OLD OIL FIELDS AND NEW LIFE: A VISIT TO THE GIANTS OF THE LOS ANGELES BASIN

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INTRODUCTION

This field trip is designed to illustrate the changes that have occurred in the last ten years to the large oil fields in the Los Angeles Basin. In 1973 Truex and others showed the importance of environmental issues when oil fields are developed in an urban setting. A Geologic Field Guide to the Long Beach Area (Clarke and Henderson, 1987) was published in conjunction with the National AAPG meeting in Los Angeles. This guide will build upon update, and complement that work with as little repeat as possible. Wright (1991) gives an excellent overview of the structural geology and tectonic evolution of the Los Angeles Basin.

A helpful aid in navigating the field trip route is the Thomas Guide to the Los Angeles and Orange Counties which is updated annually. Mileage will start at San Clemente (mile 0) and accumulate until the end in Long Beach (mile 77).

The trip will start with brief stops at San Clemente and Dana Point to view some sand bodies that show lateral variations that are difficult to map and model with standard oil field data. Afterward, stops will be made in Newport Beach to investigate the gas leaks that result from poor abandonments of old oil wells. At Reservoir Hill we will observe the large-scale rehabilitation of the giant Huntington Beach Oil field into residential development. Here we will also learn about the latest regulations that impact the clean-up and mitigation practices. In Long Beach, new life is brought to the Wilmington Oil Field through high technology applications. Even high technology is not enough to stop the inevitable demise of the old giant. Everywhere are signs of new uses for the old oil properties. Here we will visit the oil islands and several sites of oil operations and rehabilitation. Finally we will visit the old Long Beach Oil Field at Signal Hill. Here we will observe sites of redevelopment in all stages from planning to completion.

in Patrick L. Abbott and John D. Cooper., eds., 1996,
Field Conference Guide 1996. Pacific Section A.A.P.G, GB 73,
Pacific Section S.E.P.M, Book 80, p.409-430.

ROAD LOG

Day 1

Meet at San Diego Convention Center

Drive north on Interstate 5 and exit at Avenida Magdalena (mile 0), (Avenida Calafia going southbound; Fig. 1). Turn right onto Mendocino and cross over the freeway then turn left onto Avenida Del Presidente. Turn right onto Avenida Calafia and then left into San Clemente State Beach. Parking is at the top of the cliff in the day use area (mile 1). Take the southeast trail down to the beach to view the cliffs. The excellent exposures are easily observed from the train grade. The first two stops provide a rough visual analogy to the larger sand reservoirs of the Wilmington oil field.

STOP 1 - San Clemente State Beach

Here we will observe the transect along the lower part of the sea cliffs. The cliffs and canyons offer an excellent three dimensional view of the upper Miocene portion of the Capistrano Formation. These nested submarine channels illustrate how rapidly stratigraphy can change. Walker (1975) interpreted these rocks as a braided suprafan or suprafan depositional lobe. Hess (1979) considered the sequence as pre-channel sediments on a lower suprafan that were prograded over and cut into by upper suprafan channels. Figure 2 shows Walker's (1975) eight nested channels.

In the Wilmington oil field, geologists have attempted to define the sedimentologic variations that are analogous or comparable to these channels. The Pliocene rocks (Repetto Formation) show great lateral variations. These variations are due to many episodes of rapid deposition. This has resulted in a highly variable series of lobate sands deposited adjacent to, above, or partially cutting through previously deposited sediments. The large lenticular lobes eventually produced a blanket over the Repettian-age basin and the future structures that would later become oil traps.

The channels preserved at San Clemente have many features of significance. The mudstone beds in the channels appear to merge with the mudstone drapes that occur farther up the walls. The sands pinch out against the channel walls only to extend laterally up the walls a short distance. The channel sequences show considerable variation in thickness, and vertical and lateral grading (both coarsening and fining upward).

If these variations can be understood, then more oil can be extracted. Currently efforts are underway in the Wilmington oil field to characterize the Pliocene reservoirs and model the variations. Many of the lobes and channels that were unrecognized several years ago are now being mapped. The lateral extent and thickness are defined first then variations within each unit must be defined or more often estimated because of insufficient data. First a deterministic model is made then, a stochastic model is constructed, and finally a reservoir model is run. This process does not always progress nicely to completion, but as the models are constructed familiarity and experience with the units develop. Subsequently the well profiles are modified and the water flood is adjusted to more effectively produce the oil.

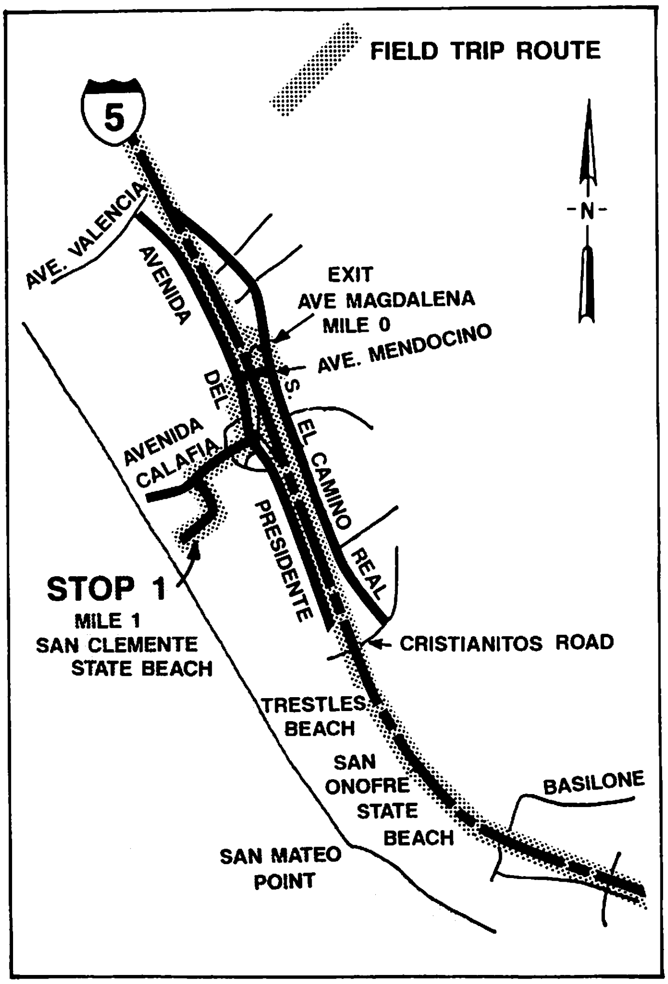

Figure 1. Location map for San Clemente State Beach.

Leave San Clemente State Beach and return to northbound Interstate 5 (mile 2; Fig. 1). Exit Interstate 5 at Beach Cities (mile 7.2). This will take us to the Pacific Coast Highway (Fig. 3). At mile 8.4 is San Juan Creek. Turn left at Dana Point Harbor Drive (mile 8.7). Between mile 9.4 and 9.9, the Doheny Channel of the Capistrano Formation is exposed on the cliffs. Continue around the harbor to the parking area near the Dana Point Maritime Museum at Dana Cove Park (mile 9.9). This area is known locally as Mothers Beach. Here we will observe the deep-water Doheny Channel deposits.

STOP 2 Dana Point and the Doheny Channel

Dana Point Marina is where we will observe the Doheny Channel as exposed on the cliffs behind the harbor. These deposits of the Miocene Capistrano Formation provide an excellent view of the upper submarine fan. The area has been well described in the literature (Reed and Hollister, 1936 ; Normark and Piper, 1969; Piper and Normark, 1971; Vedder and others, 1975; Bartow, 1966, 1971; Ehlig, 1977, 1979; Schlemon, 1978; Normark, 1979; Schweller, 1990). Basically these beds are turbidites composed of poorly graded sandstones of comparable facies to the southeastern portion of the San Clemente channel. But instead of nested channels or diagonal mud drapes to laterally segregate the channel deposits, the turbidites represent a single massive sand body over 800 feet wide. Both channels are cut into fine-grained deep-water siltstones and mudstones. Walker (1975) assigned the San Clemente Channel to the braided suprafan part of the submarine fan, but Schweller (1990) feels that the channel may actually represent the channel deposits that fill part of the canyon near the base of the slope. This may also apply to the Doheny Channel at Dana Point, which Piper and Normark (1971) assign to a suprafan setting in the upper parts of a deep-sea fan. The important thing to observe here is that there can be significant lateral variation in an apparently massive sandstone that would be difficult to accurately model for reservoir analysis. The upper Ranger sands in the Wilmington oil field show these characteristics.

Leave Dana Cove Park along Cove Road (Fig. 3). A fault crosses this road part way up (mile 10.2) as evidenced by the reddish San Onofre Breccia on the left contrasting with the buff colored Capistrano Formation.

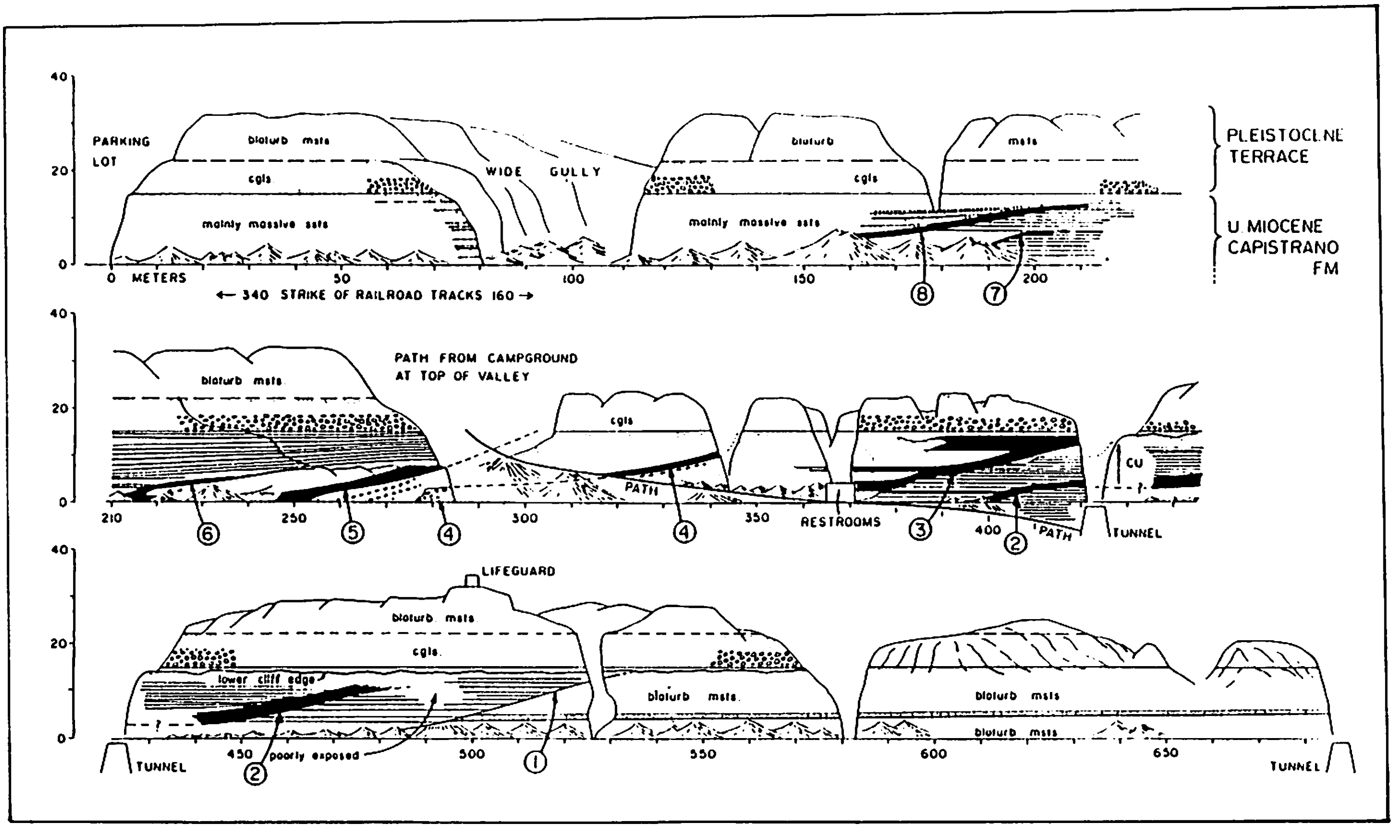

Figure 2. Transect along the cliffs at San Clemente State Beach showing the deep-sea channel outcroppings. Walker (1975) has delineated eight channels. (from Walker, 1975).

