STRUCTURE AND HYDROCARBON EXPLORATION IN THE TRANSPRESSIVE BASINS OF SOUTHERN CALIFORNIA

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Guidebook for Field Trip #5
AAPG Annual Convention
Long Beach, CA
April 22-25, 2012

Reprinted from
Guidebook
AAPG Annual Convention
1996
San Diego, CA

Figure 8B is a regional cross section that parallels our present route, and shows an interpretation of the 1994 Northridge earthquake (M=6.8) and structure of the upper crust (Davis and Namson, 1994). We interpret the Santa Monica Mountains and Santa Susana Mountains anticlinoria as crustal-scale fault-propagation folds above blind thrusts. Movement along the Pico thrust, making the Santa Susana Mountains anticlinorium, generated the Northridge earthquake. The Elysian Park and Pico thrusts flatten into a mid-crustal horizontal detachment. An alternative model by Yeats and Huftile (1994) places the earthquake on the Oak Ridge fault which they interpret to dip steeply into the mid-crust.

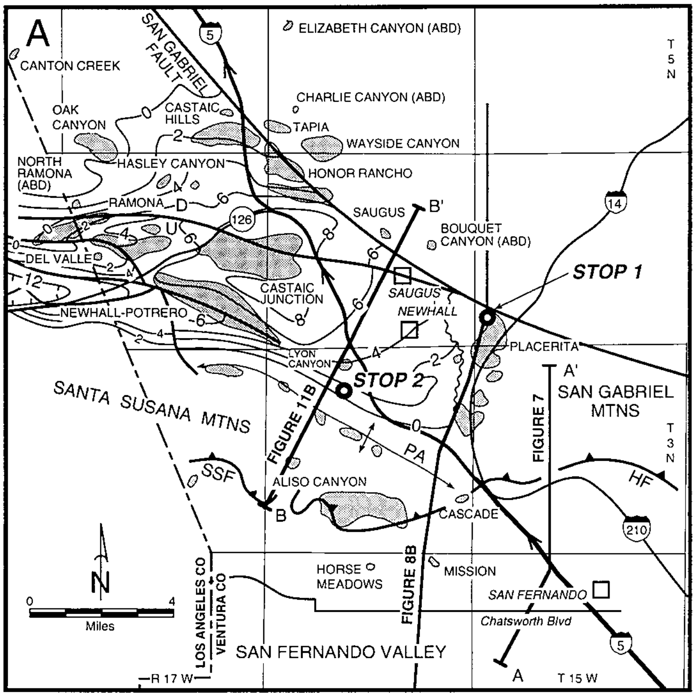

Figure 8A. Structure contour and oil field map of the eastern Ventura Basin (modified from Hindle et al, 1991 and DOG, 1974). Contours on top of Modelo Formation (Monterey Formation equivalent). Abbreviations: HF=Hospital fault; PA=Pico anticline, SSF=Santa Susana fault.

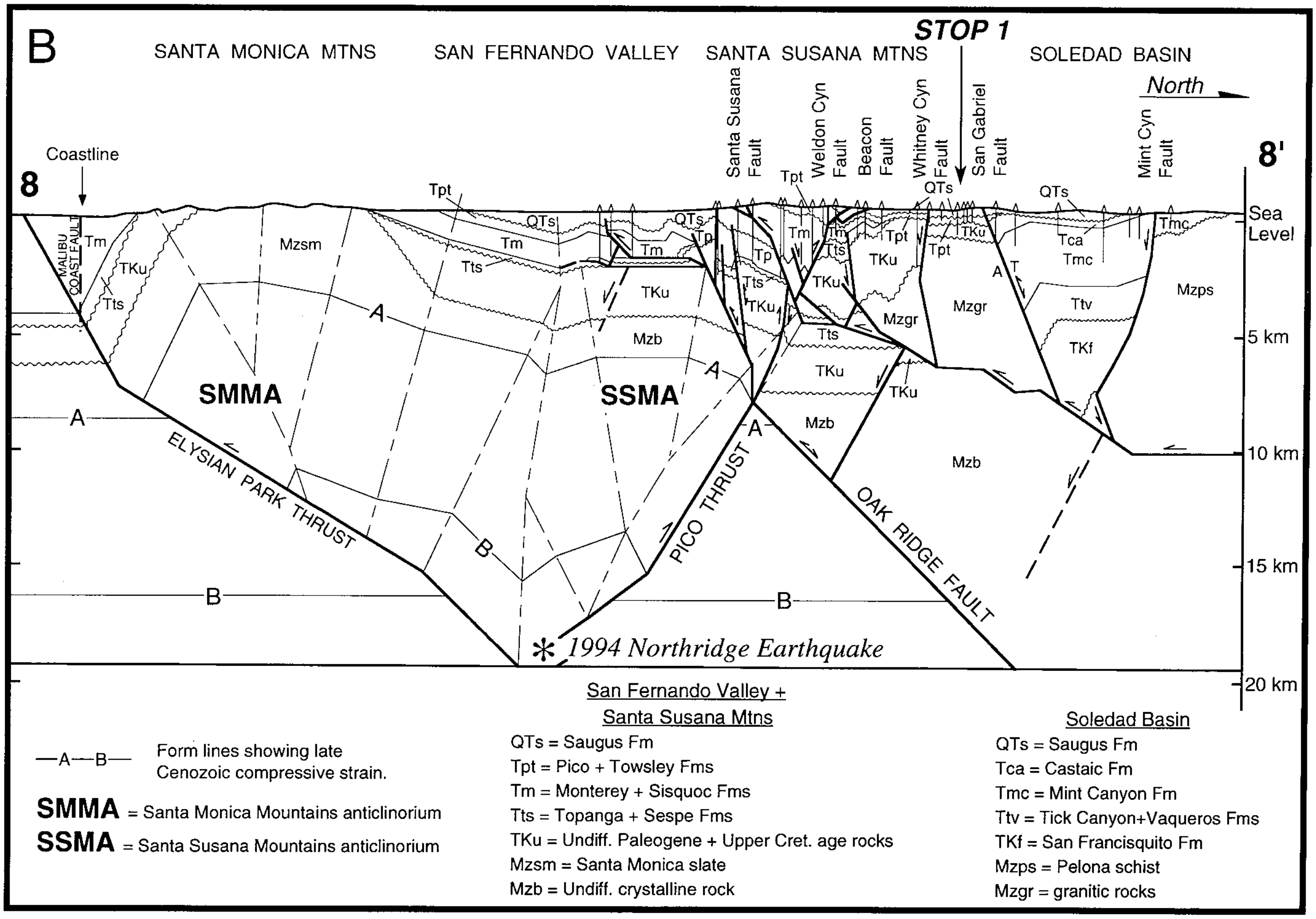

Figure 8B. A regional cross section across the Santa Monica and Santa Susana Mountains showing a fold and thrust belt interpretation of the 1994 Northridge earthquake (modified from Davis and Namson, 1994).

