Department of the Interior

U.S. Geological Survey

GEOLOGIC BASIS FOR THE ASSESSMENT OF UNDISCOVERED OIL AND GAS RESOURCES OF THE VENTURA BASIN PROVINCE, CALIFORNIA, 1987 NATIONAL ASSESSMENT

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Open-File Report

87-450 M

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Geological Survey.

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Introduction

This report presents a summary of the geology as a basis for the United States Geological Survey's 1987 assessment of undiscovered conventional oil and gas resources of the Ventura Basin assessment province of California. A great many studies of the geology of this region have been done in the 100 plus years since oil was first discovered here. This report is a summary of some of the published literature on the region; however, the references cited only partially represent the large body of available literature including many of the general summary papers on the basin and topical reports that were examined in the preparation of this report.

Province Description and Location

The Ventura Basin assessment province is located in the southern part of the state of California and consists of the area both north and east of the Santa Barbara Channel bounded approximately on the north by the Santa Ynez fault (east of the Santa Barbara-Ventura County line) and the Big Pine fault (west of the Santa Barbara-Ventura County line), on the east by the San Gabriel fault, and on the west and south by the 3 mile limit offshore the Santa Barbara-Ventura coast and the Santa Monica (-Malibu Coast) fault (Fig. 1). In this report "Ventura basin" is used following the definition of Bailey and Jahns (1954): "the Ventura basin lies between the Santa Ynez and Topatopa Mountains on the north and the Santa Monica Mountains and Channel Islands on the south .... The western half of the basin is occupied by an epicontinental sea, the Santa Barbara Channel. The Ventura basin, including the submerged portion, is about 120 miles long and 20 to 40 miles wide. Its axial portion is marked by the valley of the Santa Clara River.... The Ventura basin is bounded on the east by the San Gabriel fault". The Ventura basin of Bailey and Jahns (1954) and others (Curran, 1971; 1982; Nagle and Parker, 1971; Taylor, 1976; Bostick and others, 1978; Dickenson and others, 1987) is also referred to as the Santa Barbara-Ventura basin (e.g. Isaacs and Petersen, 1987), or as Santa Barbara Basin for the submerged western part and Ventura basin for the onshore eastern part (Fischer, 1976; Ingle, 1981).

The area covered by the Ventura Basin assessment province differs from that of the Ventura basin -- the geologic and topographic feature defined by Bailey and Jahns (1954) -- in that the Santa Barbara Channel, except for state waters, is excluded and adjacent areas on the north and south are added to the assessment province. The added areas include four of Nagle and Parker's (1971) nine subprovinces for the onshore Ventura basin: the Santa Ynez-Topatopa uplift, the San Rafael uplift and Upper Piru, part of the Ridge-Soledad basin, and the Santa Monica uplift (Fig. 2). The assessment province covers approximately 2400 square miles on land including parts of Santa Barbara, Ventura, and Los Angeles Counties, and contains an additional 230 square mile area of state waters offshore from the Santa Barbara and Ventura coast from west of Point Conception to Point Dume (Figs. 1 and 2).

Stratigraphy

The sedimentary section in the Ventura Basin assessment province has a combined maximum thickness of approximately 49,550 ft (15,103 m) (Fig. 3,

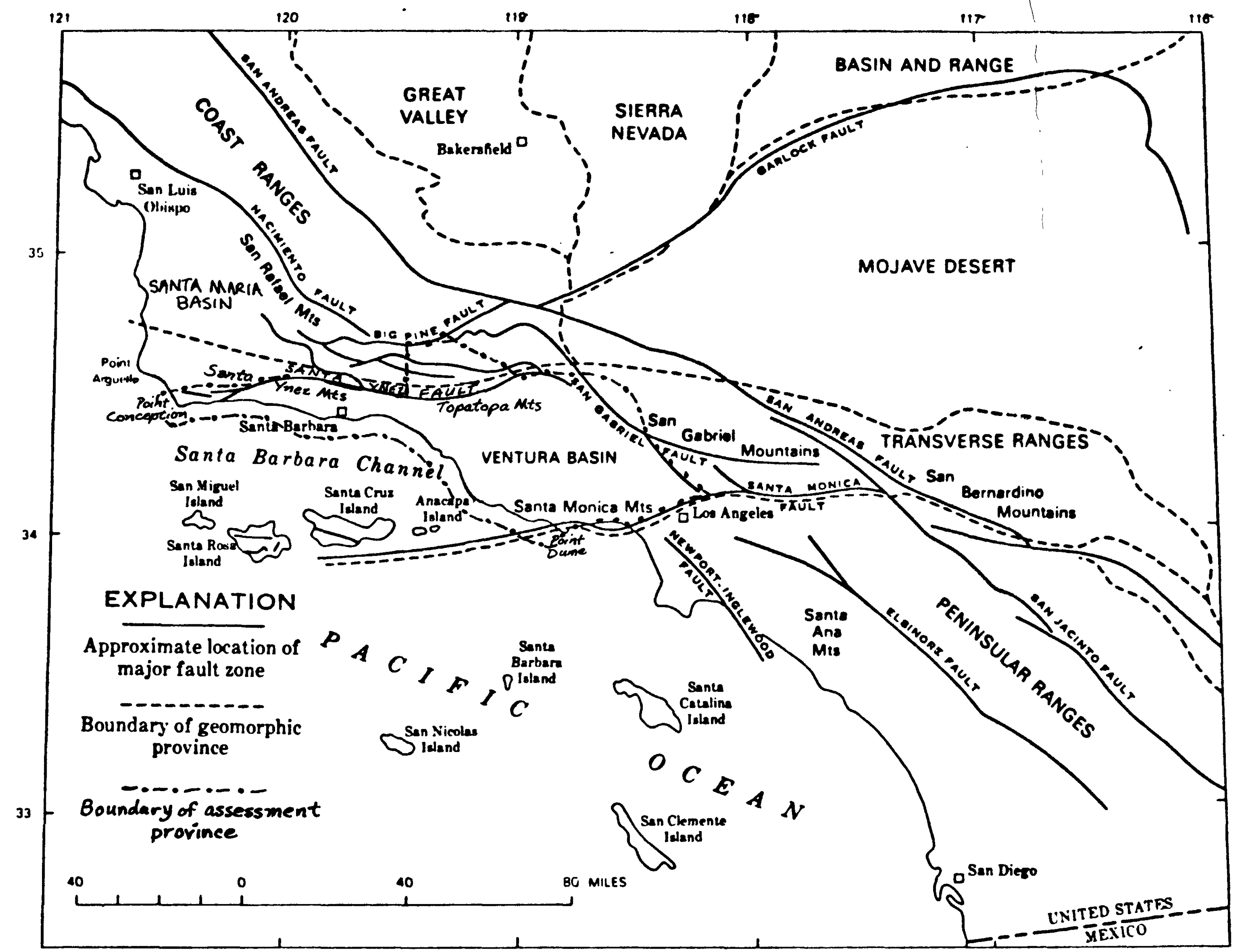


Figure 1. Index map showing location of Ventura Basin assessment province of this report and major geomorphic provinces of southern California. Modified from Vedder and others (1969) as modified from Yerkes and others (1965).