Make a right turn at the top of the hill (mile 10.4) and another right turn onto Santa Clara (mile 10.5). To the right is an excellent view of Dana Point Harbor. But our trip continues left onto Blue Lantern (mile 10.6) and then left again onto the Pacific Coast Highway (mile 10.7). We will drive north along the Pacific Coast Highway until we reach Huntington Beach.

Mile 12.6 is Monarch Bay.

Mile 14.8 is Aliso Beach where excellent exposures of the middle Miocene San Onofre Breccia occur in the sea cliffs.

Mile 17.7 puts us in Laguna Beach which is Southern California's best known artists colony. This portion of the San Juan Hills is also famous for landslides. Blue Bird Canyon makes the news annually. Since 1994 this area has been subjected to major wildfires, flooding and landsliding. A brief look around will reveal little evidence of these disasters, however the scenic coastline here is part of a marine preserve and offers some of the best diving in California. The sea cliffs offer excellent exposures of the San Onofre Breccia and the Topanga Formation to the beach-walkers.

The exclusive Emerald Bay is at mile 19.3. Soon after we pass Emerald Bay the coastal area is undeveloped. At mile 19.9 on the left is Crystal Cove State Park. The area on the right will one day be developed as part of the Irvine Ranch Company's master plan. We traverse the surface of a Pleistocene terrace cut on Middle Miocene Monterey Shale. Some of the higher terraces are still visible on the hill side.

At mile 21 is Reef Point a Late Miocene intrusive andesite, and a nice diving spot.

Corona Del Mar at mile 23.8 is another exclusive community along the coast.

The high-end Newport Fashion Island is on the right at mile 25.

At mile 26.4 in the Newport Dunes area Newport Bay can be seen to the right. Warren (1970) points out that the bluffs around the lagoon have provided some of the finest southern California exposures for late middle Miocene marine strata.

Balboa Island and Lido Isle are to the left.

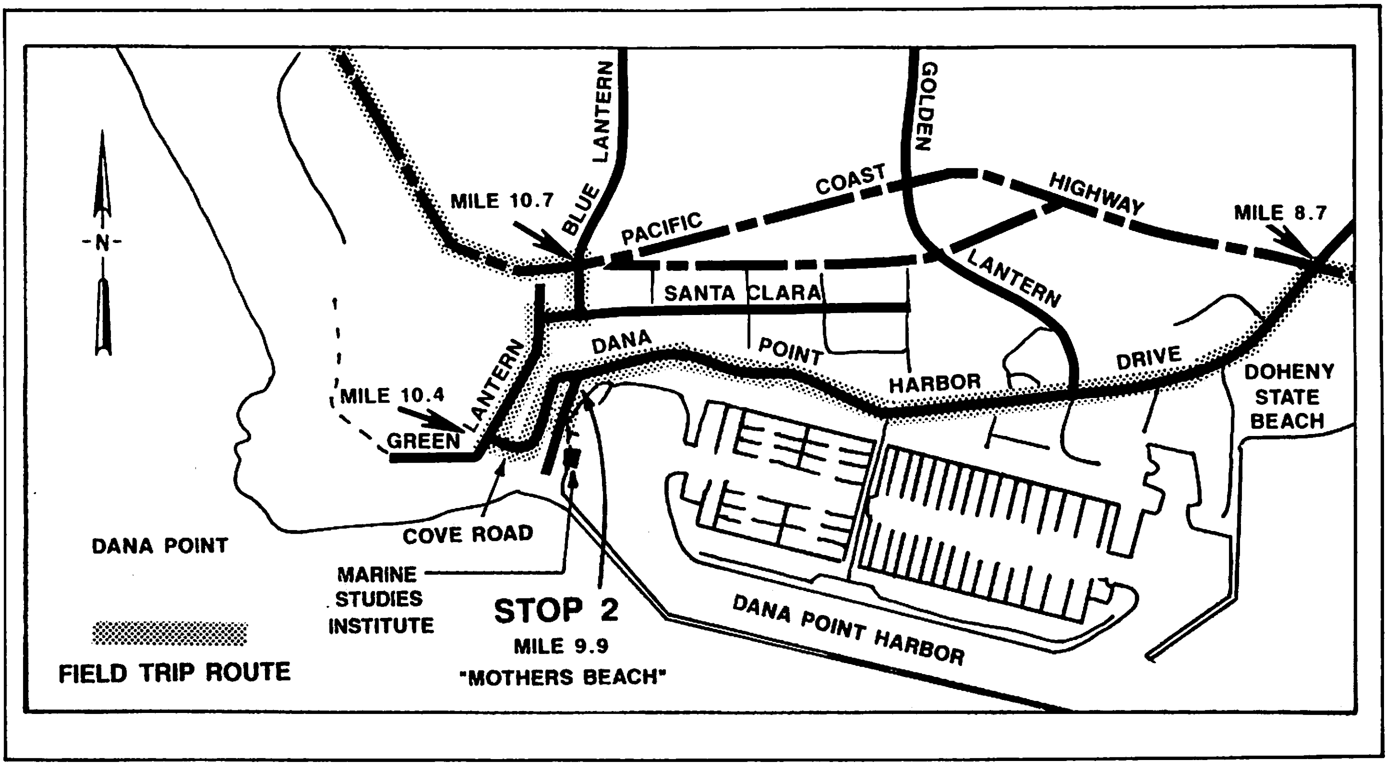

Figure 3. Location of Dana Point Harbor where the Doheny Channel can be observed at Stop 2.

In this area is the Newport oil field discovered in 1922, and has produced 187,000 barrels of oil and condensate and 711,000 Mcf of gas (Parker, 1944; Ingram, 1968b; DOGGR, 1995). Activity in this field is all but gone. Only three wells are still producing. But many gas leakage problems remain. Mel Wright (1996) details many of the problems that we will see at Stops 3, 4, and 5. Because this field was marginally economic from the very beginning many of the oil wells were plugged and abandoned in the 1920's. These wells have developed leaks. Problems range from petroleum or hydrogen sulphide smell to actual building fires resulting from methane ignition.

At mile 26.6 we cross part of Newport Bay (San Diego Creek channel).

Turn right at Old Newport Boulevard (the Arches, mile 28.1).

Turn right onto Catalina Drive (mile 28.2).

Turn left onto Broad Street (mile 28.4).

STOP 3 Noxious Gas Vent

Corner of Broad Street and Holmwood Drive (mile 28.5; Fig. 5). Mel Wright (1996) explains the gas leakage problems in the Newport Beach area. This is the site of a low-volume combustible and noxious gas vent over a vault in a residential front yard next to a small olive tree. This vent has burned for 25 years! There is no well in the immediate vicinity, but a dry hole was drilled 700 feet to the west and a producer was once 2700 feet to the northwest. At this stop and the next two stops we will view the vent stacks for areas that overlie the old Newport oil field. The old abandonments here may have proved to be troublesome, but it is possible that some of the gas seeps are natural. Smell the air.

Turn left onto Westminster Avenue (mile 28.5).Return to Newport Boulevard via Hospital Road (mile 28.7) and go south to 32nd Street (mile 29.2) and turn right again at Balboa Boulevard (mile 29.4). Turn right onto 35th street (mile 29.6) and continue to Marcus Avenue.

STOP 4 Leaking Abandoned Well Vent

In the alley between 35th Street and 36th Street on Marcus Avenue (Mile 29.8) is the southerly most gas problem area in Newport Beach. A leaking abandoned oil and gas well from 1925 has a passive vent that passes through a metal light standard next to a telephone pole

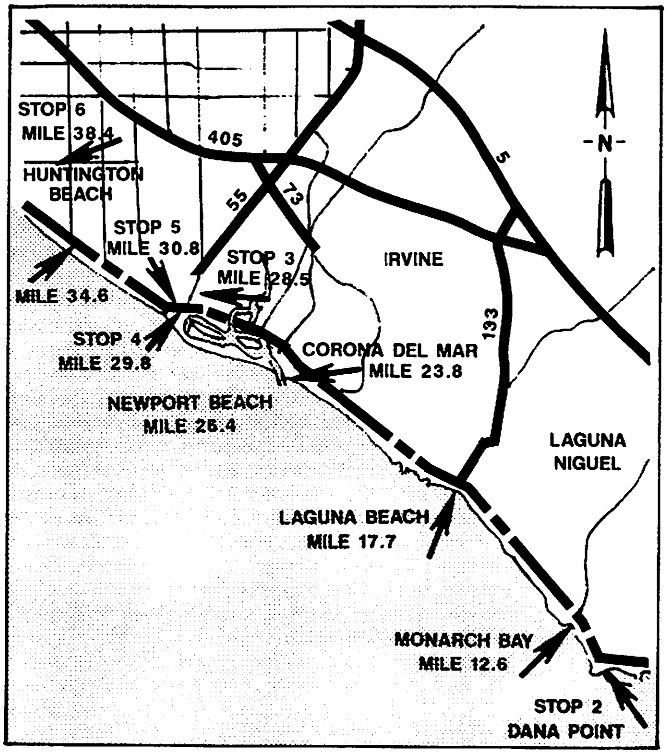

Figure 4. Map of California State Highway 1 from Dana Point to Huntington Beach. Stops 2, 3, 4, 5 and some trip mileage markers are shown with arrows.

that is fed by an underground collecting system. Take a sniff. Maybe the system is inadequate for this residential area. The leaking oil well should be found and reabandoned. To date it has not been done because of the high-density development here.