Take Interstate 5 across the northwest portion of the Los Angeles basin. Cross the San Fernando Pass which is the break between the San Gabriel Mountains on the east and the Santa Susana Mountains on the west. Take the Antelope Valley Freeway east off of Interstate 5 and exit at Sierra Highway. Enter the Placerita oil field via the main entrance off the Sierra Highway. The field is private property and hazardous, and permission must be obtained from ARCO before entering the field. Take a field road up to drilling pad near the wellhead of Kennedy #11-22.

Stop #1, Eastern Ventura Basin and Placerita Oil Field

From the oil field is a sweeping view of the San Gabriel Mountains to the east, and to the west the north side of the Santa Susana Mountains with outcrops of upper Miocene and Pliocene clastic rocks-some equivalent to the Placerita oil field reservoirs. These outcrops are along the Pico anticline which will be visited at Stop #2 (Fig. 8A). The oil field produces from the lower Pliocene Kraft zone of the Pico Formation derived from erosion of the crystalline rocks of the San Gabriel Mountains. Hike up a short distance to the top of the ridge behind the well pad and observe the linear northwest-trending canyon formed by erosion along the San Gabriel fault. Steeply-dipping beds of the non-marine Saugus Formation are exposed along the trace of the fault. In the subsurface the fault dips about 60° to the northeast and its most recent motion is reverse separation. Here the San Gabriel fault is the eastern termination of the petroliferous Ventura basin and to the east is the Soledad basin-a mostly non-marine basin of late Oligocene through late Miocene age. To the northwest, on the skyline, is the Ridge Basin which formed along the San Gabriel fault during late Miocene right strike-slip (Crowell, 1975a,b). The Placerita Canyon area is also noteworthy because commercial quantities of gold were discovered in 1842, six years before the famous gold rush of the northern Sierra Nevada.

Placerita's oil is probably sourced from the Monterey Formation (Fig. 9A), and ARCO proprietary geochemical data suggest that the gravity of the oil is inversely related to the degree of biodegradation. Placerita sits on a high block which lacks Modelo Formation (Monterey Formation equivalent). Burial history modeling shows that all of the Neogene strata are extremely immature for hydrocarbon generation, which is corroborated by the high porosity and permeability of the reservoir rocks.

Placerita's oil was sourced from the eastern Ventura basin deep, located 10-15 km to the northwest (Fig. 8A) and Figure 9B shows a burial history from that area. This thermal modeling suggests that the top of the thick Modelo Formation is just now beginning oil generation (Figs. 9B-D). The base of the Modelo Formation began oil generation during rapid deposition of the Saugus Formation, starting approximately 2 Ma (Yeats and others, 1994). It may be generating gas today, accounting for the free gas (as gas zones or gas caps on oil fields) that occurs in several eastern Ventura fields (Castaic Junction, Aliso Canyon, Oak Canyon, and Honor Rancho). Free gas is uncommon elsewhere in the onshore Ventura basin, possibly because Monterey Formation maturity is not high enough to cause gas generation.

Oil migration paths to Placerita field from the generation area probably changed markedly in the last 1 Ma, due to crustal shortening and uplift. Miocene and Pliocene isopach maps (Yeats and others, 1994) suggest that before shortening started, the basin was dominated by a southwest dip, so that any lower Modelo Formation oil that was generated migrated mainly north and east toward the San Gabriel fault. Present-day structure maps of the Modelo Formation (Hindel and others, 1991) show that migration paths are now much more tortuous and shorter. Large amounts of oil are now migrating into the crests of the anticlines containing Newhall-Potrero, Castaic Junction, and other fields where the monoclinal dip previously predominated.

Summary of Placerita Oil Field

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This article is a summary of Berkman (1994). Placerita oil field was discovered in 1920 but full-scale development did not take place until 1949 when light oil was discovered in an area known as Confusion Hill. The discovery started one of the biggest town-lot leasing booms in California history as much of the area had been subdivided into tiny parcels (71 acres sold as 80 acres). At one point in 1949, 48 rigs were working and production peaked at 36,000 BOPD from 100 wells. Production declined rapidly and many of the leases were abandoned and left in disarray with some of the old tanks and corroded wellheads still remaining. Presently the field produces approximately 3500 BOPD (12° API) with cyclic steaming and steamflood injection support. Here we discuss the results of ARCO's geological and reservoir analyses of the main producing interval, the Pliocene lower Kraft zone, and completion and steam management strategies developed to optimize recovery from the complex reservoir.

A structure contour map shows the field is a west-dipping homocline bounded on two sides by faults (Fig. 10A). On the north is the San Gabriel fault, which is actually a complex zone of north-dipping faults, formed during several episodes of deformation involving right strike-slip with normal separation followed by reverse separation. Several strands of the fault cut the upper Kraft zone and Saugus Formation

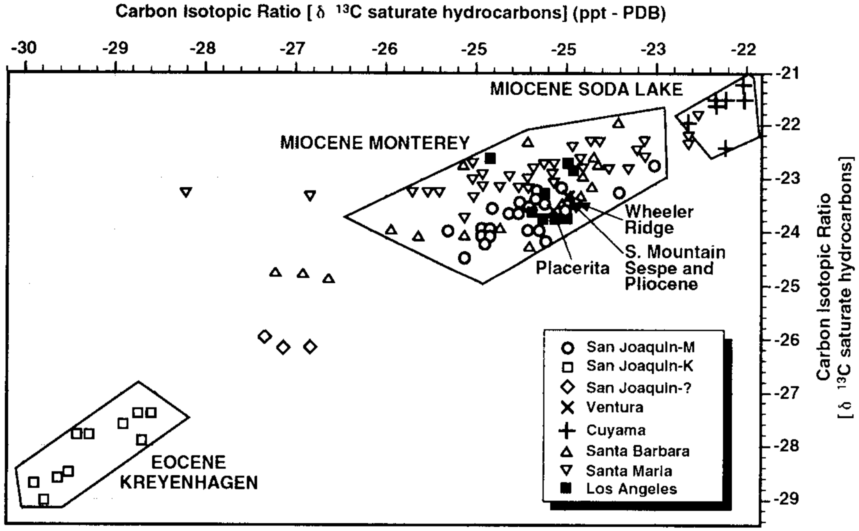

Figure 9A. California oil families showing Placerita, Wheeler Ridge, and South Mountain fields. Courtesy of Albert Holba, ARCO Exploration and Production Technology Company.