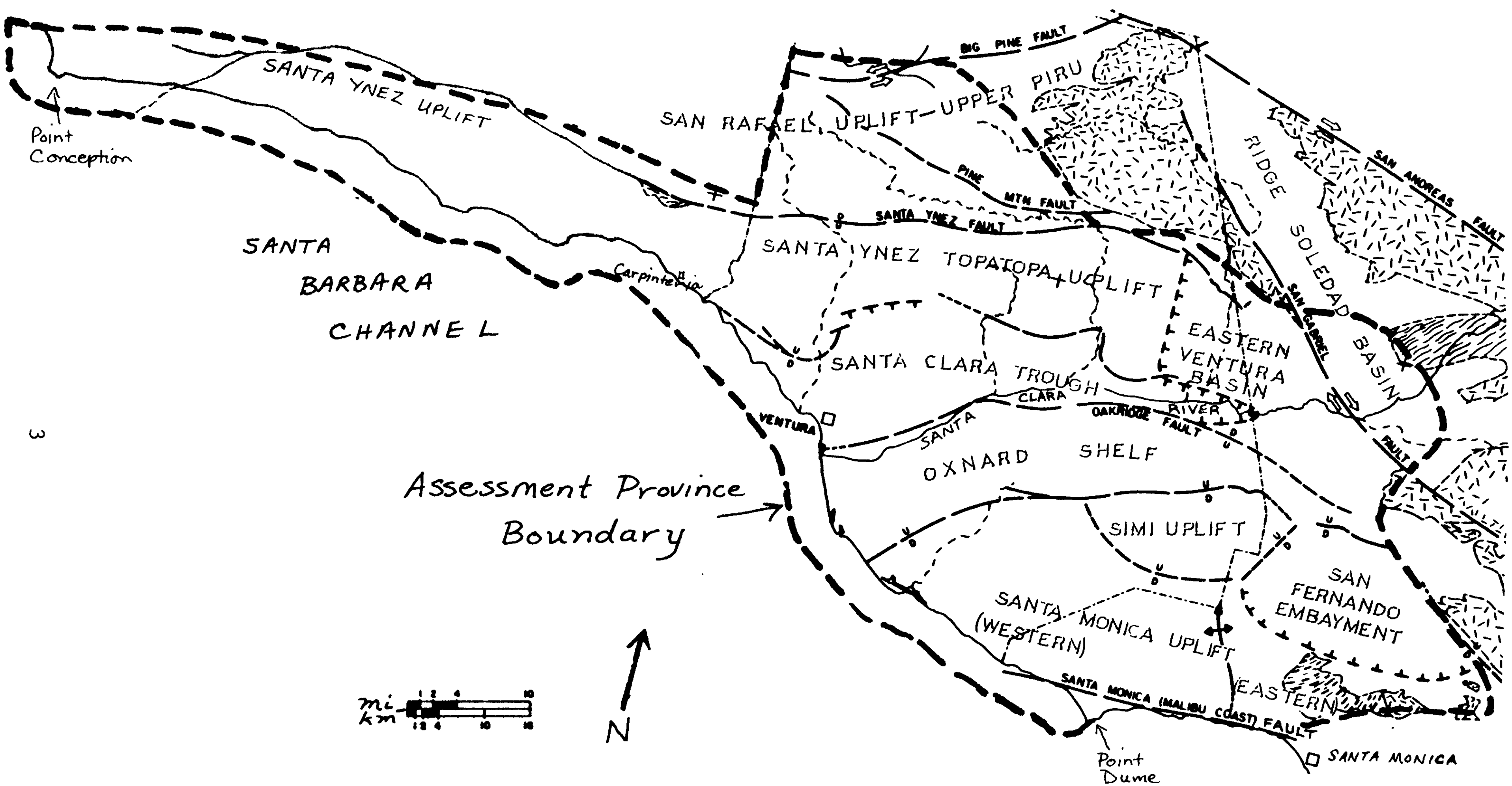


Figure 2. Ventura Basin assessment province showing tectonic subprovinces and major faults in the onshore. Modified from Nagle and Parker (1971) (area east of Carpinteria) and from Jennings (1959) and Jennings and Strand (1969) (area west of Carpinteria).

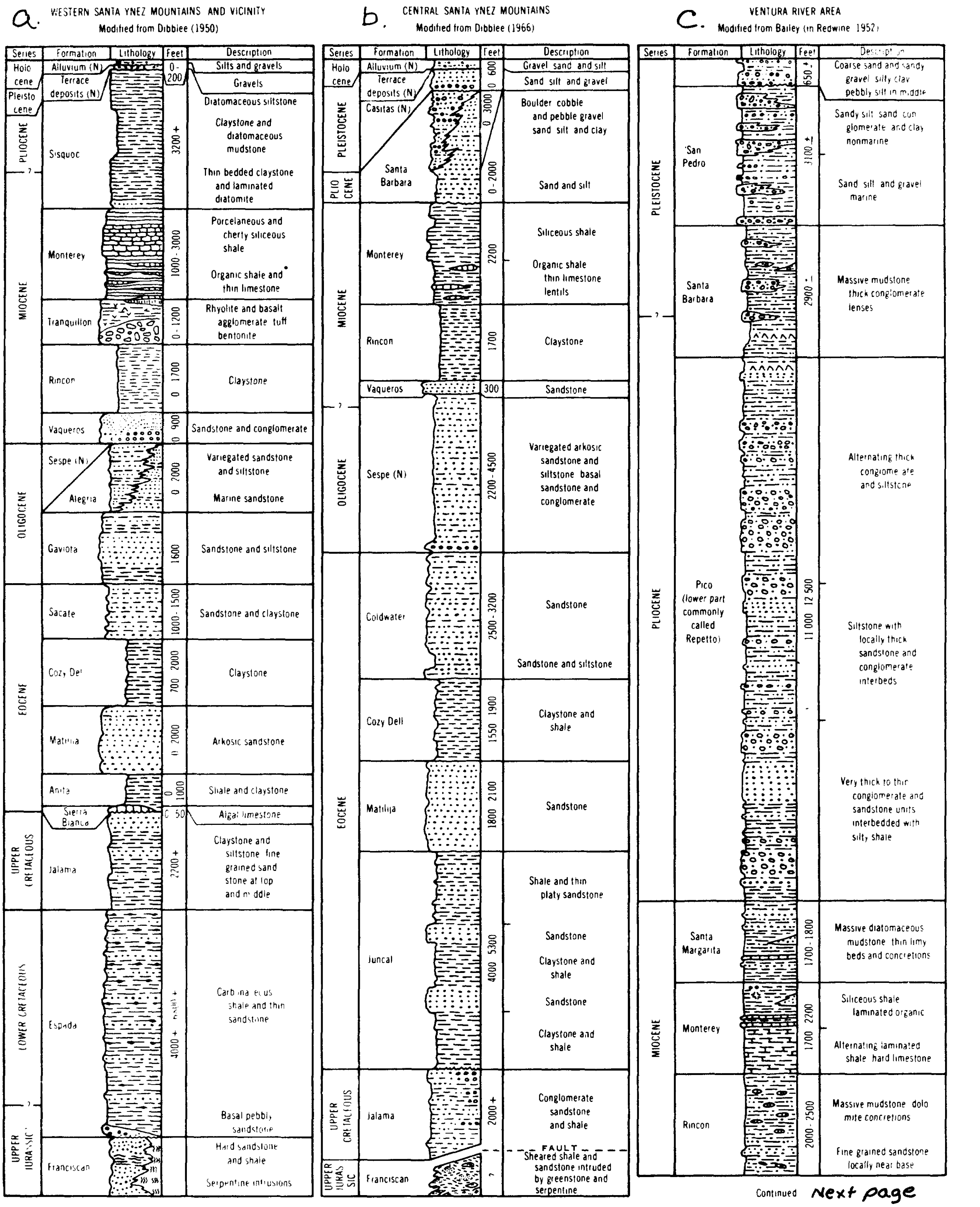
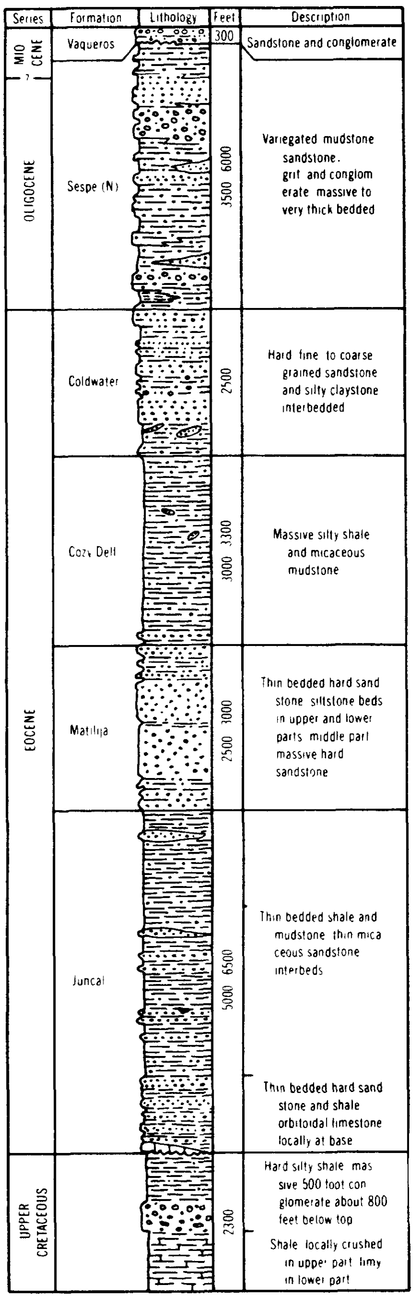


Figure 3. Stratigraphic columns from the western and central Santa Ynez Mountains, the Ventura River area (from Dibblee, 1950; 1966, and Bailey in Redwine, 1952, as modified by Vedder and others, 1969), and the central Santa Monica Mountains (from Yerkes and Campbell, 1979). Note that column from the western Santa Ynez Mountains and vicinity includes the Espada and Franciscan Formations from north of the Santa Ynez fault; these formations are not known south of the fault in this area.

VENTURA RIVER AREA

c. Continued from prior page



a-c

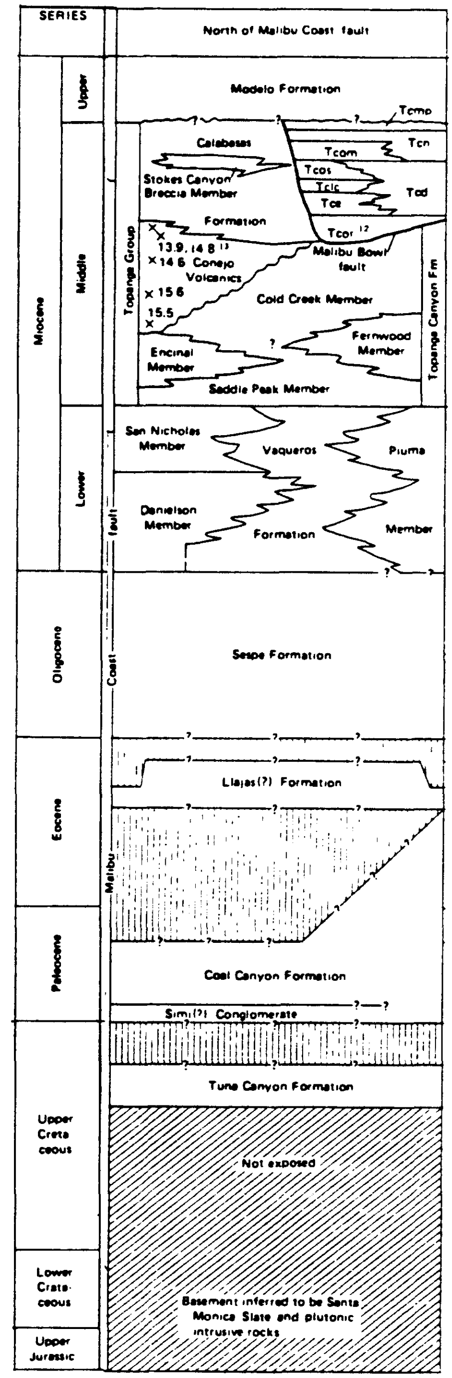
EXPLANATION

(N)