Turn left onto Marcus Avenue and turn left onto 36th Street. Make a right turn onto Balboa Boulevard (mile 30) and another right turn onto Pacific Coast Highway (mile 30.4). Turn left onto Hoag Hospital Drive (mile 30.8) and park to the right.

STOP 5 The Big Gas Leak in Newport Beach

At mile 30.8 is the largest and probably oldest (1930's) gas leak in Newport Beach. Three wells have been drilled to collect the high-in-hydrogen sulphide methane gas which is flared at the base of the cliff. These wells have produced 90 Mcf per day since 1976. The decision was finally made to put the gas to work, so in 1996 the newly installed compressor, scrubber tanks, and gas meter will supply gas to Hoag Medical Center for heating.

Return to Pacific Coast Highway and turn right onto PCH.

Mile 31.2 The West Newport oil field which was discovered in 1943 extends west from here to Beach Boulevard. West Newport has produced 61,677,000 barrels of oil and 8,058,000 Mcf of gas to date (Corwin, 1956; Hunter and Allen, 1956; DOGGR, 1995). There are currently about 130 active wells. In 1964 cyclic steam was used for stimulation, and in 1969 a fire flood project was initiated.

At mile 32.4 is the mouth of the Santa Anna River and the start of Huntington State Beach. A dune restoration project is underway on the right.

Edison electricity generating plant (mile 34.2).

Turn right at Beach Boulevard (mile 34.6).

Turn left at Garfield Avenue (Mile 37.2).

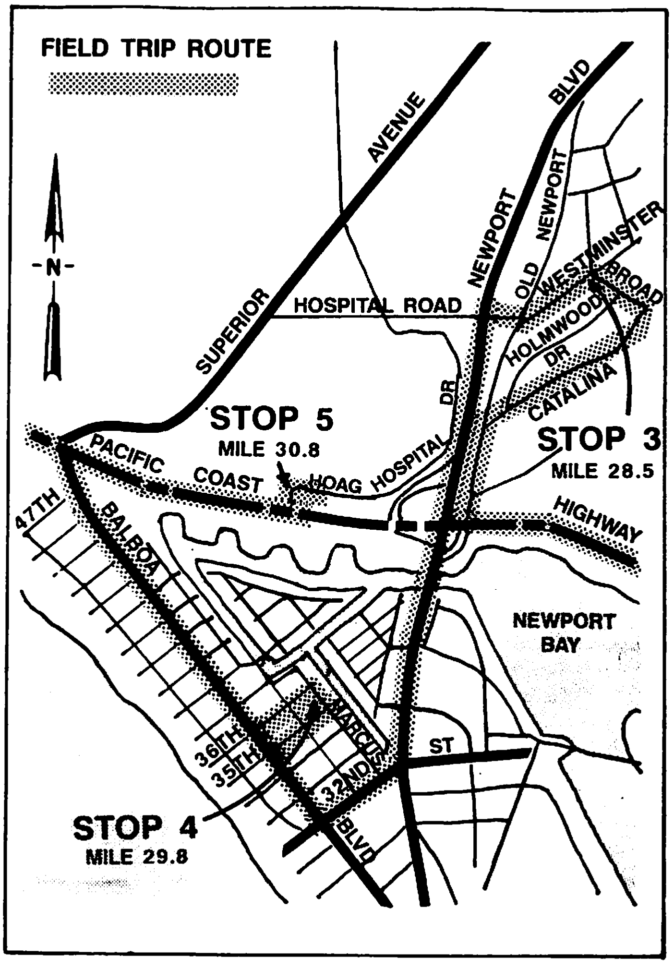

Figure 5. Detail of the Newport Beach gas leak area. Stops 3 and 4 are small residential streets. Stops and mileage markers are shown with arrows. The gas flare at Stop 5 is visible from Pacific Coast Highway.

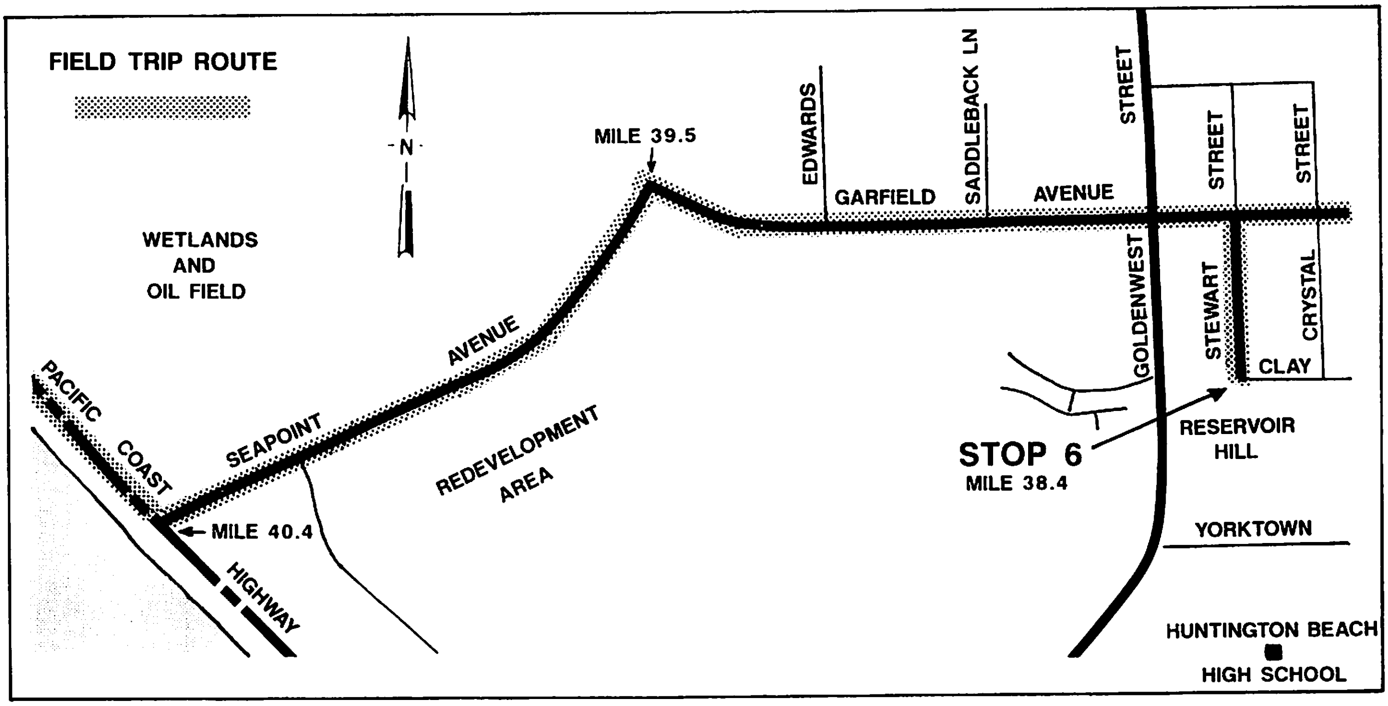

Figure 6. Detail map of central Huntington Beach showing the location of Reservoir Hill; Stop 6. The route along Garfield Avenue and Seapoint Avenue pass through the heart of the redevelopment.

Turn left at Stewart Street (mile 38.1; Fig. 6).

Continue south to Clay Avenue (mile 38.4).

STOP 6 Top of Reservoir Hill

Here we will view the old Huntington Beach oil field area that is undergoing a progressive rehabilitation. This giant that was discovered in 1920 has produced over a billion barrels of oil and 836,000,000 Mcf of gas (Hazenbush and Allen, 1958; Carls, 1949; Carriel, 1942; Case, 1921; Case and Wilhelm, 1923; Dolman, 1928; Graser, 1927; Hunter and others, 1955; Frame, 1960; Murray-Aaron, 1947; DOGGR, 1995). Thirty-six percent of the production is from offshore. Roughly 440 wells are producing and 400 wells are shut-in. Over the years several methods of stimulation were tried. These include water flood (1961), cyclic steam (1964), and steam flood (1965). Oil field activities can be seen but this area is far down the decline curve and soon the entire area will be residential and commercial developments (Fig. 7).

This hill also provides an excellent view of the pressure ridges along the Newport-Inglewood Fault Zone that have provided the oil traps for many of the fields in the Los Angeles Basin. This is also an area designated by the State of California as an active fault area that is subject to earthquakes. The 1933 Long Beach Earthquake occurred along this fault zone. We will cross this fault zone several more times on this trip. According to Carlson (1996) of the sixty oil fields in the Los Angeles basin nineteen have been or are in the process of abandonment and eleven others are in the last few years of economic recovery. Because of the public safety concerns the California Division of Oil, Gas and Geothermal Resources (DOGGR) has created the Construction Project Site Review and Well Abandonment (CPSRWA) program to help developers and landowners working with old oil field properties. Under this program old wells must be found, surveyed for location, and checked for proper abandonment to today's standards. If a well is not abandoned properly it must be re-entered and properly abandoned if possible.

Dave Seymour (1996) details the engineering geology and geotechnical engineering aspects of redevelopment in portions of the Huntington Beach Oil Field.

This area lies atop the Huntington Beach Mesa and along the Newport-Inglewood Fault Zone. Residential development started in the 1950's. The development south of Clay Street and west of Goldenwest Street was developed in the early 1970's. Chevron developed oil well islands of two to five acres to make room for the housing. But by 1992 even several of these islands were to succumb to residential development.

Late Pleistocene age shallow-marine sandstones and siltstones with a few mud beds underlie the near surface of the mesa. Overlying this is a well-developed reddish brown, four to ten-foot-thick argillic soil horizon

Figure 7. Photograph of the top of Reservoir Hill showing the old reservoir on the left, pumping units in the center and a tank battery on the right.

that is stiff and suitable for light foundation loads.

Pipelines both existing and unknown, storage tanks, hydrocarbon impacted soils and abandoned oil wells all add to the geotechnical constraints. Undocumented fills and active faulting are also common constraints to development in this area.

Undocumented fills were found throughout the redevelopment area. They were typically associated with pipeline trenches, subsurface storage tanks, abandoned oil wells, and foundations. All of this had to be removed in accordance with today's environmental standards and properly filled and recompacted.

Abandonment of old oil wells was part of this redevelopment. Ken Carlson (1996) details the current California Division of Oil, Gas and Geothermal Resources procedures in an accompanying paper. The wells were vented and back-filled to the proper compaction.

Hydrocarbon impacted soils called HIS presented many challenges. Hydrocarbons in the near-surface soils ranged from zero to over one hundred parts per million. Depths to contamination and lateral extent could not be determined prior to rough grading. The City of Huntington Beach Fire Department provided tough guidelines for the environmental consultants HIS content determinations and removal. Large pits up to twenty feet deep resulted and these had to be laid back to about thirty degrees to soften the transition in the fill. Also stiffer foundations were designed.