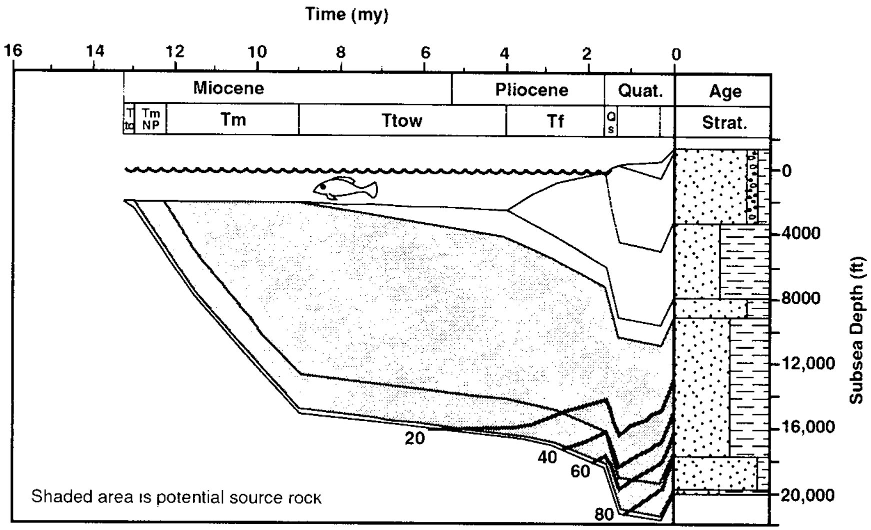

Figure 9B. Eastern Ventura kitchen burial history showing transformation ratio (%). Castaic field vicinity. Composite of Exxon NL&F #18, 53, and 78 wells. Heat flow = 1.1 HFU.

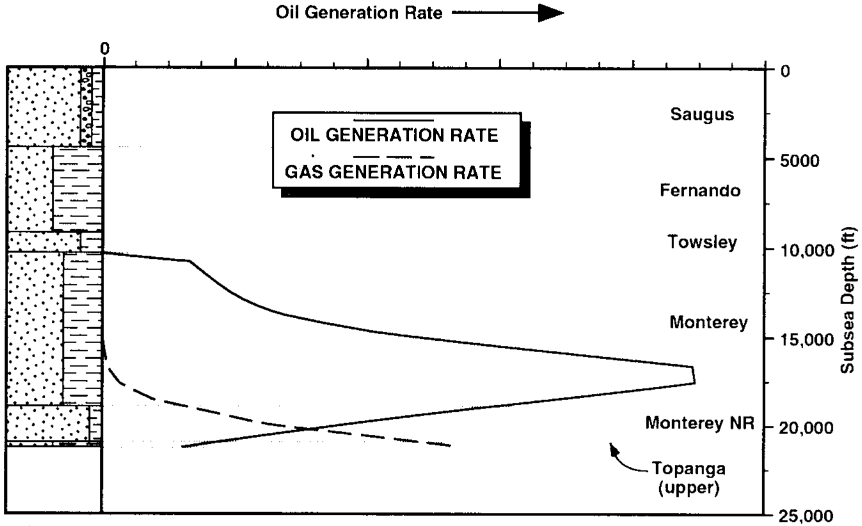

Figure 9C. Eastern Ventura kitchen hydrocarbon generation rates versus depth.

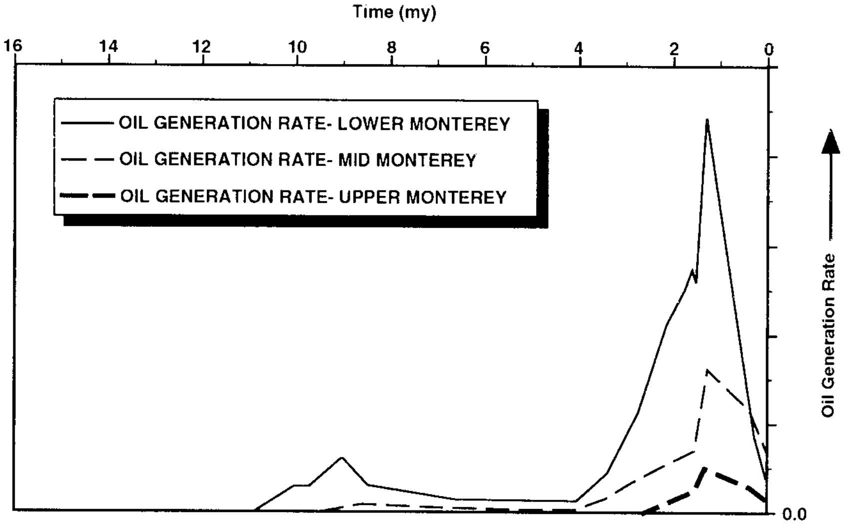

Figure 9D. Eastern Ventura kitchen Monterey oil generation rates versus time.

in wells along the northern margin of the field. The west-dipping Whitney Canyon reverse fault bounds the field on the east and oil-stained cores and seeps east of fault show it is a broken or leaky trap. Miocene movement along the San Gabriel fault may be responsible for Placerita anticline (Fig. 10A) which existed as a high during the Pliocene and restricted deposition of the lower Kraft zone. The west edge of the field is defined by a very irregular oil/water contact (Fig. 10A) which varies by about 200 m in less than 1.6 km, and equivalent reservoir sands are productive in the north while wet in south. The field has an edge-water drive, with a handful of wells in the southwest through the oil-water contact.

The Placerita oil field has reservoir characteristics comparable to other fields in California, such as Midway Sunset and Kern River, where steam flooding has been extremely successful at maximizing ultimate recovery. At Placerita reservoir steam heating lowers the oil viscosity from about 10,000 cp at 90°F to 13 cp at 300°F. Understanding the complex lower Kraft reservoir is critical to the success of the steamflood and although intra-field correlations are difficult they are solvable by integrating all available geological, engineering and production data. Early interpretations of the lower Kraft zone as a continuous reservoir with a few shale interbeds were ideal for steamflooding, however, additional drilling shows these sands are independent packages which may or may not be connected at some point in the field.