Nonmarine unit

All others are marine

d. CENTRAL SANTA MONICA MOUNTAINS



Ventura River area of Vedder and others, 1969); however, a complete sequence is not exposed in outcrop or penetrated by drilling. Estimated thicknesses of the sedimentary section throughout the assessment province and the gross structural configuration of the basin are shown in basement structure contour maps (Fig. 4) (Curran and others, 1971; Nagle and Parker, 1971). The section includes marine beds ranging in age from Cretaceous to Pleistocene and two major nonmarine sequences within and above the marine beds; the nonmarine Sespe Formation was deposited during the Oligocene as well as parts of the late Eocene and early Miocene times (Vedder and others, 1969; Nagle and Parker, 1971; Howard, 1987), and the nonmarine Saugus and Casitas Formations and equivalents were deposited during Pleistocene and Holocene times (Vedder and others, 1969; Nagle and Parker, 1971) (Fig. 3). In addition, an extremely thick (>8,000 ft or 2,438 m) section of middle Miocene volcanic rocks and volcanic derived sedimentary rocks of relatively shallow marine deposition is present in the Santa Monica Mountains and in lesser thicknesses in the areas of the Oxnard shelf and San Fernando embayment (Fig. 5) (Nagle and Parker, 1971). Stratigraphy varies in the nine tectonic subprovinces of the Ventura Basin assessment province (Fig. 5) (Nagle and Parker, 1971); however, because most hydrocarbon occurrences are concentrated in the area of the Santa Clara trough and adjacent subprovinces, the stratigraphy of these areas is emphasized in the following.

Cretaceous strata are predominantly interlayered marine sandstone, silty claystone, and conglomerate (Vedder and others, 1969). The Lower Cretaceous is not mapped in the Ventura Basin assessment province (Dibblee, 1966; Jennings and Strand, 1969); however, the Lower Cretaceous is presumed to be in the subsurface and it outcrops north of the Santa Ynez fault (Vedder and others, 1969; Nagle and Parker, 1971). The paleobathymetry and depositional history of overlying Cenozoic strata have been described by Ingle (1980; 1981) (Fig. 6, b-d) at three locations in the Ventura basin close to those reported by Vedder and others (1969) (Fig. 3, a-c). Apparently in the Santa Ynez Mountains the age of strata overlying the Cretaceous beds is equivocal; Ingle (1980; 1981) shows the Paleogene strata overlying the Cretaceous as Paleocene age (Fig. 6), whereas Dibblee (1950; 1966) and Vedder and others (1969) show the same formations as Eocene age with the Paleocene absent (Fig. 3). If the Sierra Blanca Limestone, Anita Shale, and Juncal Formation are Eocene (Fig. 3) (Vedder and others, 1969), then Paleocene strata are of limited extent and not known north of the Oak Ridge fault (Figs. 2 and 5). In any case, the Paleogene marine sequence generally contains both hydrocarbon source rocks (e.g. Juncal Formation, Anita Shale, and Cozy Dell Shale north of the Oak Ridge fault; shale of the Llajas Formation south of the fault) and reservoir rocks (e.g. Matilija, Coldwater, Sacate, and Gaviota north of the Oak Ridge fault; Martinez, Santa Susana, and Llajas south of the fault) in a thick, shallowing upward sand-shale sequence (Figs. 3 and 6).

Overlying and -- in the western Santa Ynez Mountains -- interfingering with the Paleogene marine strata is the nonmarine Sespe Formation, deposited during a period of major and widespread marine regression (Fig. 6) (Vedder and others, 1969; Nagle and Parker, 1971; Ingle, 1981; Howard, 1987). The Sespe Formation consists of variegated strata, including red beds, composed chiefly of nonmarine conglomerate, sandstone, and claystone (Vedder and others, 1969; Howard, 1987). For the most part, Sespe deposition took place during the Oligocene; however, in places it is as old as late Eocene and as young as early Miocene (Figs. 3 and 6) (Vedder and others, 1969; Ingle, 1981; Howard,

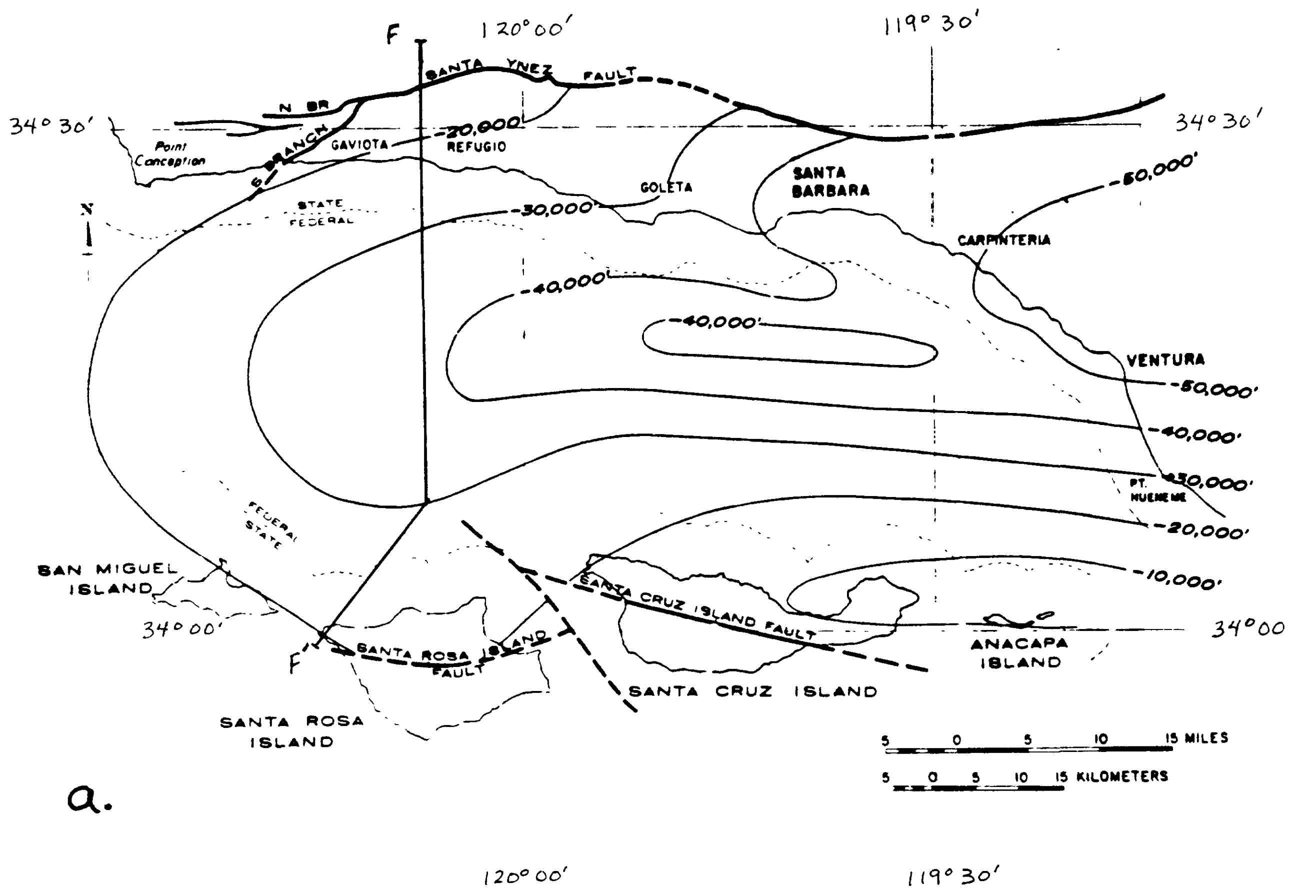
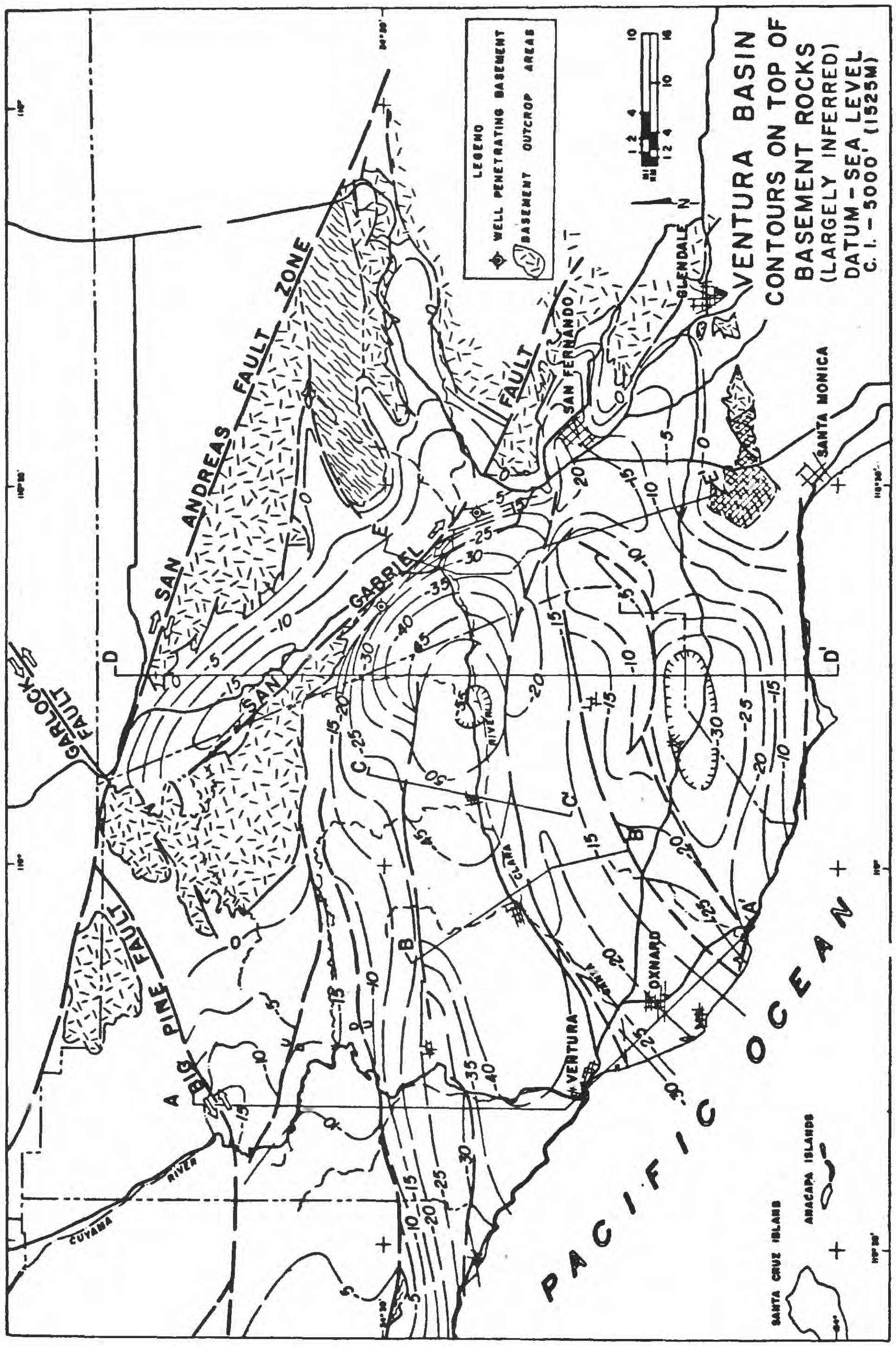