Both well vents and thick plastic membranes beneath the foundations were used to control the methane gas as per DOGGR regulations (Fig. 8). Because the area is in the Newport-Inglewood fault Zone fault evaluations are necessary. The Alquist-Priolo Fault Zoning Act enacted in 1973 provides guidelines to prevent building upon a known active fault (Hart, 1994). The Seismic Hazards Act of 1990 expands the Alquist-Priolo Act to include ground shaking hazard zones, liquefaction hazard zones, and earthquake induced landslide hazard zones. The state geologist through the California Division of Mines and Geology has not fully implemented these yet. All cities in California have at least partially addressed these problems in their Seismic Safety Element of their General Plan.

The North Branch Fault probably offsets Holocene-age soils (Seymour, 1996). Fifty-foot-wide setbacks from the fault were established for the redevelopment.

Go north on Stewart Street and turn left onto Garfield Avenue (west, mile 38.6). On both sides of Garfield new development is underway. From mile 39.5 to 40.4 you can observe the juxtaposition of oil field development and new residential development (Fig. 6).

Turn right at Pacific Coast Highway (mile 40.4; Fig. 6). Just offshore you can see the platforms of the Huntington Beach oil field. On a clear day the Beta field platforms are visible (eight miles offshore). This is the start of Bolsa Chica State Beach.

At mile 41.7 is the entrance to the Bolsa Chica Ecological Preserve on the right. This wetland habitat is home to thousands of birds.

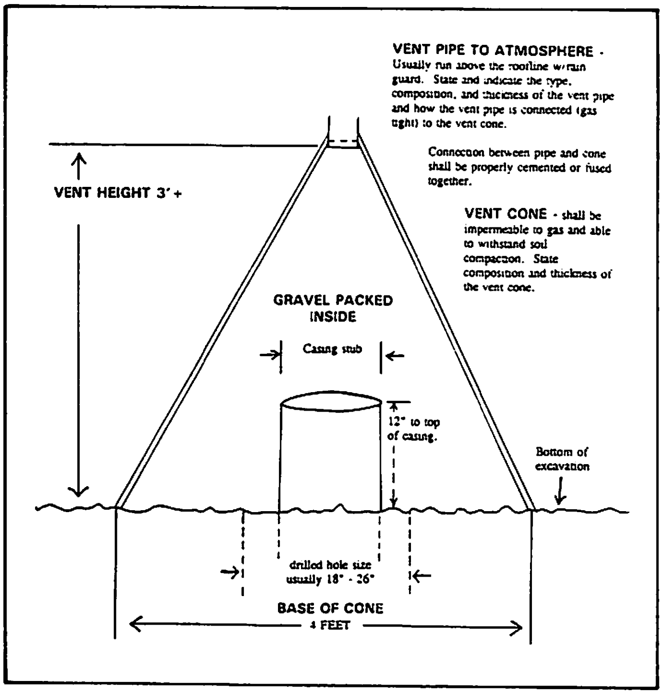

Figure 8. Division of Oil, Gas, and Geothermal Resources (DOGGR) diagram for a single well gas vent. Developers must submit a vent diagram along with a site plan that indicates the location of the vent, the direction of the vent pipe and its point of exit, above the roof line to DOGGR for review.

At mile 43.5 is Sunset Beach on the left and Huntington Harbour on the right (Fig. 9). To the right is the Sunset Beach oil field which was discovered in 1954 on the Newport-Inglewood Fault Zone and is now abandoned. Sunset Beach produced 6,791,000 barrels of oil and 9,591,000 Mcf of gas (Allen and Hazenbush, 1957; DOGGR, 1995).

At mile 45 is Anaheim Bay and the Alamitos Naval Weapons Station and Ecological Reserve (Fig. 9). The Navy stores various ordinance here and keeps people out, thus providing a nice safe place for animals.

Mile 46.5 is Seal Beach. Just off the coast are the two platforms of Belmont Offshore oil field which was discovered in 1947 and has produced about 60 million barrels of oil and 35,260,000 Mcf of gas (Frame, 1960; Olson, 1978; DOGGR, 1995). Like many of the other fields in the Los Angeles Basin Belmont Offshore, with only 14 active wells, will soon be gone.

At mile 47.1 is the mouth of the San Gabriel River and the Los Angeles County line (Fig. 11). To the right is a small pressure ridge on the Newport-Inglewood Fault Zone. Under this area is the Seal Beach Oil Field which was discovered in 1924. Seal Beach has produced about 210 million barrels of oil and 216,392,000 Mcf of gas to date (Copp and Bowes, 1927; Barnes and Bowes, 1930; Ingram, 1966a; DOGGR, 1995). There are still about 140 active wells in this field . We will parallel this oil field for the next two miles.

To the left is the Long Beach Marina.

At mile 47.3 Chevron recently remediated the property on the left.

At mile 47.8 the Marina Pacifica property has just compled a cleanup of old oil field contaminants (Fig. 10).

Alamitos Bay over-crossing (mile 48).

Turn left at Loynes Avenue (mile 48.3). The immediate area has had numerous geological and environmental problems (Fig. 10). These problems include liquefaction, water up-welling, methane gas, ground instability, past oil field activities, old improperly closed dump, and the Newport-Inglewood fault crosses here.
The street paving behind us is over 12 feet of thick!

Turn right onto Bellflower Boulevard (mile 48.6) and then left onto Eliot (mile 48.7; Fig. 10). There have been many oil wells drilled in this area; most are assigned to the Seal Beach oil field but some are drilled to the Recreation Park portion of the giant Long Beach oil field which was discovered in 1921 and has produced nearly a

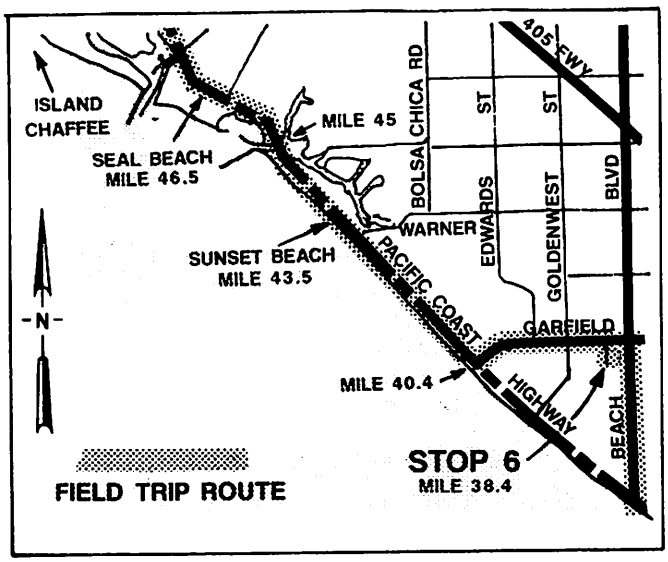

Figure 9. Map of the trip route from Stop 6 to Long Beach. Arrows show selected cumulated field trip mileages.

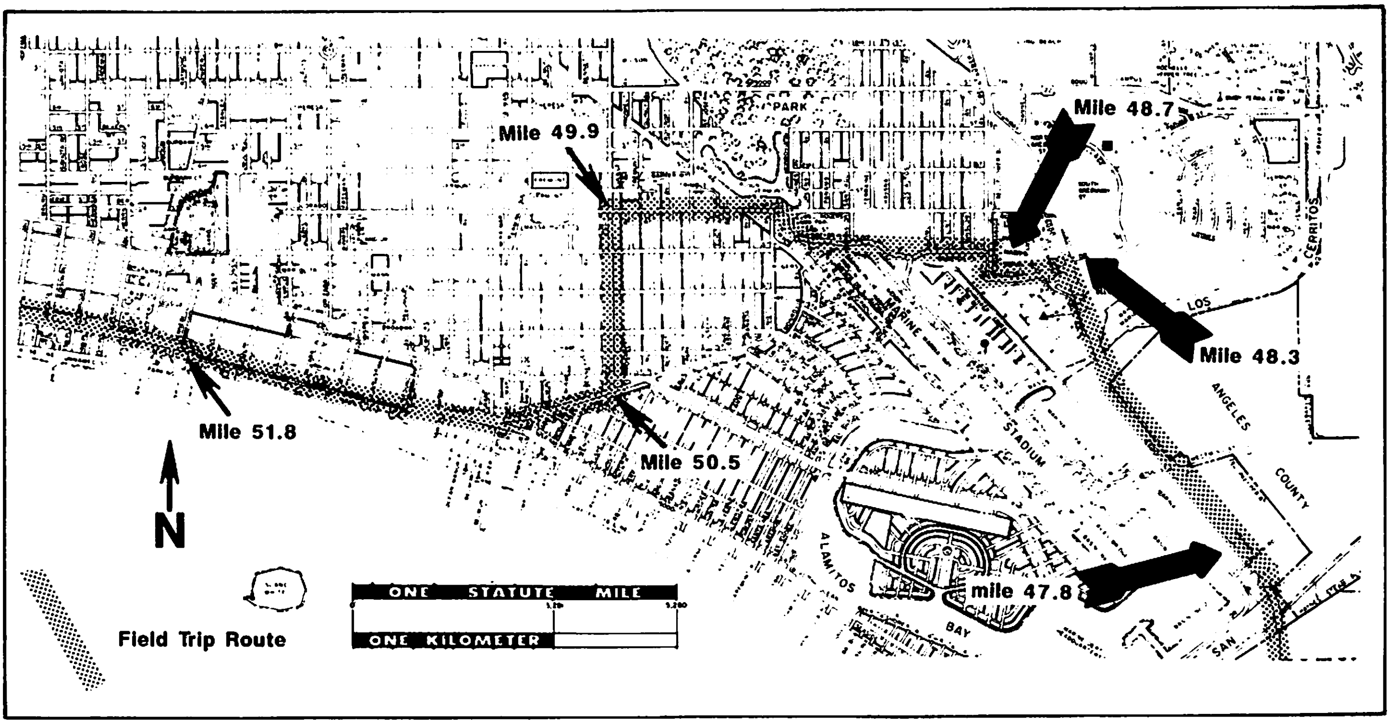

Figure 10. Map of the field trip route in eastern Long Beach. The arrows show the cumulative mileages. (altered from Long Beach Department of Public Works map).

billion barrels of oil and over a billion Mcf of gas (Ingram, 1966b and 1968a; DOGGR, 1995). We will again visit this field on top of Signal Hill. The short drive to Colorado Street provides us a look at oil activities coexisting with residential and recreational activities. It is interesting to note that some operators are very responsible with their activities and try to minimize the negative impact on the community (Note the pumps behind the trees at mile 48.9), while others do not seem to care (Note the rusty tanks at mile 48.8).

Marine Stadium is to the left at mile 49.1 (Fig. 10).

Turn left onto Colorado (mile 49.3) and continue to Ximeno.

Colorado Lagoon is to the right at mile 49.4.

Turn left onto Ximeno (mile 49.9) and then turn right onto Livingston Drive (mile 50.5; Fig. 10). Livingston Drive merges into Ocean Boulevard. Randell and others (1983) give an excellent view of the geology of Long Beach from an engineering standpoint. Geo-hazards in Long Beach are delineated by the Seismic Safety Element of the General Plan.