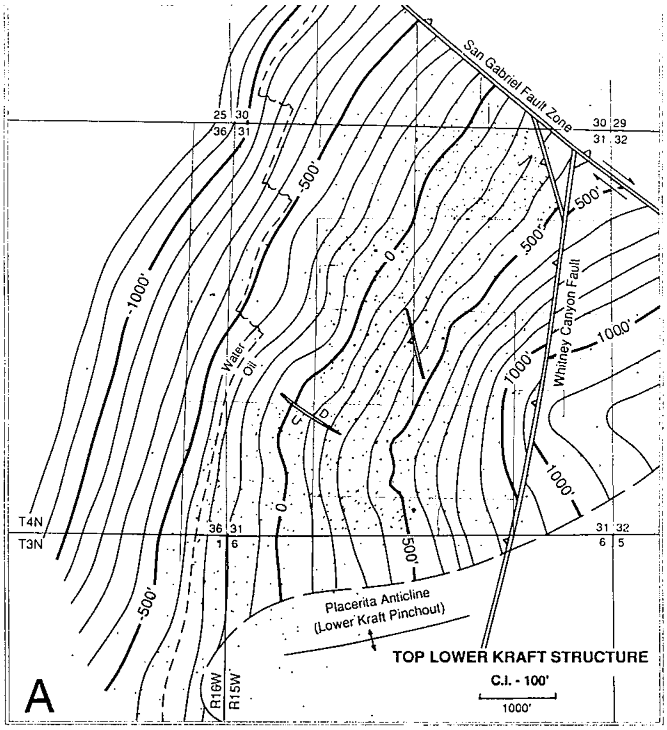

Figure 10A. Structure contour map of the Placerita oil field. Contours on the top of lower Kraft zone which is the main producing horizon.

Excellent exposures of the lower Kraft zone are along the Sierra Highway near the Tunnel area of Newhall field, and in old roadcuts and cliff exposures east of Highway 14 via the gated Remson Street underpass. The Sierra Highway locality contains spectacular exposures of large-scale channel facies hundreds of feet high and the irregular terrain allows three-dimensional views. In the subsurface, we have subdivided the lower Kraft zone into four main sandstone bodies each with separate subzones (Fig. 10B). These bodies have linear to lobate forms up to 50 m thick separated by discontinuous shale beds. Figure 10B shows a complex reservoir consisting of numerous amalgamated channels, sudden facies changes, interbedded sand-shale sequences, and onlap against an Eocene paleo-high (Placerita anticline) located to the south. It is evident that individual channelized sandstone bodies in the lower Kraft are of limited lateral extent. For example, the "Sand 2" channel is approximately 200 m wide in the center of the field. The shale is even less continuous than the sandstone bodies. The shale records interchannel levee and overbank fine-grained deposition, which were sometimes eroded by the next channel system.

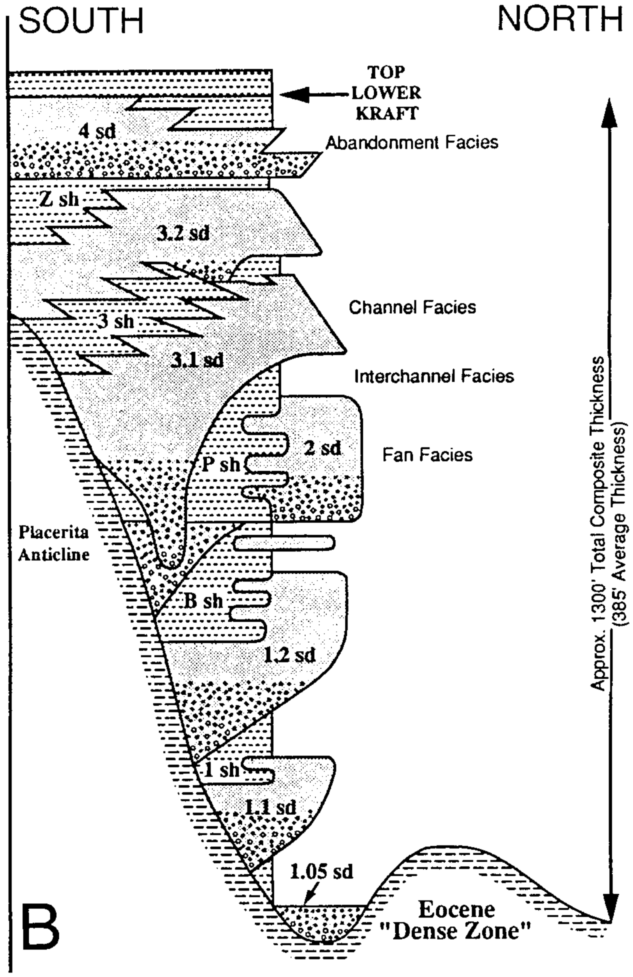

Figure 10B. Lower Kraft zone type log for the Placerita oil field. See text for discussion of subdivisions and facies.

Temperature logs indicate that the shale forms effective seals and baffles for confining steam. In a single five spot steamflood pattern, it is often necessary to complete surrounding injectors in different zones to achieve flooding of all perforated zones in corresponding producers.

The lower Kraft zone was deposited in middle to outer neritic water depths by rapid turbidite deposition based on fossil (mainly foraminiferal) and lithologic data, regional setting, and stratigraphic position. The lower Kraft facies is similar to facies of the late Miocene Puente Formation of the Los Angeles basin where nested channels and sediment lobes were formed along the shelf-edge and slope (Lyons, 1991). Microfossils recovered from core and ditch samples from the lower Kraft zone place it in the "middle Pico" member of the Pico Formation (Dumont, 1990a,b). Foraminiferal checklists from Dumont were compared with published lists from exposures of "type" Pico deepwater deposits in nearby Pico Canyon (Winterer and Durham, 1962) where water depths are significantly deeper than the range of depths for forms at the Placerita field. The Pico Canyon section indicates prograding up section from water depths of 600-900 m to a depth of 200-500 m reflecting regional regression of the Ventura Basin.

Lower Kraft sands at the Placerita field are similar in thickness to coeval sands at Pico Canyon and in the Newhall Potrero oil field. This is in contrast with the gross Pico thickness which decreases from 1,500 m in the Newhall-Potrero field to about 100 m at Placerita field. Most of the decrease occurs in the upper part of the formation as shown by detailed mapping of coarse clastic beds by Winterer and Durham (1962). They were also able to show that the contact between the Pico and overlying Saugus Formation occurs at lower and lower stratigraphic levels eastward from Pico Canyon implying that the Pico sands at the Placerita field and those in Pico Canyon may be depositionally contiguous and time transgressive.