Figure 4. Basement structure contour maps showing deep areas of basin and basement outcrops. (a) Area of assessment province west of Ventura. From Curran and others, 1971, reprinted by permission of American Association of Petroleum Geologists. (b) Area of assessment province approximately east of area covered by figure 4a. From Nagle and Parker, 1971, reprinted by permission of American Association of Petroleum Geologists. Discrepancies between a and b are due to assumption of greater thickness of Cretaceous rocks in a (Curran and others, 1971).


VENTURA BASIN
CONTOURS ON TOP OF
BASEMENT ROCKS
(LARGELY INFERRED)
DATUM - SEA LEVEL
C. I. - 5000' (1525M)
LEGEND
WELL PENETRATING BASEMENT
BASEMENT OUTCROP AREAS
SAN ANDREAS FAULT ZONE
GARLOCK FAULT
BIG PINE FAULT
SAN GABRIEL
SAN FERNANDO
FAULT
GLENDALE
SANTA MONICA
VENTURA
OXNARD
PACIFIC OCEAN
SANTA CRUZ ISLANDS
ANACAPA ISLANDS
CUYAMA RIVER

b.

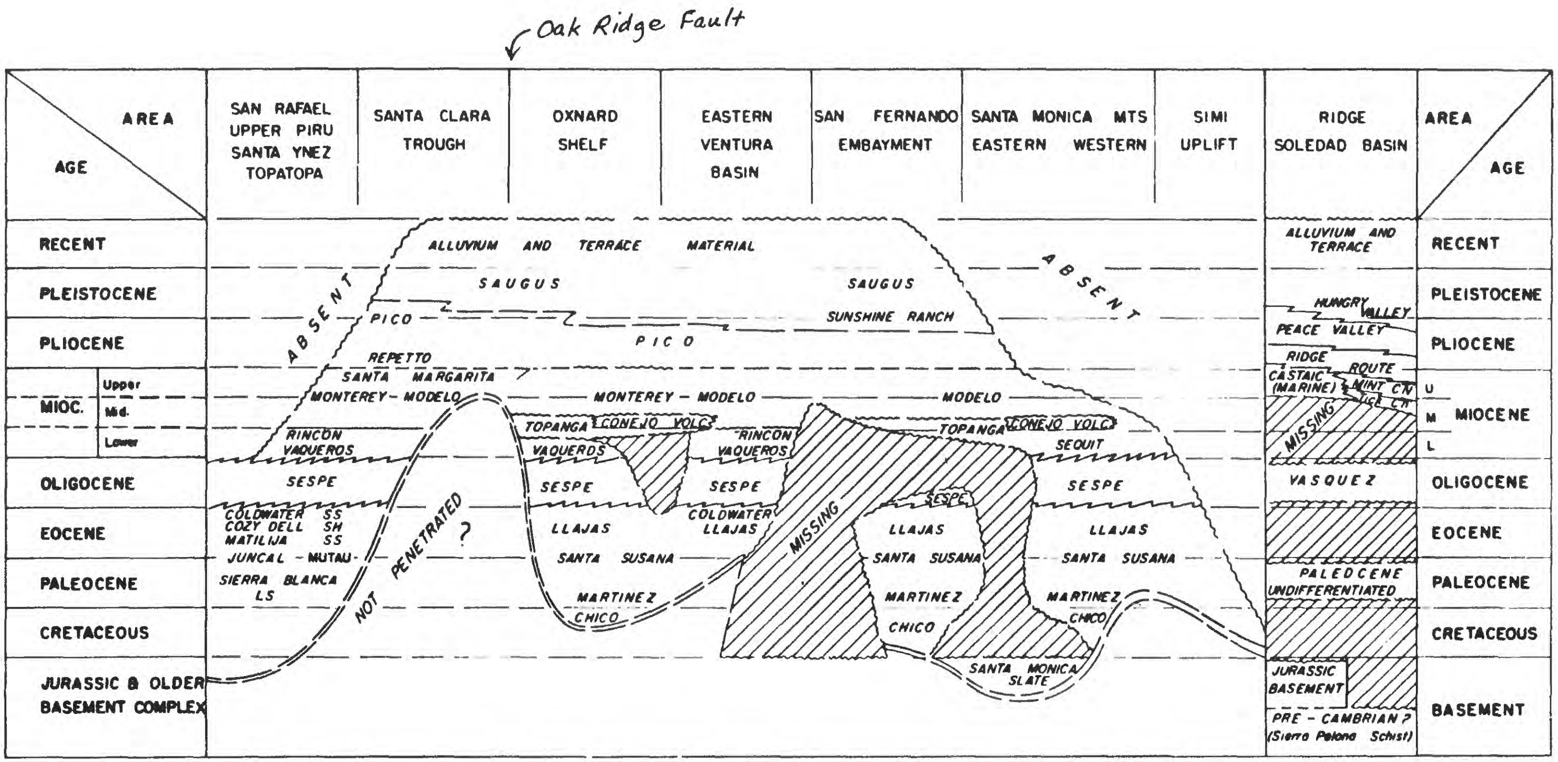


Figure 5. Stratigraphic correlation diagram for the Ventura Basin assessment province. From Nagle and Parker (1971), reprinted by permission of American Association of Petroleum Geologists. Other studies suggest the following revisions to these stratigraphies: 1) Paleocene strata shown in the San Rafael-Upper Piru and Santa Ynez-Topatopa uplifts is absent, and the Sierra Blanca Limestone is Eocene (Vedder and others, 1969); 2) the Santa Monica Mountains stratigraphy has been revised by Yerkes and Campbell (1979) (see Fig. 3, this report); and 3) in the Ridge-Soledad Basin the San Francisquito Formation is Upper Cretaceous and Paleocene age (Crowell and Link, 1982).