At mile 51 you can see the oil islands of the giant Wilmington Oil Field which was discovered in 1932. Wilmington has produced about 2.5 billion barrels of oil and 1.2 billion Mcf of gas (Crown, 1941; Mayuga, 1970; Truex, 1974; Henderson, 1987; Clarke, 1987; Slatt and others, 1988; Norton and Otott, 1996; DOGGR, 1995). Island White is just offshore.

The Long Beach Art Museum is located at mile 51.8 (Fig. 10).

Mile 51.9 Junipero at Cherry Park. In January 1995, an offshore 3-D seismic survey was conducted in the Long Beach Harbor (Fig. 11). Otott, Clarke, and Buikema (1996) detail the complexities of conducting such a survey. The plan was to better delineate the faulting in Ranger East, the Union Pacific and Ford zones, delineate the basement, and possibly clarify some stratigraphy. This was a tough survey to run because of the very complex political and environmental nature of California. The survey had to be run in one of the busiest harbors in the country under the direct eye of the residents in the greater Los Angeles area. Commercial activities include shipping, transportation, and fishing. Recreational fishing, boating and beach activities had to be considered also.

The Chambers Group and EJL and Associates were retained to evaluate the environmental effects and establish and conduct a Marine Mammal Avoidance Plan. The plan was carefully coordinated with the National

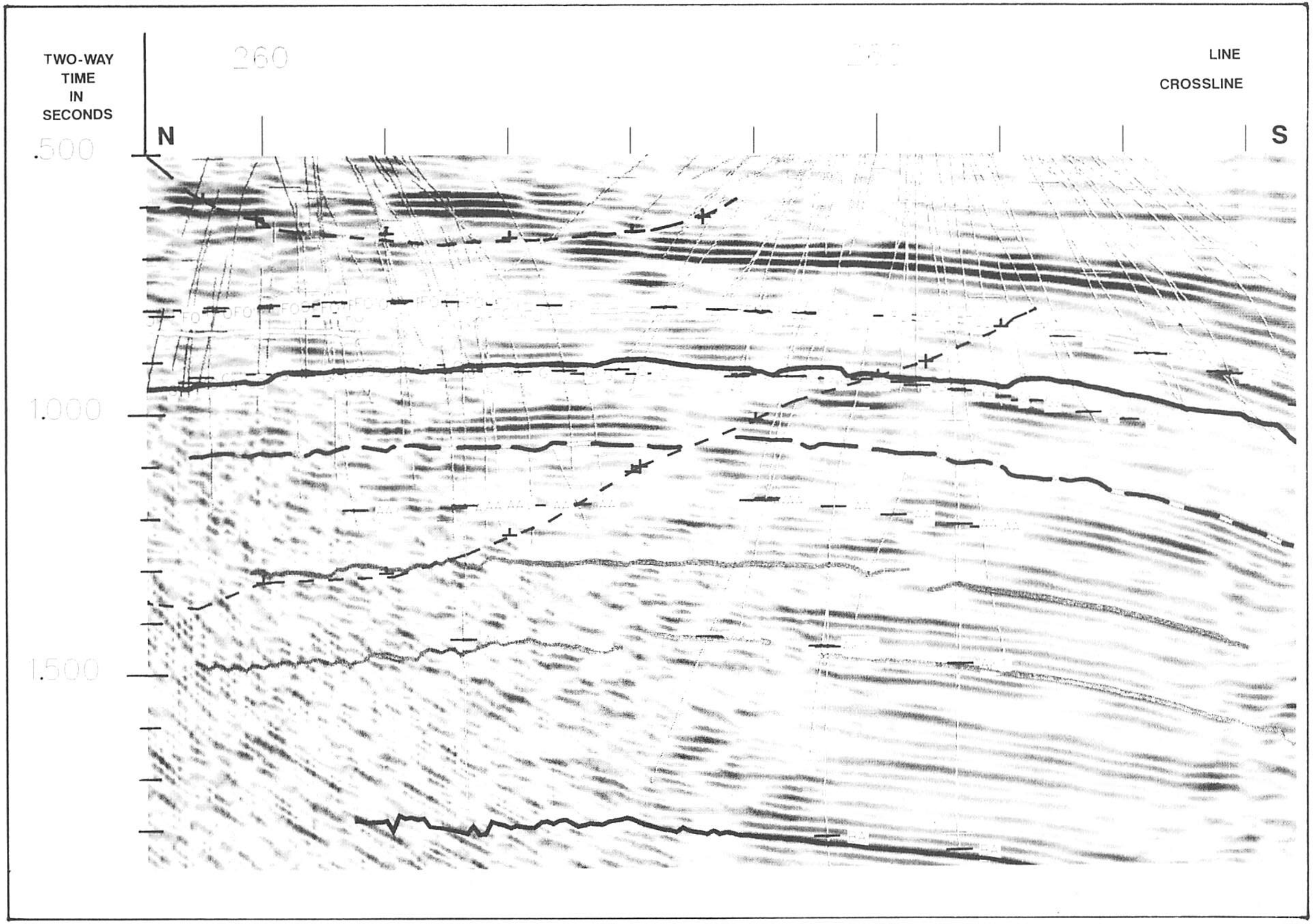

Figure 11. 3-D seismic section line 260. Long Beach Unit oil well locations near the section line are shown with selected markers. Framework interpretation of six surfaces was provided by Subsurface Consultants and Associates. The data was collected by Geco-Prakla and processed by AEPT.

Marine Fisheries Service.

More than a dozen public agencies with jurisdiction in the area were contacted early in the planning stages. As planning proceeded to conducting the survey, close interaction with the agencies allowed all interested parties to work out a survey that would be in compliance with all needs and requests. We found that even the agencies that are typically thought of as difficult were very constructive with their suggestions. The public was notified by both direct mailings and news releases and all activities were coordinated with the Harbor Department. All cooperated except the weather.

The dual sensor transition zone 3-D survey was designed by ARCO Exploration and Production Technology, Incorporated (AEPT) in Plano Texas. Geco-Prakla conducted the survey. AEPT processed the survey and framework interpretation was done by Subsurface Consultants and Associates and Seis-Strat Services, Incorporated. Early results have not been as good as expected but more processing and interpretation are in progress.

The Long Beach Terrace Theater and Arena are at mile 53.2. Whalen painted the mural around the Arena.

Mile 53.5 Pine Avenue is at the heart of Long Beach's downtown. To the right are many fine restaurants and to the left is the Long Beach Convention Center and Shoreline village.

Long Beach City Hall is at mile 53.7.

Mile 53.8 To the left is the new Aquarium of the Pacific.

Mile 54.2 We pass over the mouth of the Los Angeles River (Fig. 12). On both sides of the road you can see portions of Long Beach Harbor. To the right is the shipping point for most of the Wilmington oil. It is locally called Broadway and Mitchell. In January 1996 three new gas compressors went into operation, thus reducing the need for compression at the Lomita gas plant and also reducing emissions. By 1997 a refrigeration unit should be installed to remove the propane from the gas.

Mile 55.1 We cross from the mainland on the Gerald Desmond Bridge to Terminal Island (Fig. 12). To the left is the United States Naval Shipyard at Long Beach. This base is scheduled to close in the next five years. The Long Beach Navy Base and the Long Beach Naval Hospital closed recently. The Navy has already started to identify the contaminated areas and has hired Bechtel Southern California and Brown and Caldwell to verify their findings. Twelve "hot-spots" have been identified. Cleanup will follow. The Port of Long Beach is already making plans for this area.

More distantly to the left are the larger piers of Long Beach Harbor.

To the right is the Edison Electric Plant and the center of the subsidence bowl. This area dropped a total of 29 feet prior to Long Beach's successful efforts to halt the sinking. Subsidence, the loss of ground elevation as a result of fluid withdrawal, has been a major problem for the Wilmington oil field since the 1940's (Fig. 13). Strehle (1987) gives a brief history of the attempts to find causes and combat subsidence, and Colazas and Strehle (1995) give a detailed accounting of subsidence. The implementation of a water flood and constant pressure maintenance since the late 1950's has proved effective at mitigation. Strehle (1996) points out that it does not stop there. The process that causes subsidence (compaction within the layers) is not fully understood. A predictive model is needed. As enhanced oil recovery methods become more sophisticated so does subsidence prevention. Steam floods have been especially problematic. As the steam chest cools and condenses, the pressures drop significantly thus requiring follow-up water injection. The result is temporary ups and downs. Two methods of net injection modeling are now used. The first method uses a combination of "month to date" and "three month to date" graphs of voidage ratio, injection, production, and excess net injection for each block. Adjustments to injection and production are made weekly based on these graphs. The second method is the Roaming Tank Model (RTM) which is a computer program that sums all of the production and injection data within a known radius of each node of a grid that has been superimposed on the field. The grid is then contoured onto a map. The result is an excellent visualization of the reservoir fluid movement.

In 1995 the Department of Oil Properties (Unit Operator for most of the Wilmington oil field) and the field contractors joined forces with Lawrence Berkeley Laboratory under the U. S. Department of Energy Advanced Computational Technology Initiative (ACTI) to develop a predictive numerical model for subsidence.

Leveling surveys have always been the "report card" for successful subsidence abatement. These surveys are expensive (roughly $500,000 per year). In 1995 the Department of Oil Properties joined forces with California State University, Northridge to test the feasibility of using Global Positioning System (GPS) to abbreviate the leveling survey. The desired accuracies of one centimeter have not been attained. A hybrid system that uses both GPS and optical transits may still work. This could save the oil field operators $100,000 per year.

Portions of Fault Block III have gone uneconomic and a post-production plan is being initiated to monitor