Convergent folding and faulting in the east Ventura basin initiated during the late Pliocene (Yeats and others, 1994). Ongoing tectonism resulted in pulses of coarse clastic sediment into the basin and structural warping and faulting occurred along the basin edges as well as sediment loading within the basin. Regression along the basin edge caused fan deltas to prograde across the exposed shelf with turbidite complexes formed at the distal toes of the deltas. Uplift and erosion along the San Gabriel fault resulted in a complex of nested channel fill deposits in the Placerita field.

Take the Antelope Freeway west to the intersection with Interstate 5 and take the Interstate north. Outcrops along the highway are Towsley and Pico Formations along the northeast limb of the Santa Susana anticlinorium. To the north the Santa Clara Valley is underlain by a thick sequence of Quaternary non-marine deposits (Saugus Formation), the erosional products of crustal convergence and uplift. Exit at Calgrove Road and go left to the Ed Davis Regional Park.

Stop #2, Eastern Ventura Basin, Towsley Canyon and the Santa Susana Mountains

Park at the upper parking area of Ed Davis Regional Park (Fig. 11A). We will hike about one kilometer up Towsley Canyon to the core of the Pico anticline (Note as of March 1996 the upper part of the canyon was still closed to visitors). Towsley Canyon is located along the northeast side of the Santa Susana Mountains which have uplifted and exposed rocks of the petroliferous eastern Ventura basin. Here is a good place to consider the short and long term effects of the 1994 Northridge earthquake. The high ridge line to the southwest is Oat Mountain which was uplifted about one meter during the earthquake and the nearby steeply-dipping strata belong to the north limb of the Santa Susana Mountains anticlinorium which Davis and Namson (1994) interpret to be the result of numerous movements on the Pico thrust.

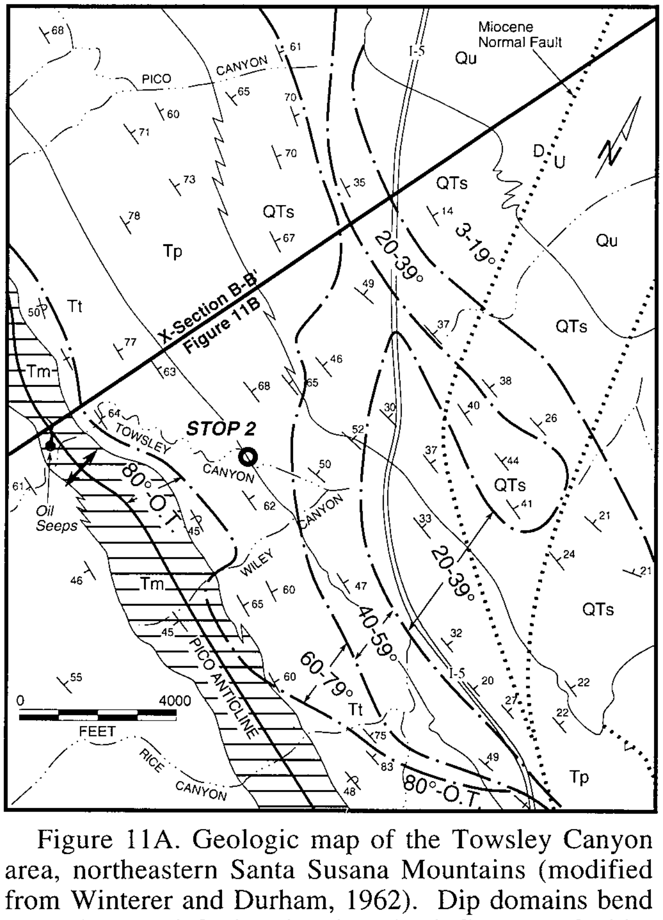

Figure 11A. Geologic map of the Towsley Canyon area, northeastern Santa Susana Mountains (modified from Winterer and Durham, 1962). Dip domains bend around normal faults showing the influence of older basin structure during basin inversion. Abbreviations: Tm=Modelo Formation, Tt=Towsley Formation, Tp=Pico Formation, QTs=Saugus Formation, Qu=undifferentiated alluvial strata.

Surface mapping (Winterer and Durham, 1962) combined with a number of deep exploration wells drilled in the eastern Ventura basin allow the construction of deep cross sections and subsurface maps in this complex area. During Miocene and Pliocene time the eastern Ventura basin was a graben between the Oakridge fault system and, on the east, the San Gabriel fault and an unnamed subsurface fault (Fig.11B). Subsequently the Santa Susana Mountains anticlinorium propagated basinward to the unnamed normal fault creating a curvature in the fold geometry (Fig. 11A). The Santa Susana fault is exposed near the crest of the Santa Susana Mountains southwest of Towsley Canyon. The fault dips to the northeast and the Pico anticline and Towsley Canyon lie in the hanging wall of the fault. During late Pliocene and Quaternary convergence the thickest portion of the eastern Ventura basin was thrust southward over the basin margin by the Santa Susana fault. Davis and Namson (1994) propose that the Santa Susana fault formed prior to being folded by the anticlinorium since the north limb of the anticlinorium folds both the hanging wall and footwall of the Santa Susana fault (Fig. 11B). For an alternative interpretation of the structure of the eastern Ventura basin see Yeats and others (1994). The Aliso Canyon oil field (59 MOEB) is in the footwall of the Santa Susana fault (Fig. 8A), and the previously presented basin modeling (Figs. 9B-D) suggest the field was charged with hydrocarbons during basin inversion.

Deep erosion of Towsley and several other canyons along the northeast flank of the Santa Susana Mountains provide easily accessible transects through the basinal portions of a typical southern California coastal basin. Canyon exposures provide an excellent record of deep marine deposition during the late Miocene and Pliocene, basin shoaling beginning in the late Pliocene, and Quaternary non-marine deposition. Winterer and Durham (1962) in their pioneering work on deep-water deposition provide an excellent map, field descriptions, and paleoenvironmental interpretation of this area. Upstream (west) from the upper parking lot the Pico Formation grades downward to interbedded sandstone, mudstone and conglomerate of the Towsley Formation. About 500 m upstream from the upper parking area Towsley Canyon becomes steep-walled and narrow with excellent exposures of the lower part of the Towsley Formation. Paleontological data show the lower unit