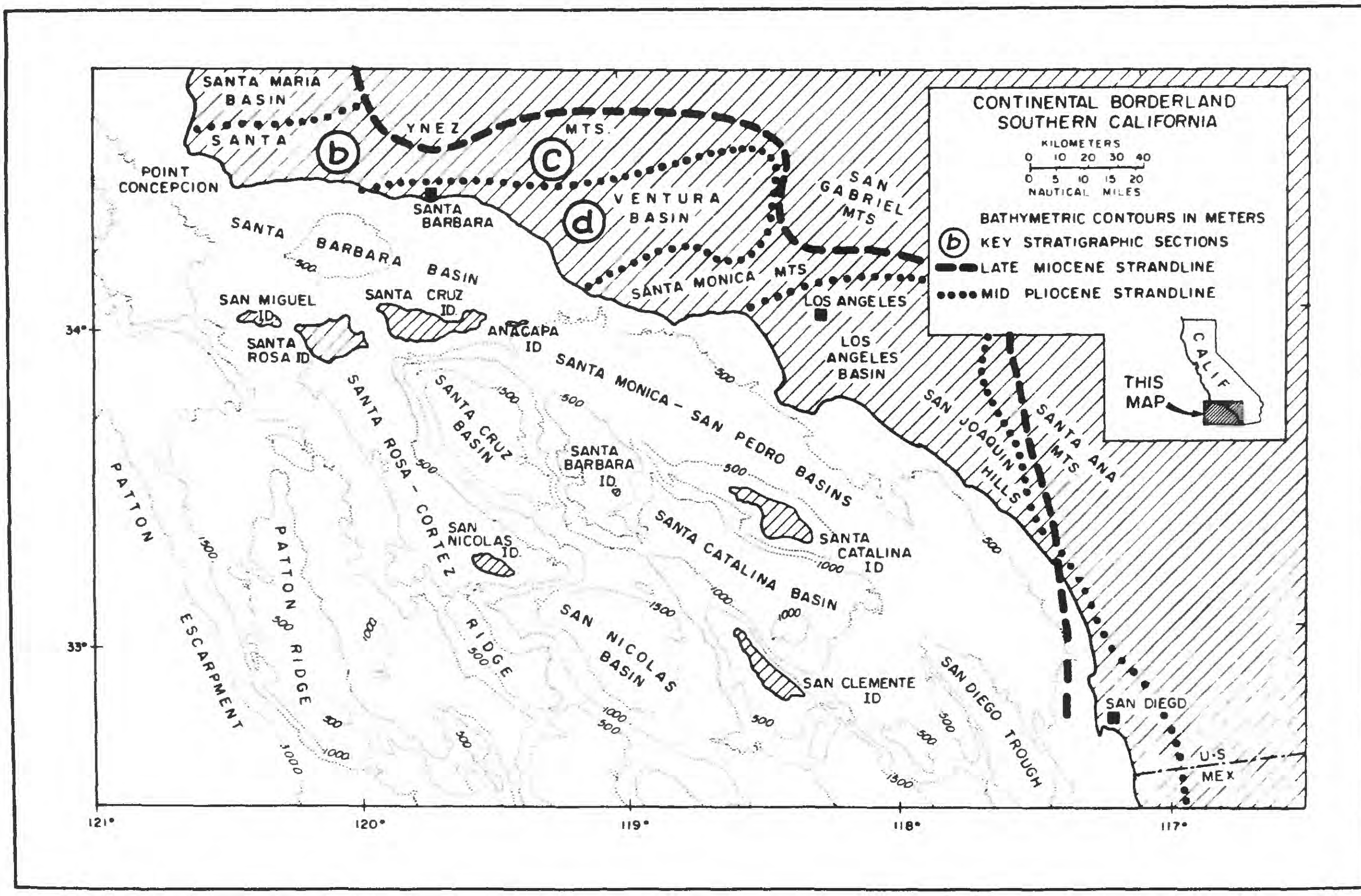
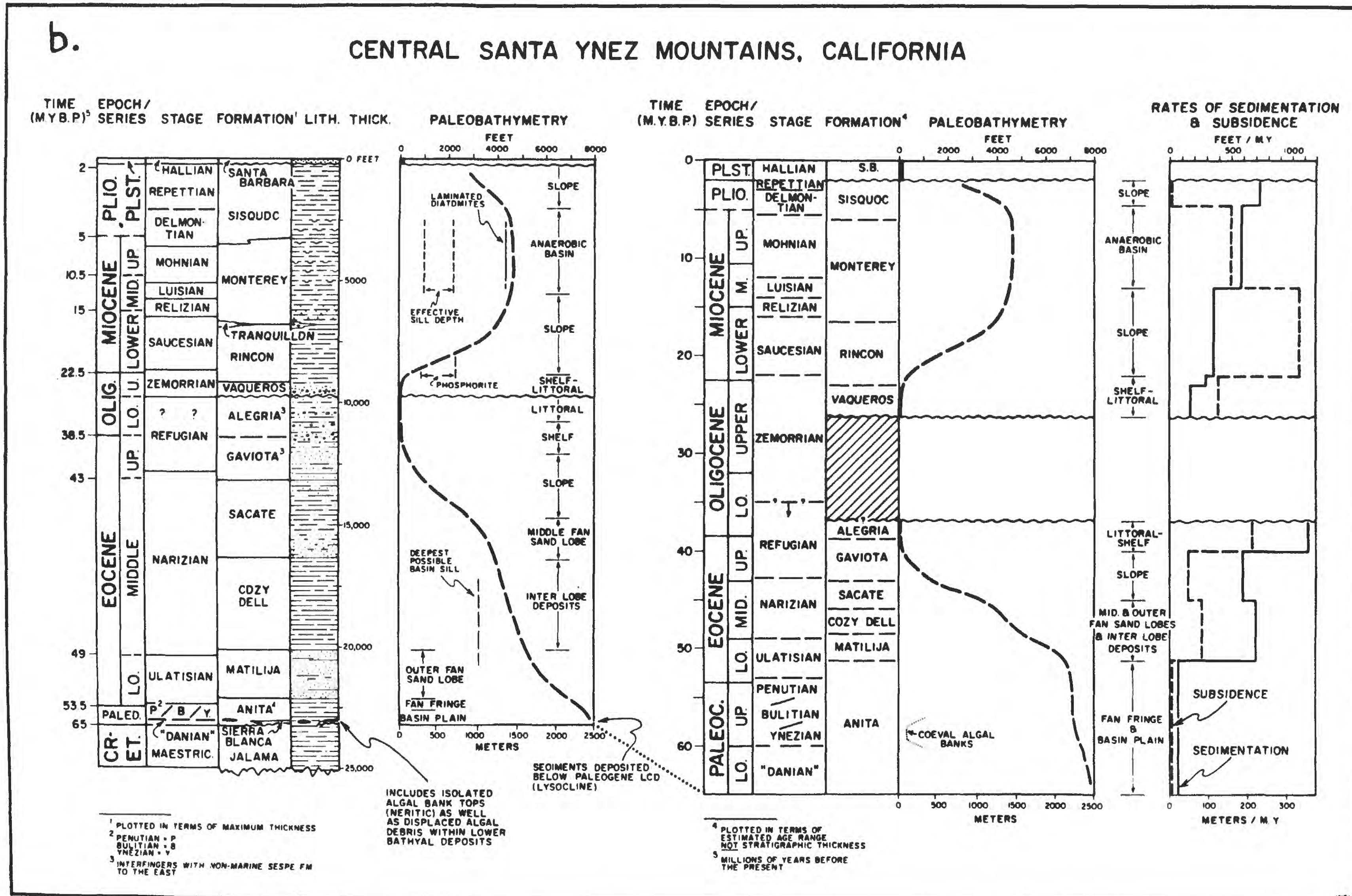
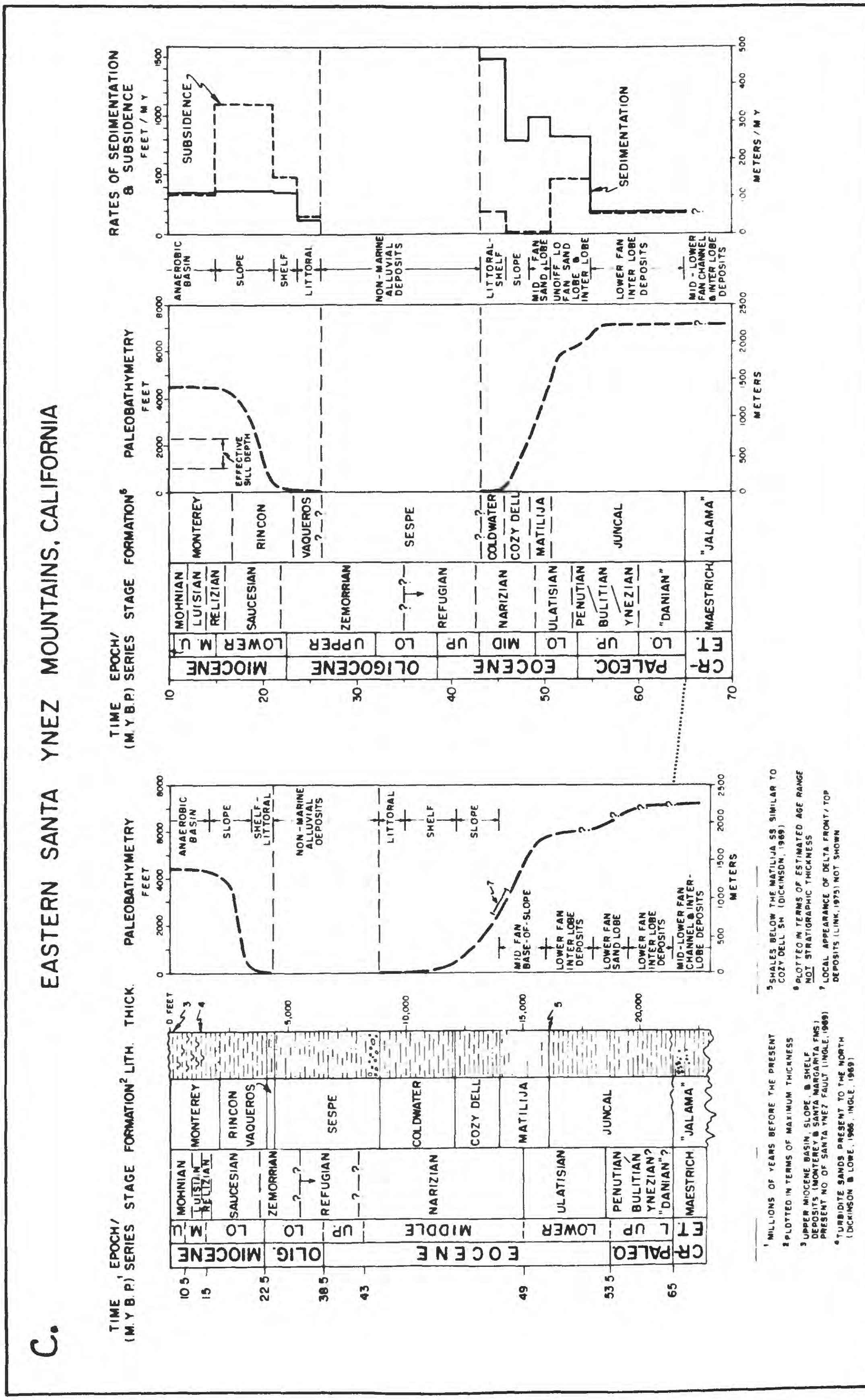