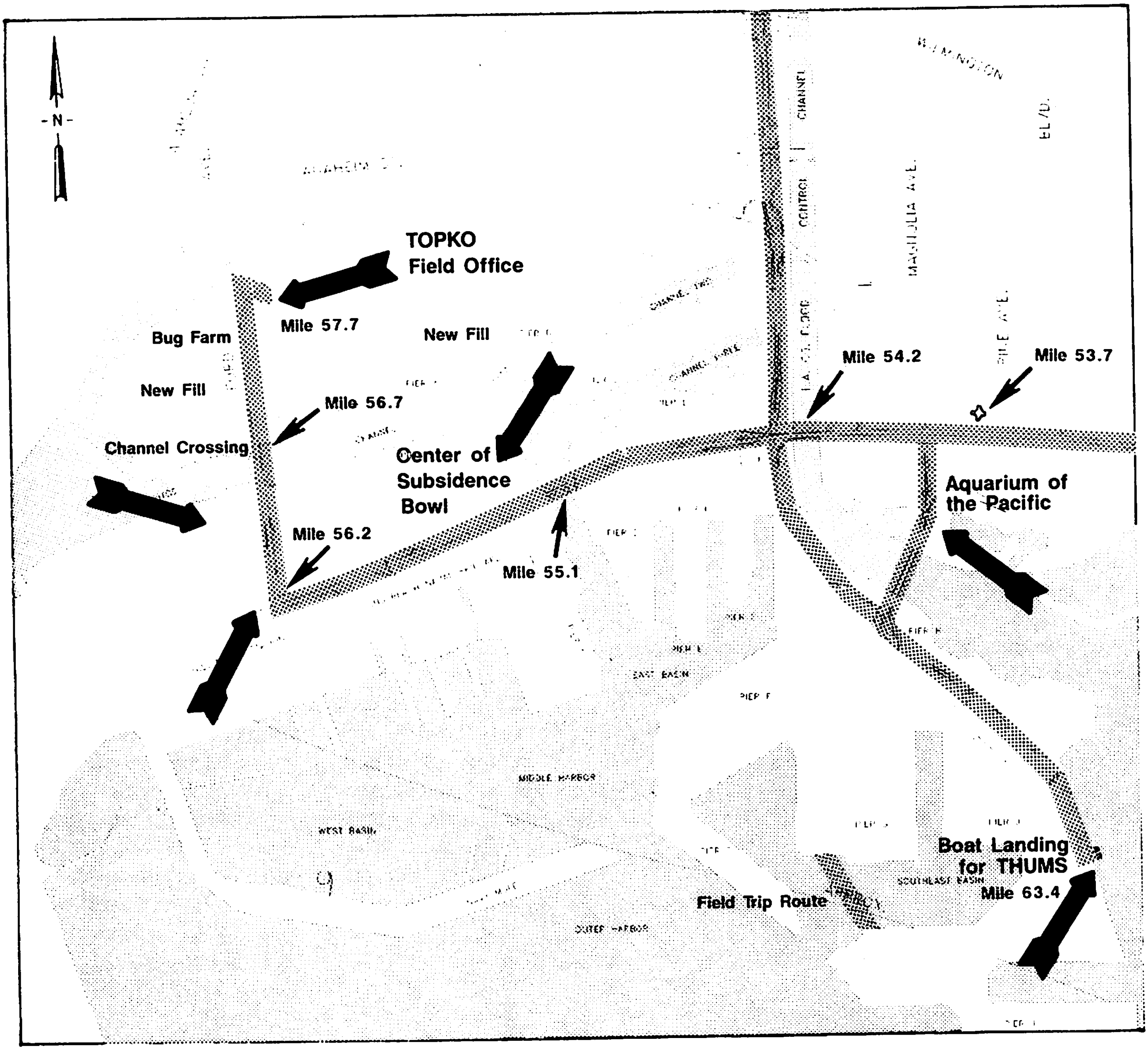

Figure 12. Map of the Terminal Island and Long Beach Harbor area. Arrows indicate cumulative field trip mileage and points of interest.

reservoir pressures and continue injection if necessary to prevent further subsidence. The costs for this plan could well exceed $50,000,000 over the next twenty years!

Note that large earthen dikes surround Terminal Island. Much of the old oil activity is still evident here.

Mile 56.2 Turn right onto the Terminal Island Freeway (Henry Ford Avenue; Fig. 12). To the left is the SERF Project where Long Beach Burns its trash. This facility is an attempt to better handle urban waste in an environmentally and cost effective manner. Just behind the SERF Project and next to Dow Chemical is the Cerritos Channel undercrossing for the steam project in Wilmington Fault Block II. This horizontally drilled crossing brings steam from the steam plant on the mainland to Terminal Island. And it is the longest such crossing. The large bridge ahead (Commodore Schuyler F. Heim Lift Bridge) and the smaller bridge to the west (Henry Ford Bridge) have been used in many movies.

Mile 56.7 At the north end of the Heim bridge. To the left is where General Petroleum drilled Terminal #1 in January 1936. This well came in at 1350 barrels per day of 20.5 degree API crude and initiated the oil boom for the Wilmington oil field. To the right is the location of

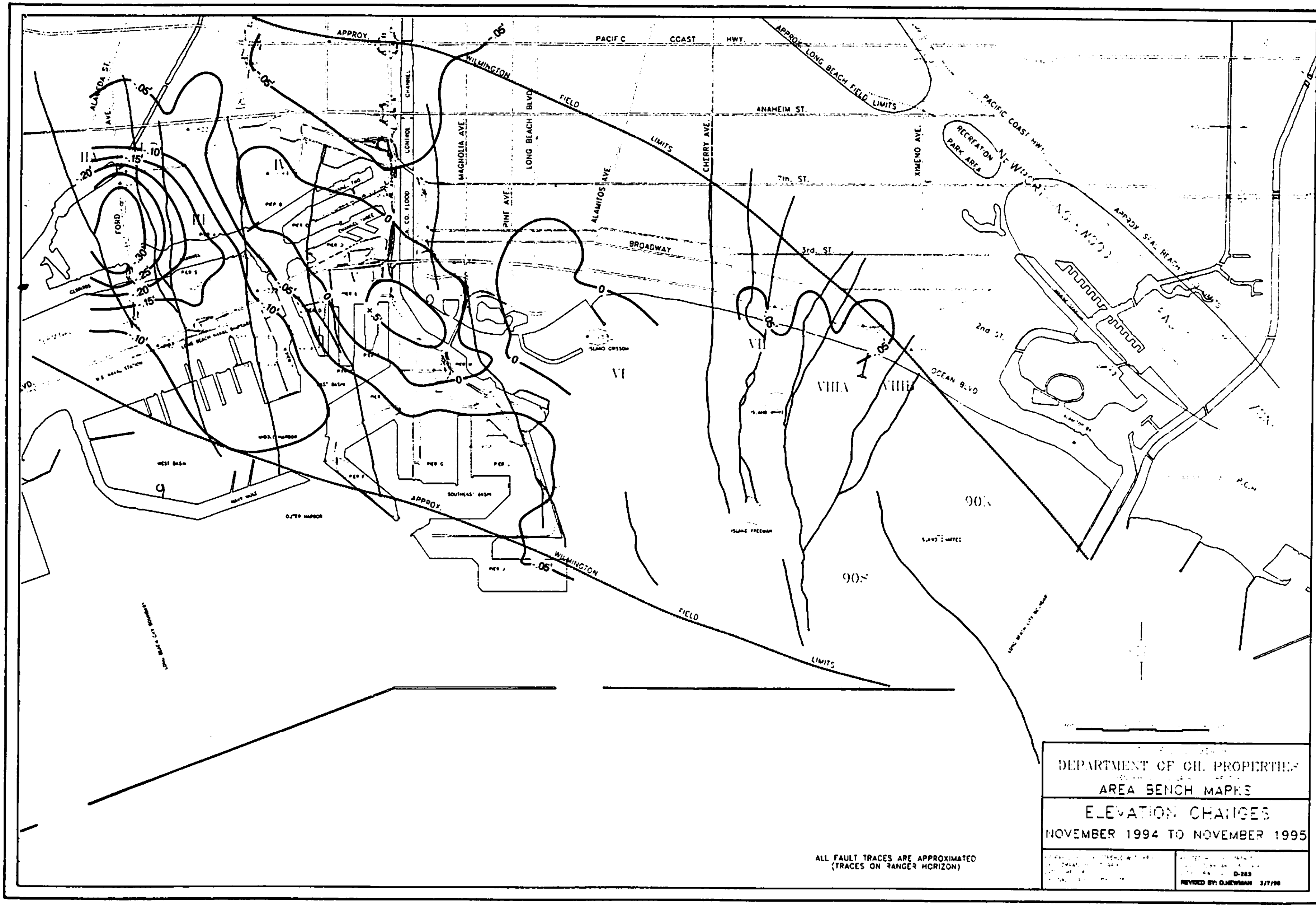

Figure 13. Elevation changes in the Wilmington Oil Field area from November 1994 to November 1995. The City of Long Beach, Department of Oil Properties conducts precision elevation surveys twice a year to monitor subsidence. The changes are contoured in 0.05 foot intervals.

the old Ford automotive plant. It was torn down in the early 1990's and the ground is currently being raised to the height of the dikes as part of the harbor expansion. Fill activity is visible in many places here on Pier A.

Over the years the operators and contractors used portions of the oil field for waste disposal that was inconsistent with permitting. Because of this the site was added to the California superfund list in 1983. In 1988 UPRC agreed to investigate and remediate the site. These activities have been taken over by the Port of Long Beach and much of the remediation of the site involves excavation and stabilization of the soil. The environmental and safety issues in this area are addressed by Shemaria (1996).

Mile 57.3 Turn off to the right at "Anaheim Street west" and enter the old Champlin and then UPRC and now Tidelands Oil Production Company offices.

STOP 7 Mile 57.7 New Life for the Field

In 1989 Tidelands Oil Production Company took over the tidelands leases for the City of Long Beach from Long Beach Oil Development Company which had the leases for fifty years previously. In 1990 Tidelands took over the Mobil Oil Corporation and Chanse Energy Corporation properties in Wilmington. Tidelands has 670 active wells and produces 10,000 barrels of oil per day and 12,000 Mcf of gas per day.

The Harbor Cogeneration Company steam plant produces 30,000 barrels per day of water-equivalent steam for enhanced oil recovery project in Fault Block II. Just north is the small Ultramar oil refinery. This portion of the Wilmington Oil Field has been under production and is rapidly going uneconomic. The Long Beach Harbor Department purchased this area from Union Pacific Resources Company in 1994. The Department of Oil Properties acts as the unit operator and Tidelands Oil Production is the Field Contractor. The Harbor Department has been preparing the land for cargo storage and the oil facilities are in the process of consolidation into designated drilling "islands". The facility movement and cleanup process is well underway.

In 1995 the City of Long Beach , Department of Oil Properties (LBDOP), Tidelands Oil Production Company, the University of Southern California (USC), David K. Davies and Associates initiated a cost share project with the Department of Energy (DOE) to extend the thermal recovery project in the Tar Zone of Fault Block II of the Wilmington Oil Field (DOE cooperative agreement no. DE-FC22-95BC14939). Phillips (1996) expands on the advanced technology for this project. Nine advanced technologies to be applied include.

1. Develop 3-D deterministic and stochastic geologic models. More than 400 wells in the Tar Zone were rigorously subdivided into 10 sub-units for structural modeling in Earthvision. A modern data base utilizes data from as far back as 1937. Subsidence caused many problems for building the model. The wells were drilled over a span of 50 years and the ground elevation dropped over twenty feet at a varying rate over the same period of time. The loss of elevation came from within the formation. The wells were located with many old coordinate systems. These problems had to be resolved and modeled prior to the construction of a successful geologic model.
2. Develop 3-D deterministic and stochastic thermal reservoir simulation models to aid in reservoir management and subsequent development work. Two new wells were cored and several older cored sections were studied. Core analysis included porosity, permeability and oil saturation measurements along with the high-temperature core work to determine the impact of varying steam temperatures on the formation and contained fluids.
3. Develop 3-D visualizations of the geologic and reservoir simulation models to aid in analysis.
4. Perform a detailed study of the geochemical interactions between the steam and the formation rock and connate fluids.
5. Drill four horizontal wells, two producers and two injectors for a steam pilot. Five observation wells were drilled and two were cored.
6. Start a hot water alternating steam (WAS) drive pilot in the existing steam drive area to improve thermal efficiency.
7. Install a 2400 foot insulated, subsurface harbor channel crossing to supply steam to Terminal Island. The undercrossing was completed in 1995.
8. Test a novel alkaline steam completion technique to control well sanding problems and fluid entry profiles.
9. Apply advanced reservoir management through computer-aided access to production and geologic data to integrate reservoir characterization, engineering, monitoring, and evaluation. These cybertools have proved most useful.