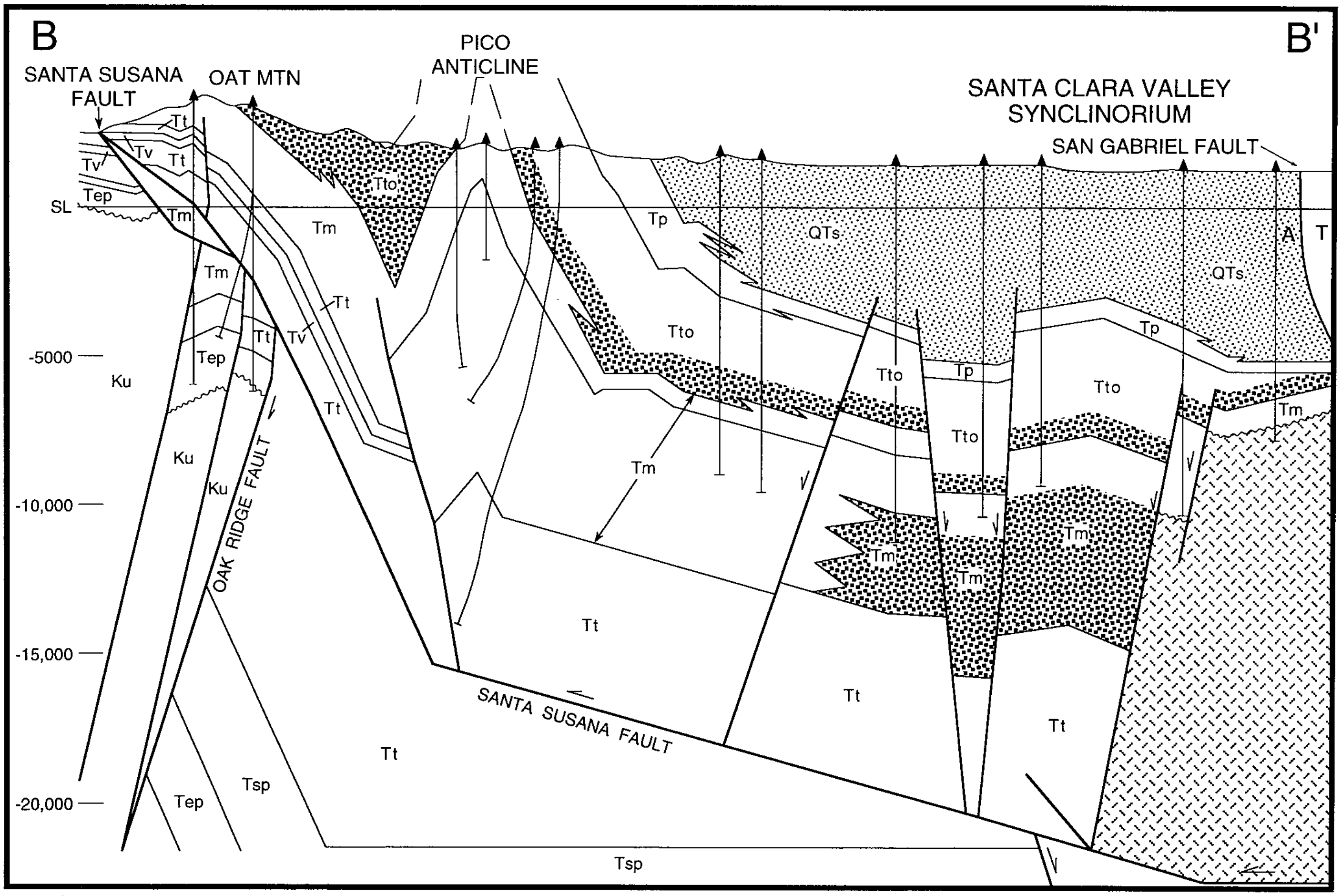

Figure 11B. Cross section across the Santa Susana Mountains showing inversion of the eastern Ventura basin. Abbreviations: Ku=upper Cretaceous strata, Tep=undifferentiated Paleocene and Eocene strata, Tt=Topanga Fm; Tv=Topanga Fm igneous unit; Tm=Modelo Formation, Tto=Towsley Formation, Tp=Pico Formation, QTs=Saugus Formation.

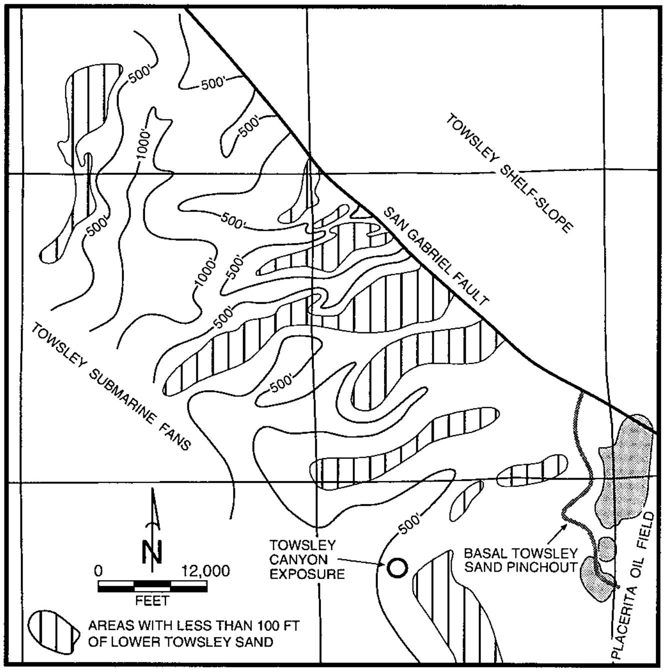

Figure 11C. Isopach map of the lower sandstone (Hasley Conglomerate) of the Towsley Formation (modified from Sitt, 1986).

was deposited at outer neritic to bathyal depths, and Winterer and Durham (1962) proposed this coarse-grained unit was a turbidite deposit. Stitt (1984) mapped out the lower Towsley Formation showing a pattern of southwest-trending alternating fan and interfan deposits that emanated from the area of the San Gabriel fault (Fig. 11C). Crystalline rock clasts suggest the fan system was derived from a horst block along the San Gabriel fault, or the fan system was offset by the fault from its source in the western San Gabriel Mountains (Crowell, 1952).

Beyond the gorge the Towsley Formation is underlain by silty shale of the Modelo Formation which is exposed in the core of Pico anticline. Numerous oil seeps occur along the crest of the anticline (Fig. 11A) which was the site of some of California's earliest exploration efforts. In 1876, in nearby Pico Canyon, Pacific Coast Oil Company completed California's first commercial oil well.