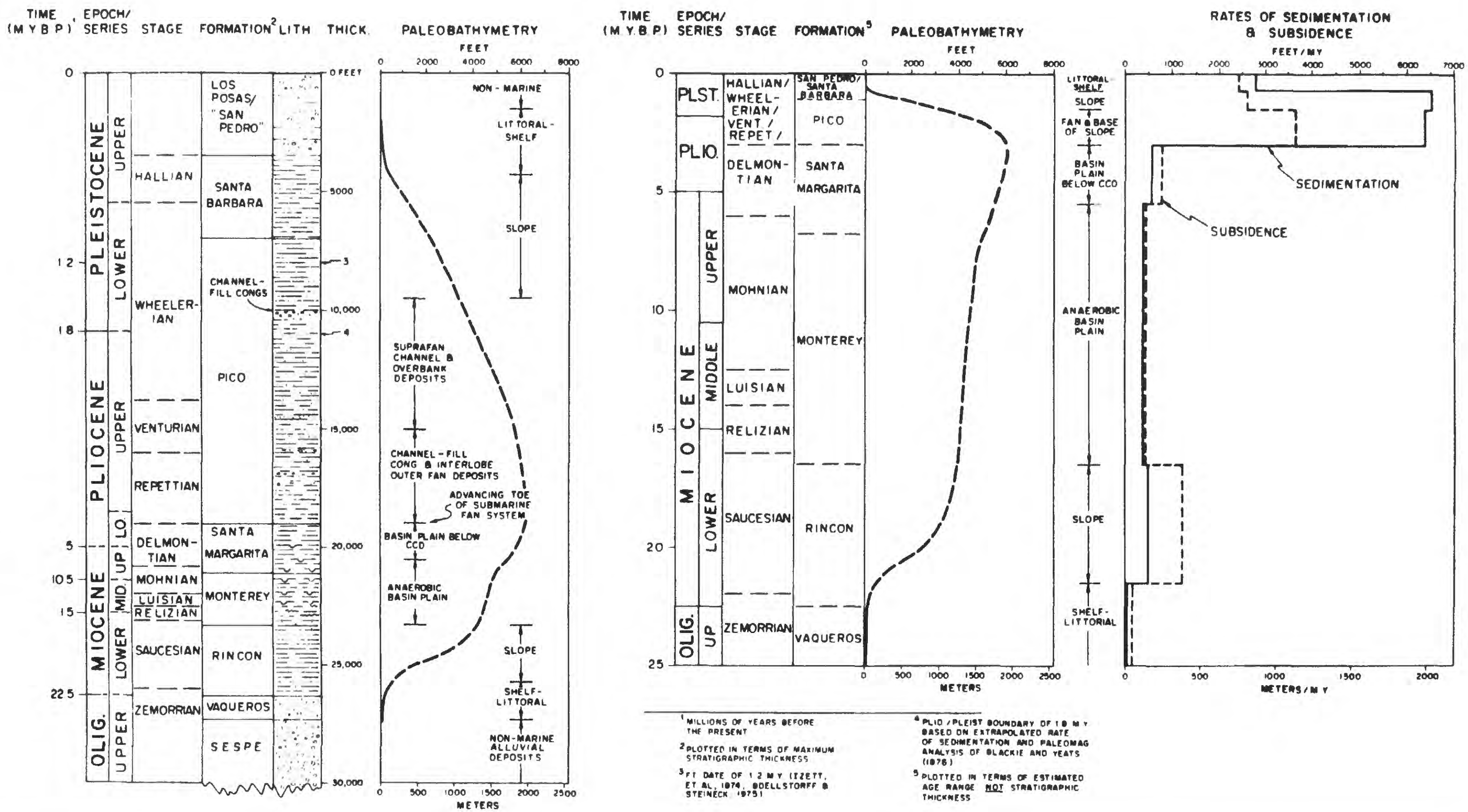
Figure 6. Paleoenvironments, paleobathymetry, and estimated rates of sediment accumulation and subsidence within Cenozoic deposits of the central Santa Ynez Mountains, California. From Ingle, 1980 (b and c reprinted by permission of the Cushman Foundation for Foraminiferal Research) and Ingle, 1981, (a and d reprinted by permission of the Pacific Section American Association of Petroleum Geologists). (a) Location Map (b) Central Santa Ynez Mountains (c) Eastern Santa Ynez Mountains (d) Ventura area. Note that paleobathymetry is plotted both in terms of maximum stratigraphic thickness of each formation (left column) and alternately in terms of estimated duration of each unit in time (right column). For references see Ingle (1980; 1981).


b.
CENTRAL SANTA YNEZ MOUNTAINS, CALIFORNIA
TIME (M.Y.B.P)[5]
EPOCH/ SERIES
STAGE
FORMATION[1]
LITH. THICK.
PALEOBATHYMETRY
FEET
METERS
PLIO.
PLST.
MIOCENE
OLIG.
EOCENE
PALED.
CR-ET.
HALLIAN
REPETTIAN
DELMONTIAN
MOHNIAN
LUISIAN
RELIZIAN
SAUCESIAN
ZEMORRIAN
REFUGIAN
NARIZIAN
ULATISIAN
"DANIAN"
MAESTRIC.
SANTA BARBARA
SISQUOC
MONTEREY
TRANQUILLON
RINCON
VAQUEROS
ALEGRIA[3]
GAVIOTA[3]
SACATE
COZY DELL
MATILIJA
ANITA[4]
SIERRA BLANCA
JALAMA
0 FEET
5000
10,000
15,000
20,000
25,000
LAMINATED DIATOMITES
EFFECTIVE SILL DEPTH
PHOSPHORITE
DEEPEST POSSIBLE BASIN SILL
OUTER FAN SAND LOBE
FAN FRINGE
BASIN PLAIN
SLOPE
ANAEROBIC BASIN
SHELF-LITTORAL
LITTORAL
SHELF
MIDDLE FAN SAND LOBE
INTER LOBE DEPOSITS
INCLUDES ISOLATED ALGAL BANK TOPS (NERITIC) AS WELL AS DISPLACED ALGAL DEBRIS WITHIN LOWER BATHYAL DEPOSITS
SEDIMENTS DEPOSITED BELOW PALEOGENE LCD (LYSOCLINE)
[1] PLOTTED IN TERMS OF MAXIMUM THICKNESS
[2] PENUTIAN = P BULITIAN = B YNEZIAN = Y
[3] INTERFINGERS WITH NON-MARINE SESPE FM TO THE EAST
OLIGOCENE
PALEOC.
UPPER
LOWER
PENUTIAN
BULITIAN
YNEZIAN
S.B.
COEVAL ALGAL BANKS
LITTORAL-SHELF
MID. & OUTER FAN SAND LOBES & INTER LOBE DEPOSITS
FAN FRINGE & BASIN PLAIN
RATES OF SEDIMENTATION & SUBSIDENCE
FEET / M.Y.
METERS / M.Y.
SUBSIDENCE
SEDIMENTATION
[4] PLOTTED IN TERMS OF ESTIMATED AGE RANGE NOT STRATIGRAPHIC THICKNESS
[5] MILLIONS OF YEARS BEFORE THE PRESENT
INGLE


C.
EASTERN SANTA YNEZ MOUNTAINS, CALIFORNIA
TIME (M.Y. B.P.)
EPOCH/SERIES
STAGE
FORMATION
LITH.
THICK.
PALEOBATHYMETRY
FEET
METERS
RATES OF SEDIMENTATION & SUBSIDENCE
FEET / M.Y.
METERS / M.Y.
SUBSIDENCE
SEDIMENTATION
MONTEREY
RINCON
VAQUEROS
SESPE
COLDWATER
COZY DELL
MATILIJA
JUNCAL
"JALAMA"
MOHNIAN
LUISIAN
RELIZIAN
SAUCESIAN
ZEMORRIAN
REFUGIAN
NARIZIAN
ULATISIAN
PENUTIAN
BULITIAN
YNEZIAN
"DANIAN"
MAESTRICH
MIOCENE
OLIGOCENE
EOCENE
PALEOC.
CR.-ET.
EFFECTIVE SILL DEPTH
ANAEROBIC BASIN
SLOPE
SHELF
LITTORAL
NON-MARINE ALLUVIAL DEPOSITS

d.