In 1995 The City of Long Beach, Department of Oil Properties, Tidelands Oil Production Company, Stanford University, and Magnetic Pulse, Incorporated entered into a near-term cost share project with the Department of Energy to increase water flood reserves by identifying bypassed oil, reservoir characterization and better reservoir management (DOE cooperative agreement no. DE-FC22-95BC14934). The detection of bypassed hydrocarbons through casing has not been as successful as hoped but the reservoir characterization and reservoir management have helped greatly in extracting more oil (Moos and others, 1996).

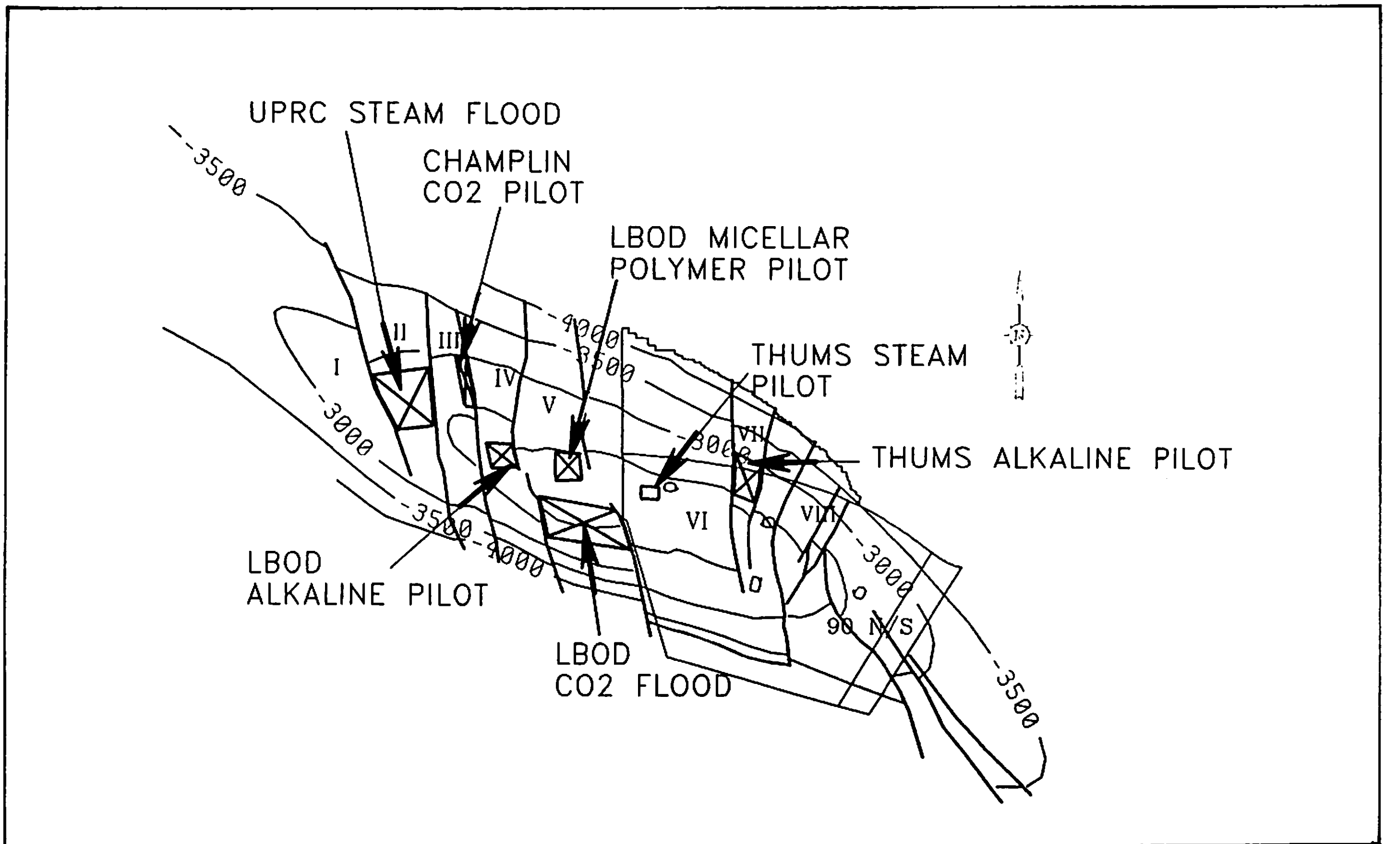

Figure 14. Locations of the enhanced oil recovery projects in the Wilmington Oil Field.

Return to Henry Ford Avenue and make a hard left turn and go back over the bridge again (California 47). Turn left again onto Ocean Boulevard (mile 59.1) and continue eastbound until Magnolia Avenue (the street between the Federal Building and the L. A. County Court House, mile 61.6; Fig. 12). Turn right and continue over the Queensway Bridge. To the right is the Catalina Terminal and on the left is the new aquarium. Continue towards the Queen Mary (stay left). Stay in the right lane and turn right and then an immediate left onto Harbor Scenic Drive (mile 63). Continue about ½ mile south to the THUMS boat landing.

Day 2

STOP 8 Mile 63.4 Tour the THUMS Oil Islands

The THUMS oil operations were well summarized by Berman and Clarke in 1987 but many new changes have occurred in the last ten years. Otott and Clarke (1996) updates the history as reported by Ames (1987). The four billion dollar Long Beach Unit Equity was finalized in 1990. ARCO purchased the THUMS partners outright by 1992 thus making THUMS wholly owned by ARCO. In 1992 the State of California, City of Long Beach and ARCO entered into an Optimized Waterflood Plan Agreement, which received authorization by California Assembly Bill 227. This allowed ARCO to insure at least $100 million would be invested in development drilling and waterflood optimization projects and the State would be guaranteed a baseline of income. ARCO, the city, and the state would share the incremental profits from the new development.

The history of advanced recovery technologies in the Wilmington Oil Field is reviewed by Otott (1996), and Blesener and Henderson (1996) highlight the latest high technology efforts in the Long Beach Unit. Onshore Wilmington has had thermal recovery, immiscible carbon dioxide, and water-alternating-gas (WAG), polymer, micellar polymer, and alkaline enhanced recovery projects. Offshore Wilmington has had caustic water flood, steam flood, and several different simulations and profile modification schemes along with water flood realignment. Figure 14 shows the locations of the various enhanced oil recovery projects in Wilmington.

The new technologies offer the most promise. Horizontal drilling has been used to increase the contact between the well bore and the productive formation in order to increase production in areas with vertical conformance problems. Typically the top portions from heavily injected Pliocene sands are targeted with 800 to 1500 foot intervals (Fig. 15). Over two dozen horizontal

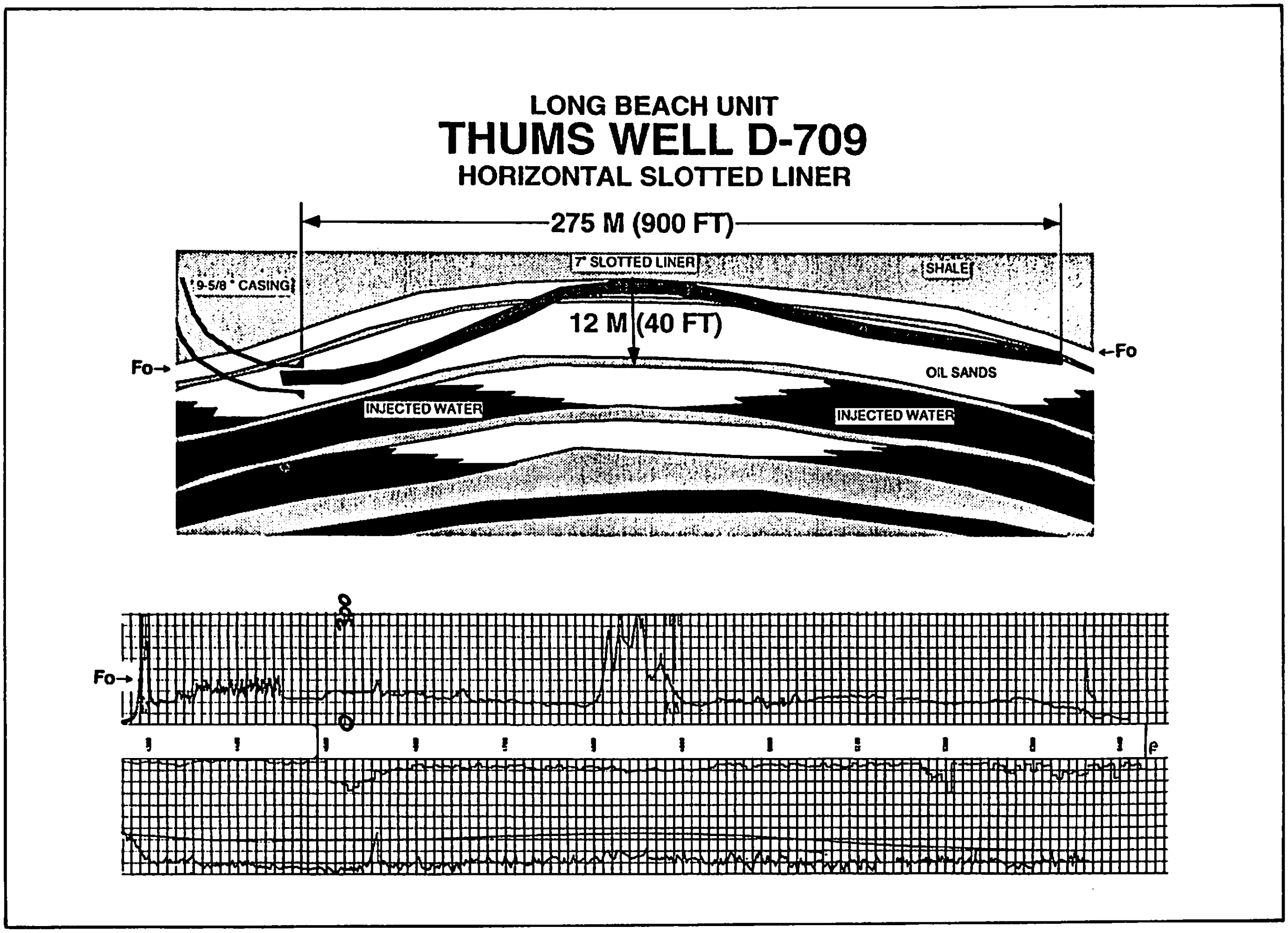

Figure 15. THUMS horizontal well D-709. Cartoon of the penetrated section shows how the upper two sands of the "Fo" in the Ranger zone are penetrated. The electric log for the well is below.

wells have been drilled in the Wilmington oil field.