Take Interstate 5 north across the Santa Clara Valley. The deepest part of the eastern Ventura basin is just west of the intersection of Highway 126 and Interstate 5 (Fig. 8A). Outcrops east of the intersection are folded Saugus Formation along the San Gabriel fault and the fault crosses Interstate 5 at the Honor Rancho. Just before climbing the steep grade look west (left) up a small canyon for resistant outcrops of the Violin Breccia, a late Miocene age scarp deposit along the San Gabriel fault. We are now entering the lowermost portion of the Ridge basin (Fig. 12A), and roadcuts along the steep grade expose the upper Miocene Castaic Formation-a deep marine deposit. Exit the interstate at Templin Highway and go east to the intersection with the Old Ridge Route

Stop #3 (optional) Ridge Basin

At the intersection of the Old Ridge Route and Templin Highway are excellent road-cut exposures showing the marine to non-marine transition within the Ridge Basin and a nearby overview of the southern Ridge Basin (Fig. 12A). The marine to non-marine transition is within the Marple Canyon Sandstone Member, the lowermost portion of the Ridge Route Formation. Marine strata are exposed south and east of the intersection along the Old Ridge Route and Templin Highway and consist of slope facies and channel and interchannel turbidites with numerous slump-folded beds and other soft sediment structures. West and north of the intersection and above the marine beds are non-marine fluvial-deltaic deposits which prograded over deep marine as the basin filled.

Climb the small hill north of the intersection for a view of the southern Ridge basin. To the east is Castaic Canyon which exposes the lower portion of the Ridge Basin. Outcrops across Castaic Canyon are the upper Cretaceous to Paleocene San Francisquito Formation which, near the bottom of the canyon, are overlain with angular discordance by the Castaic Formation. Southwest of the view location and across Interstate 5 is an elongate ridge underlain by the Violin Breccia and the San Gabriel fault.

Ridge Basin is a northwest plunging asymmetric synclinorium along the east side of San Gabriel fault (Fig. 12A). Extensive research on the basin (Crowell, 1975b; Crowell and Link, 1982; and Link 1987) has shown that the basin formed from 12-8 Ma during large scale right-lateral slip on the San Gabriel fault, an early strand of the San Andreas fault (Fig. 12B). These workers believe the basin fill was laid down, shingle-like, from south to north as a result of movement along the San Gabriel fault (Fig. 12C). The total stratigraphic thickness of the basin (13.5 km) was never present at any one location which is consistent with maturity data (Fig. 12D). To explain the filling of the Ridge Basin Crowell (1982) postulated a conveyor-belt mechanism where the depocenter migrates northward remaining adjacent to a source area across the San Gabriel fault (Fig. 12C middle and upper). This model fails to explain the shingle nature of the bulk of the Ridge Basin deposits which were not derived from across the San Gabriel fault. The shingle-like nature of the Ridge Basin strata resembles stratal arrangements commonly observed above active structures (Suppe and others, 1992). A seismic line across the northern portion of the San Gabriel fault shows it to have a listric shape and dip under the Ridge Basin (May et al., 1993). If the listric-shaped fault surface has a north plunge under the Ridge Basin, right-slip would produce a shingle-like pattern of growth strata in the overlying basin regardless of the position of the source area (Fig. 12C lower).