VENTURA AREA, CALIFORNIA



1987). The vicinity of Gaviota Pass is the western limit of the Sespe red bed sequence (Fig. 3a) (Vedder and others, 1969); paralic marine deposition -- the Alegria Formation -- continued to the west of here until at least early Oligocene time (Ingle, 1981).

Conformably overlying the Sespe Formation are shallow marine sandstone and conglomerate of the Vaqueros Formation which mark the onset of widespread marine transgression during the late Oligocene (Ingle, 1981) and/or(?) early Miocene (Vedder and others, 1969; Nagle and Parker, 1971); however, in the western Santa Ynez Mountains nonmarine deposits are absent, and the Vaqueros unconformably overlies the marine Alegria Formation (Ingle, 1981). Conformably overlying the Vaqueros Formation, the Neogene marine sequence consists of deep-marine organic-rich fine-grained rocks of Miocene and early Pliocene age overlain by, and in part interbedded with, turbidite sands of late Miocene, Pliocene, and Pleistocene age (Fig. 6). The Neogene sequence (including the Vaqueros), as thick as approximately 26,000 ft (7,925 m) (Fig. 3c, Vedder and others, 1969), contains the most important hydrocarbon source rocks (Rincon, Monterey, Modelo, Sisquoc, and Santa Margarita) as well as hydrocarbon reservoir rocks (Monterey, Modelo, and Pico) of the assessment province (Figs. 3 and 6) (Nagle and Parker, 1971). Overlying the Neogene marine sequence in the areas of the Santa Clara trough, Oxnard shelf, eastern Ventura basin, and San Fernando embayment are Pleistocene and Holocene nonmarine deposits of the Saugus Formation and equivalents (Fig. 5) (Nagle and Parker, 1971).

Structure and Tectonic Setting

The Ventura Basin assessment province includes the southernmost part of the Coast Ranges and the westernmost part of the Transverse Ranges Geomorphic Provinces, two of several large geomorphic and structural provinces of southern California (Fig. 1). The Transverse Ranges and most of the assessment province have a west-trending structural grain in contrast to the dominant regional northwest grain of the Coast Ranges and most of California (Figs. 1 and 7) (Vedder and others, 1969). One hypothesis to explain the anomalous structural orientation of the Transverse Ranges Geomorphic Province is based on paleomagnetic data. Luyendyk and Hornafius and many colleagues (Luyendyk and others, 1980; 1985; Hornafius, 1985; Hornafius and others, 1986; Luyendyk and Hornafius, 1987) measured the paleomagnetic declination on rocks throughout southern California. Their modeling of this data indicates that the westernmost Transverse Ranges (including most of the Ventura Basin assessment province) have rotated -- as a coherent block -- approximately 90 ° in a clockwise sense since about 16 Ma (Fig. 8) (Hornafius and others, 1986).

Very little is known about basement rocks in the assessment province (Fig. 4); however, the configuration of basement rocks in southern California and northern Baja California is described in the tectonostratigraphic terrane model of Vedder and others (1983) and Howell and others (1987) (Fig. 9). In their model, most of the westernmost Transverse Ranges (i.e., most of the assessment province) is placed in the Stanley Mountain terrane (Fig. 9), for which the basement is a Jurassic ophiolite sequence known only in two places near the Transverse Ranges: in the San Rafael Mountains and west of Santa Maria at Point Sal (Vedder and others, 1983). In the Ventura Basin assessment province, the ophiolite basement complex of the Stanley Mountain terrane is

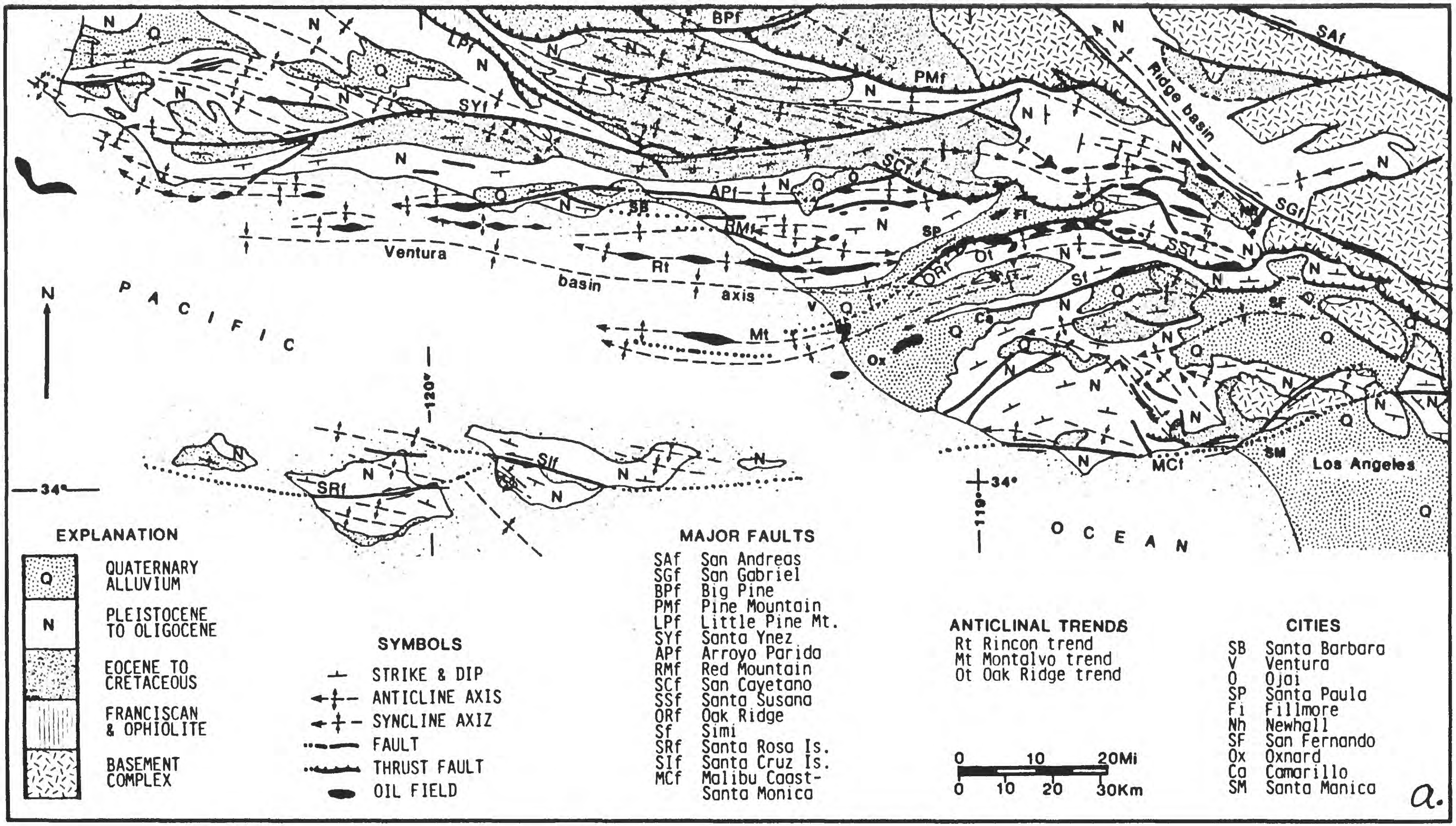
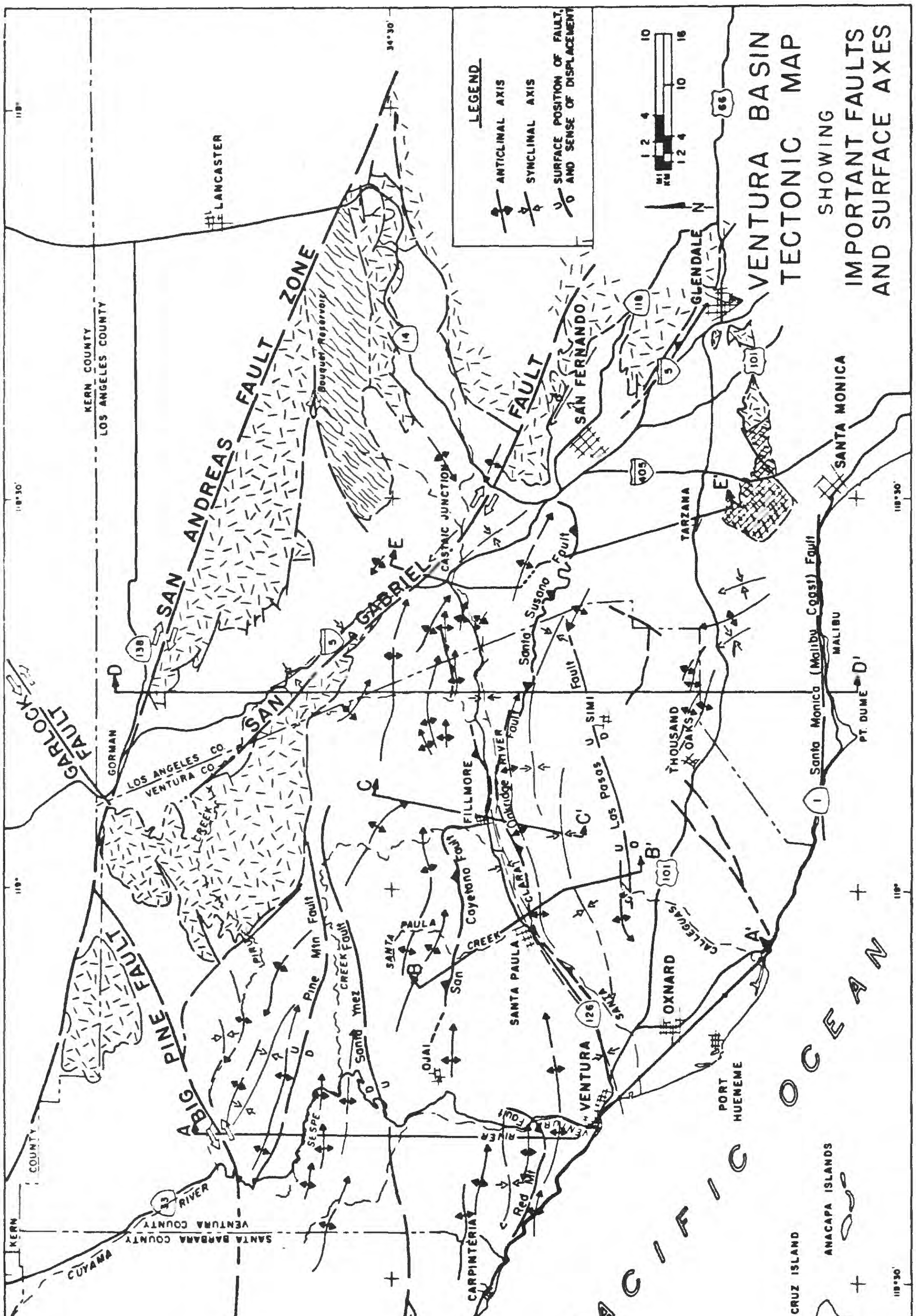
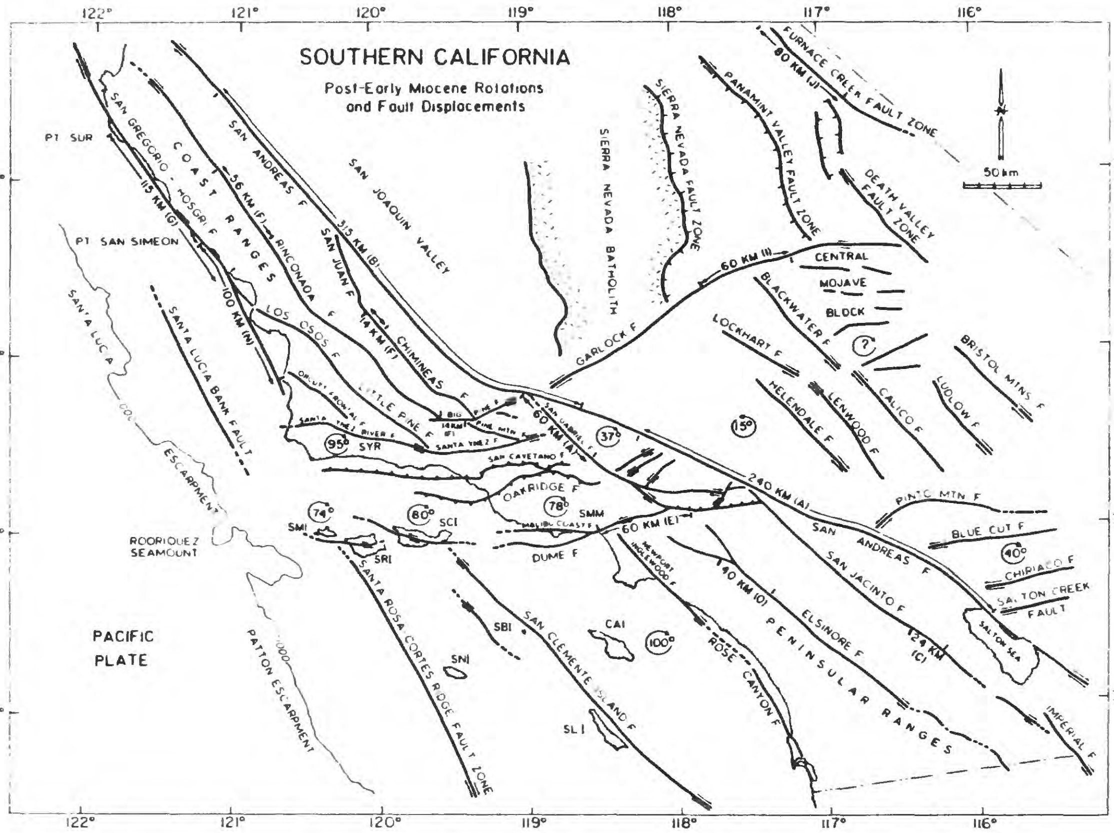