Coiled tubing drilling was first attempted in Wilmington in 1994 with well A-314. A continuous tubing string passes through a tubing injector a guide assembly and a stuffing box that are mounted over the well head. Two bidirectional hydraulic motors operate two roller chains and two gripper chains to move the tubing from the reel to the well head. This method has not yet proven cost effective for horizontal wells but plans are underway to drill under-balanced (to prevent damage from mud invasion) horizontal wells with coiled tubing into the Lower Terminal, Union Pacific and Ford Zones.

Environmentally high technology is also being applied. The drill cuttings are now injected as a solid waste slurry into the water leg of an oil formation via well C-822I. This "cradle to grave" concept puts the waste products back where they came from and allows the unit to minimize the liability of disposal of oil field wastes in class I and II landfills. Over 8,500 tons of drill cuttings, 112,000 barrels of clay and oily waste, and 50,000 barrels of tank bottoms have been injected.

The Long Beach Unit injects 680,000 barrels of water per day and produces 570,000 barrels of water per day. Most of the produced water is reinjected but there is still a need to obtain about 110,000 barrels per day of makeup water. The water is needed to replace the volume of oil produced (voidage) and also provide a five percent excess in order to maintain the reservoir pressures and prevent subsidence. The quality of this water is of great importance because poor-quality water can damage the wells, the formation, and require treatment, all of which increase the cost of operation and shorten field life.

Over the years the makeup water has come from many sources. Some of these include other producers (high in hydrogen sulphide which sours the oil), source wells in the brackish, shallow aquifers (high in barium which produces scale), and the Long Beach Water Department (expensive drinking water). In 1992 a Long Beach Unit study on alternate water sources recommended tertiary treated reclaimed sewage water as the most optimal. A pilot project is now underway and first results look extremely encouraging. Injectivity of the

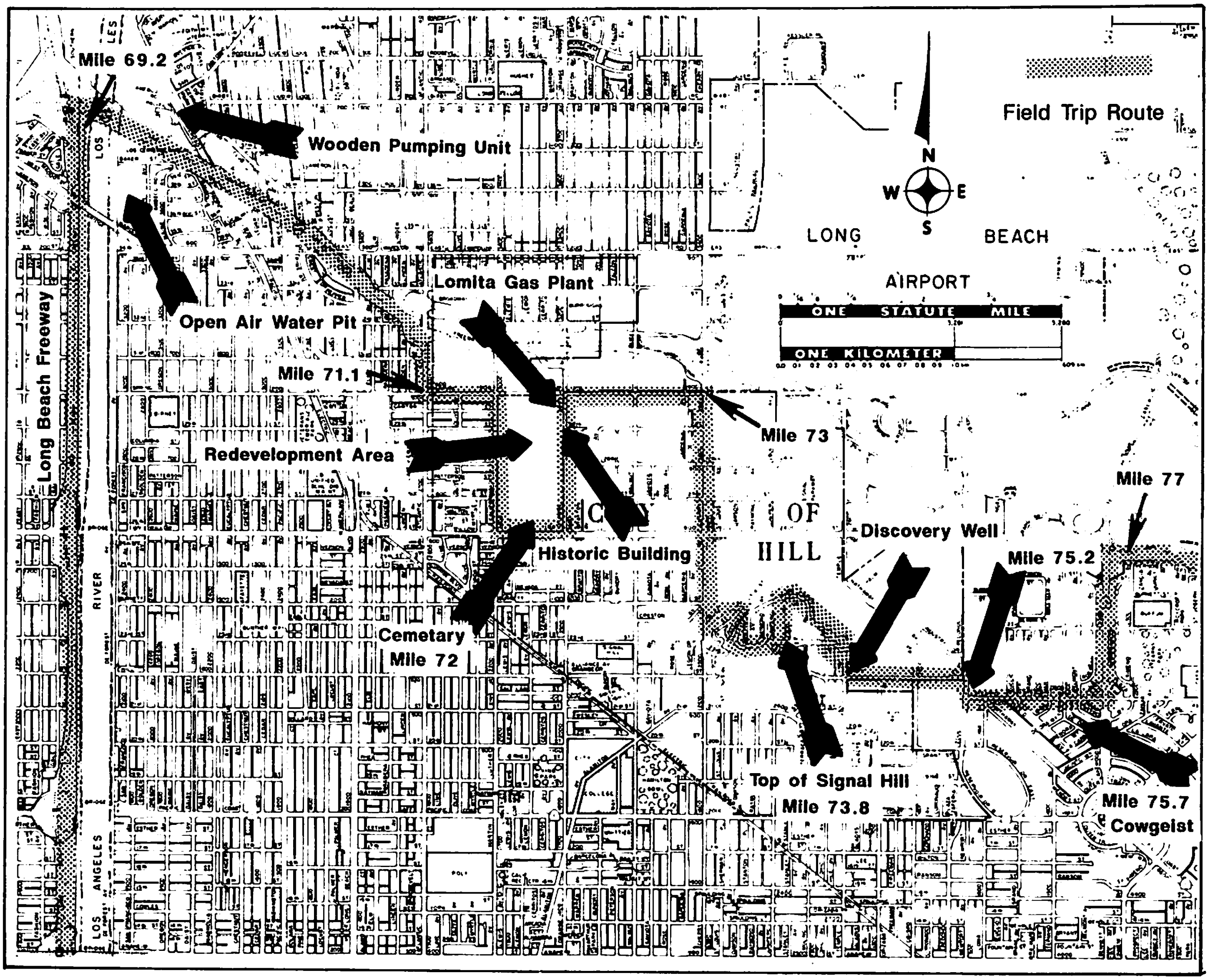

Figure 16. Map of the Signal Hill area. The arrows show points of interest and cumulative mileage. (altered from Long Beach Department of Public Works map).

water is excellent but the cost of treatment goes from one cent per barrel to two cents per barrel as the volume increases from 10,000 bwpd to 20,000 bwpd. Griffis (1996) explains THUMS environmental compliance policy.

Return to Harbor Scenic Drive and continue north onto the Long Beach Freeway (Interstate 710) at mile 64.2.

Mile 69.2 Exit the Long Beach Freeway onto the San Diego Freeway southbound (Fig. 16). To the right as we cross over the Los Angeles River (mile 69.5) you can see the open-air water pits that are used by some of the smaller producers. Just to the north but not visible on Pacific Avenue 50 yards north of the 405 Freeway is the last wooden beam pumping unit in Long Beach.

Mile 70.8 Exit at Atlantic Avenue (Fig. 16). Turn right onto Atlantic Avenue. Most of the oil production in this area is marginally economical and the oil producers are trying to do as little maintenance as possible.

Mile 71.1 Turn left onto Spring Street.

Mile 71.4 Turn right onto California Avenue. To the left is part of the old Signal Hill West Unit that is owned by the City of Long Beach. For years the city has been trying to redevelop the land parcel. First it was going to be an auto mall, then it was going to be a "power" retail center, finally a motor sports complex was planned. All of the projects fell through. The city hired no fewer than four geotechnical firms to evaluate fault hazard, slope stability and environmental contamination.

The site has had continuous oil field activity since the 1920's. There are plenty of old oil field antiques around the tank battery in the basin. There is plenty to cleanup and the total extent of the petroleum contamination is unknown. The site has several historical points of interest. Long Beach's only municipal cemetery is on the south side, and several civil war veterans are buried there. The hilltop has a cistern that was originally Long Beach's drinking water reservoir. The portion of California Avenue on the west side is part of the old railroad grade.

Turn left onto Willow Street (mile 71.8). The Cemetery is to the left.

Turn left onto Orange Avenue (mile 72.1). On the corner of Orange and Spring Street is the Gas plant that was built in the 1920's and is still operational. It is interesting to note that the gas plant is located on the Newport-Inglewood Fault Zone and the large complex to the west about ½ mile is the areas largest medical center. A large shaker epicentered here could be devastating. A quick circle down California, east onto Willow, and north on Orange will provide a nice look at the area.

Turn right onto Spring Street (mile 72.6). To the left is the Long Beach Airport Oil Field that was discovered in 1954 (Loken, 1964). It has produced 11,000,000 barrels of oil and 7000 Mcf of gas (DOGGR, 1995).

Mile 73 Turn right onto Cherry Avenue (Fig. 16). The short drive from Orange to Cherry reveals an area of heavy redevelopment. The old refinery to the north is being dismantled and the old oil field businesses have been replaced along with the wells. Now we see auto dealers and high volume retailers. As we continue south on Cherry Avenue the new businesses abound. The idea of the "power" center is a game the local cities play. Basically each city tries to get as many high volume retailers into its city as possible. The reason? The city makes its money from the sales tax.

Mile 73.8 Turn left onto Skyline Drive and continue to the top of Signal Hill (Fig. 16).

STOP 9 Top of Signal Hill (Mile 44.2)

This is the site of the Long Beach oil field which was discovered in 1921. From here we can see much of the Los Angeles basin. The City of Signal Hill has been one of the most aggressive at redevelopment

Turn right onto Panorama Drive (mile 74.4).

Follow Panorama Drive along the north part of Signal Hill to Hill Street (mile 74.8). To the left is Alamitos #1, the discovery well for the Long Beach oil field. It was completed in 1921 to a depth of 3114 feet and came in flowing 600 barrels of 22 API gravity oil per day. Turn left onto Hill Street and continue to Redondo Avenue. On both sides are empty fields that will soon be developed. Leighton and Associates geologists conducted the geotechnical evaluation.

Make a right turn onto Redondo Avenue (mile 75.2) and then an immediate left turn onto Stearns Street. To the right are high density dwellings on the north and east side of Reservoir Hill. These buildings are in the Alquist -Priolo Special Studies Area and on land that was part of the Signal Hill East Unit. Two blocks past the Armory on the right at mile 75.7 is a group of houses that were built over a large cow grave. The cows died in 1924 of hoof and mouth disease. The local dairy farmers dug large trenches and buried the cows. Years later the farmers sold the land to developers for residential construction. There have been many problems with foundations and sidewalks. Even bones have worked their way up to the surface. It was thought that there would be health problems, but I am not aware of any. The Long Beach Health Department has looked into the problem.

Turn left onto Lakewood Boulevard (mile 75.9) and continue north to Spring Street. Turn right onto Spring Street (mile 77)and enter onto the San Diego Freeway (Interstate 405) southbound on the right. Return 120 miles to San Diego and end of trip.

ACKNOWLEDGMENTS

I thank the City Department of Oil Properties: Xenophon Colazas, Director; Bruce Jackson, Bureau Manager; Tidelands Oil Production Company: Terry Smith, President; Mark Kapelke, Vice President; Jim Quay; Vice President: THUMS: Steve Freeman, President; Bill Knight, Vice President for their help in facilitating this work. I thank the Department of Energy for the financial support that was provided for this work and the companion volume through the technology transfer portion of the cost share enhanced oil recovery projects.

I thank the many co-workers who provided the strong technical papers that will accompany this work. These include Jeff Blesener, Curtis Henderson, Rick Strehle, Chris Phillips, Mark Shemaria, George Otott, Ken March, Tom Norton, Kathye Griffis, Dave Seymour, Mel Wright, and Ken Carlson.

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