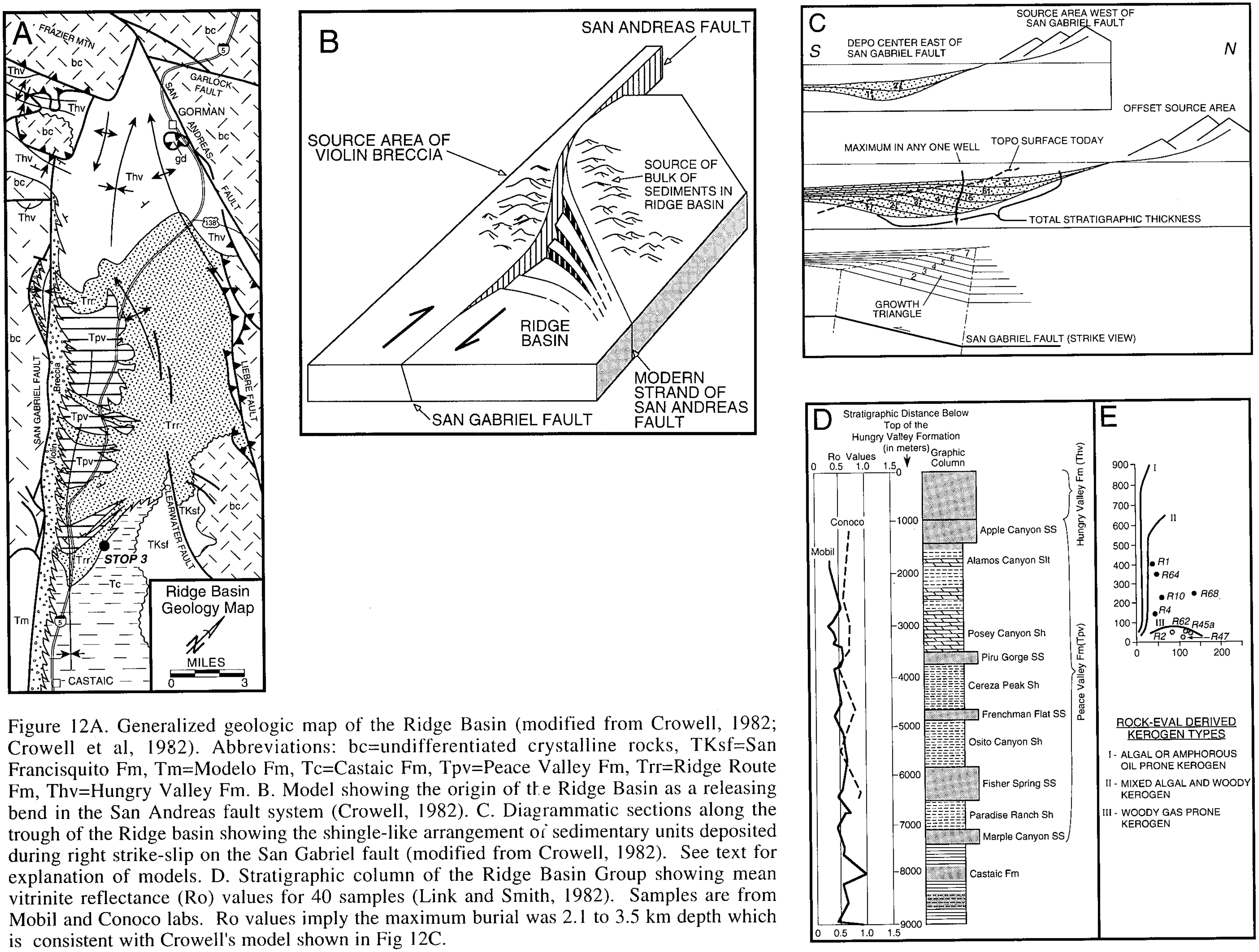

Figure 12A. Generalized geologic map of the Ridge Basin (modified from Crowell, 1982; Crowell et al, 1982). Abbreviations: bc=undifferentiated crystalline rocks, TKsf=San Francisquito Fm, Tm=Modelo Fm, Tc=Castaic Fm, Tpv=Peace Valley Fm, Trr=Ridge Route Fm, Thv=Hungry Valley Fm. B. Model showing the origin of the Ridge Basin as a releasing bend in the San Andreas fault system (Crowell, 1982). C. Diagrammatic sections along the trough of the Ridge basin showing the shingle-like arrangement of sedimentary units deposited during right strike-slip on the San Gabriel fault (modified from Crowell, 1982). See text for explanation of models. D. Stratigraphic column of the Ridge Basin Group showing mean vitrinite reflectance (Ro) values for 40 samples (Link and Smith, 1982). Samples are from Mobil and Conoco labs. Ro values imply the maximum burial was 2.1 to 3.5 km depth which is consistent with Crowell's model shown in Fig 12C.

From a petroleum standpoint, the Ridge Basin is anomalous. It is surrounded by richly-productive Neogene basins to the north, west, and south, yet the Ridge Basin itself is not productive. As Link and Smith (1988) have shown, the lack of production may result from poor quality source rock and immaturity. HI and TOC measurements on samples distributed throughout the basin (Fig. 12E) average about 150 mgHC/g rock and 1%, respectively. Vitrinite reflectance data mostly range from 0.4%-0.8, showing that the section is immature (Fig. 12D). Why is high-quality source rock not present in this basin? The basin has a number of characteristics associated with rich lacustrine source rocks: tectonic ponding, significant basin duration (approximately 7 Ma), and thick lacustrine shale deposition. A contributing factor may have been climate. The Ridge Basin's climate was probably temperate, whereas a tropical climate promotes rich lacustrine source rock development (Katz, 1990). In a more temperate climate, seasonal overturn allows yearly oxygenation of bottom waters, disrupting the anoxic conditions helpful to kerogen preservation.

Continue north on Interstate 5 along the trough of the Ridge Basin. The Interstate is built along the San Andreas fault zone at the town of Gorman and a number of tectonic geomorphic features occcur here such as sag ponds, offset gullies and pressure ridges. North of Tejon Pass the Interstate crosses the Garlock fault, a major left strike-slip fault of southern California. Interstate 5 is along Grapevine Canyon which decends steeply into the San Joaquin Valley and divides the San Emigdio Mountains on the west from the Tehachapi Mountains on the east (Fig. 13A). The mountains are being rapidly uplifted above the San Joaquin Valley and headward erosion of drainages such as Grapevine Canyon are capturing the gentler-sloped intermontane drainage network. At the front of the range Interstate 5 crosses faults scarps along the Pleito thrust. The thrust places Eocene, Oligocene and Miocene age strata over the Quaternary alluvial units of the valley. Throughout the San Emigdio Mountains the Eocene rocks, which are in the hanging wall of the Pleito thrust system, lie unconformably on the crystalline basement with no evidence of fault detachment. In southern California there seems to be few examples of fault detachment of the sedimentary cover from crystalline basement.

San Emigdio Mountains Summary

The San Emigdio Mountains are a late Pliocene and Quaternary age fold and thrust mountain range along the Pleito thrust system (Fig. 13A). Recorded in the San Emigdio Mountains are older tectonic events that have played an important role in development of the southern San Joaquin basin and other southern California basins. In addition surface exposures, abundant well data, and the proximity of the San Andreas fault make the San Emigdio Mountains an excellent site for the construction of cross sections and the study of transpression.

Figure 13B is a cross section across the San Emigdio Mountains which shows 11.5 km of structural relief on the top of the crystalline basement between the crest of the San Emigdio Mountains and the floor of the San Joaquin basin. Restoration of the cross section to late Pliocene time (Fig. 13C) show that only about 2-3 km of this relief is due to the late Pliocene and Quaternary convergence and about 8-9 km of relief developed between middle Eocene and early Pliocene.

Within the San Emigdio Mountains are several structural and stratigraphic indicators of 2-3 km of uplift during latest Eocene and Oligocene time: 1) The Pleito Formation contains submarine slides or debris flow deposits (seismites of Fig. 14A; DeCelles, 1986). 2) The coarse-grained non-marine Tecuya Formation is the result of nearby uplift. 3) The Caballo Canyon thrust fault placed crystalline basement over sedimentary rocks while an angular unconformity formed in the hanging wall (shown only in Figs. 3A,B). Convergent uplift is believed to be part of the Ynezian orogeny which separates the older expansive forearc basin setting from the younger and more restricted late Cenozoic basins (Fig. 14A).

Throughout the San Emigdio Mountains is a complex set of late Oligocene to early Miocene extensional faults related to the early phase of basin formation. These faults are overlapped by deep-marine strata of middle to late Miocene age deposited during regional subsidence. Middle Miocene to lower Pliocene strata are 3-4 km thicker along the downthrown side of the White Wolf fault than equivalent strata in the higher block suggesting the fault was a north-dipping normal fault separating two subsiding blocks: a rapidly subsiding north block and a slower subsiding south block. Well control shows that the White Wolf fault now dips steeply to the south. We believe the fault was folded into a reverse fault during late Pliocene and Quaternary shortening.

Most of the surface anticlines have formed during late Pliocene and Quaternary convergence and appear to be fault-propagation folds as they are asymmetric to the north and well and surface data show the anticlines lie along thrust ramps that dip less than 25° to the south. Recent uplift of the San Emigdio Mountains has exposed the southern end of the San Joaquin basin (Fig. 14A) and the east-west orientation of the range provides a unique stratigraphic cross section that assists the structural interpretation (Fig. 14B). Upper Eocene and lower Oligocene clastic rocks grade westward from shallow-marine to deep-marine facies and isopach and facies maps of these rocks across the Pleito thrust show little or no lateral offset (Fig. 14C). Keep in mind the San Andreas fault is never more than 10 km to the south of the Pleito thrust. Similarly small earthquakes have mostly compressive focal solutions (Webb and Kanamori, 1985).