 1, are shown on the cross section near the Whittier fault, the structure at the top of the Soquel Member is well delineated. Wells off the section and outcrop data establish the south dip of the strata in the footwall block and the north dip in the hanging wall block. The Shell wells penetrated a thin section of strata equivalent to the Yorba, Soquel, and La Vida Members overlying metamorphic basement rocks. The La Vida siltstone is less than 1000 feet thick (Yeats and Beale, 1991) in Pellissier 1. The stratigraphic thickness of the La Vida Member in the Puente Farms 1 is about 4000 feet thick, an increase in thickness of more than 3000 feet over a distance of less than 13000 feet. This suggests the La Vida strata overlapped a basement surface that dipped 15 degrees to the south. The kinematic problem of determining the deformational history that led to the present configuration of that wedge of La Vida siltstone has not been completely resolved. Both the transition from predominantly dip-slip movement to strike-slip movement on the north-trending segment of the Whittier fault in the vicinity and detachment folding may play a role in the development of the structure. The structure of the footwall block below the Soquel Member is schematic. The location of the anticline is compatible with the inversion of a thick wedge of La Vida siltstone. Oil stain and

fractures in cores suggest the presence of the Whittier fault in the Puente Farms 1 well. However, the fault geometry, the shape of the deformed basement wedge, and the kinematics that led to the inverted structure are not well known. At total depth in the Bartolo 1 well, fractured silver-gray slate has been reported. At total depth in the Pellissier 1 well, fractured, blue-green metamorphic rock with very fine-grained to "granitic texture" has been reported. These basement rocks are probably equivalent to the slate penetrated by several wells north of Montebello oil field (Figure 5). Refer to Figure 32 for a discussion of the interpretation of the Leffingwell oil field structure. The location of the Coyote Hills fault at Leffingwell is based entirely on an interpretation of reflection seismic data (Shaw and Shearer, 1999).

Figure 34. Northwestern segment of the Whittier fault from Whittier oil field to Turnbull oil field. Microfaunal divisions (Division E (E), Division D/Division E contact (D/E), Division D (D) and Division B/Division C contact (B/C)), Yorba Member (Tpy), Sycamore Canyon Member (Tpsc), Pliocene/Miocene contact (P/C), Lower Fernando Member (Tfl). Arrows along the wellbore identify locations of microfaunal data. Modified from Yerkes (1972, cross section C-C') and Herzog (1998, cross section C-C'). Interpretation of hanging-wall block based on data from Daviess and Woodford (1949). The two volcanic or diabase units are each drilled by a single well (Los Angeles Brewing Jones Community 1 and Conoco Buehler 1). Woodford, et al. (1944) reported Luisian and Relizian foraminifera in the latter well. Since the 3-D shape of these igneous units is not known, the interpretation on the cross section is speculative.

Figure 35. Puente and the Chino Hills from Montebello oil field and Whittier Narrows area to the Chino fault. The cross section shows possible spatial relationships of volcanic rocks (red) and their upper crustal source (solid black) based on an integrated interpretation of well and outcrop data and tomographic velocities. The higher-velocity tomographic anomalies have been interpreted to reflect the presence of a vertical, stock-like pluton here named the Whittier Narrows pluton. The pluton would have been emplaced into the upper crust during the Miocene and acted as magma source for volcanic rocks. Rock with a bulk density of ca. 2.9 gm/cc and dioritic composition would correlate with the average block velocity (6.6 km/s) of the pluton (Birch, 1960). The exact shape of the pluton cannot be resolved with the grid-spacing of the velocity model of 10x10x3 km. Dashed rectangles are velocity-model grid blocks with average Pwave velocities (km/s) shown (After Zhou, 1994) (See Bjorklund et al., 2002 for additional details.) Faults: Chino (CF), Handorf (HF), Whittier Heights (WHF). Toward the observer (T), away from the observer (A).

Figure 36. Anaheim nose to East Coyote oil field, Brea-Olinda oil field and the Puente Hills. The cross section shows possible spatial relationships of volcanic rocks (red) and their upper crustal source (solid black) based on an integrated interpretation of well and outcrop data and tomographic velocities. The higher-velocity tomographic anomalies have been interpreted to reflect the presence of a vertical, sill-like pluton here named the El Modeno pluton. The pluton would have been emplaced into the upper crust during the Miocene and acted as

magma source for volcanic rocks. Rock with a bulk density of ca. 2.9 gm/cc and dioritic composition would correlate with the average block velocity (6.6 km/s) of the pluton (Birch, 1960). The exact shape of the pluton cannot be resolved with the grid-spacing of the velocity model of 10x10x3 km. Dashed rectangles are velocity-model grid blocks with average P-wave velocities (km/s) shown (After Zhou, 1994) (See Bjorklund et al., 2002 for additional details.). (See [Figure 13](#) for a large-scale cross section of this part of Brea-Olinda oil field and this segment of Whittier fault, along with associated faults.)