Figure 7. (a) Simplified geologic map of the Ventura Basin assessment province and vicinity. From Dibblee, 1988, reprinted by permission of Pacific Section American Association of Petroleum Geologists. (b) Detail of structure in eastern half of assessment province showing important faults and surface axes of folds. From Nagle and Parker, 1971, reprinted by permission of American Association of Petroleum Geologists. Location of cross sections in Figure 10 (A-E).


VENTURA BASIN TECTONIC MAP
SHOWING
IMPORTANT FAULTS AND SURFACE AXES
LEGEND
ANTICLINAL AXIS
SYNCLINAL AXIS
SURFACE POSITION OF FAULT, AND SENSE OF DISPLACEMENT
SAN ANDREAS FAULT ZONE
BIG PINE FAULT
GARLOCK FAULT
SAN GABRIEL FAULT
SAN FERNANDO
GLENDALE
LANCASTER
KERN COUNTY
LOS ANGELES COUNTY
GORMAN
LOS ANGELES CO.
VENTURA CO.
SANTA BARBARA COUNTY
VENTURA COUNTY
CASTAIC JUNCTION
Bouquet Reservoir
FILLMORE
SANTA PAULA
OXNARD
VENTURA
PORT HUENEME
THOUSAND OAKS
SIMI
TARZANA
SANTA MONICA
MALIBU
PT. DUME
Santa Monica (Malibu Coast) Fault
Santa Susana Fault
San Cayetano Fault
Pine Mtn Fault
OJAI
CARPINTERIA
CALLEGUAS
Los Posas
PACIFIC OCEAN
SANTA CRUZ ISLAND
ANACAPA ISLANDS

b.



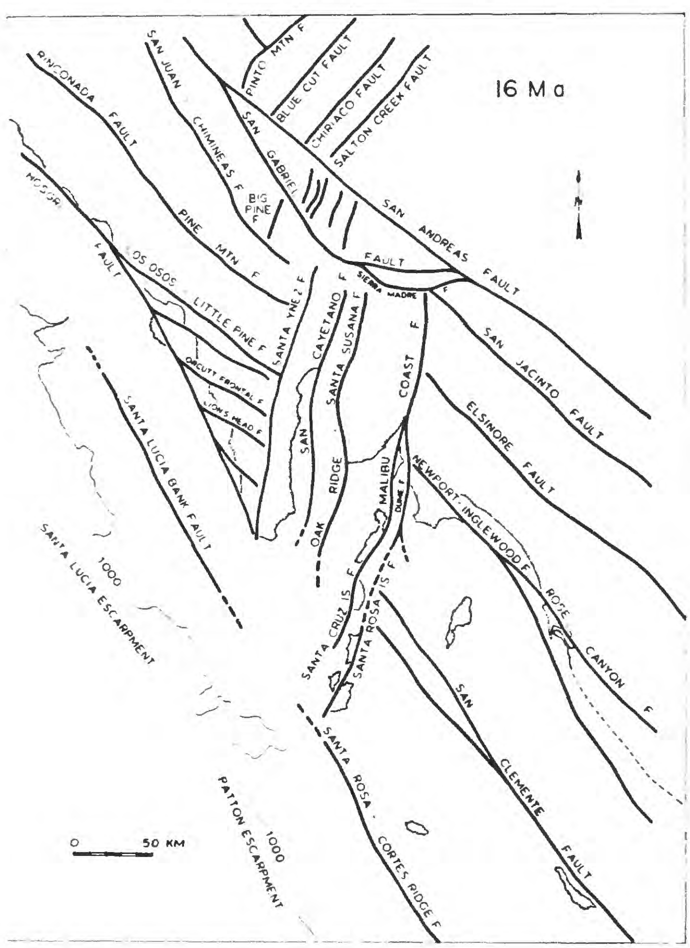


Figure 8. Shown above is a fault map of southern California with circular arrows indicating the sense and amount of post-early Miocene tectonic rotation suggested by paleomagnetic data. Straight arrows indicate the amount of displacement between piercing points along major strike-slip faults. (From Hornafius and others, 1986, p. 1477.) Shown at left is a palinspastic reconstruction of southern California at 16 Ma. Present-day shorelines shown for geographical reference. (From Hornafius and others, 1986, p. 1486.) Both figures originally published by the Geological Society of America. Reprinted with author's permission from: Geological Society of America Bulletin, v. 97, no. 12, p. 1476-1487. (For figure references see Hornafius and others, 1986).

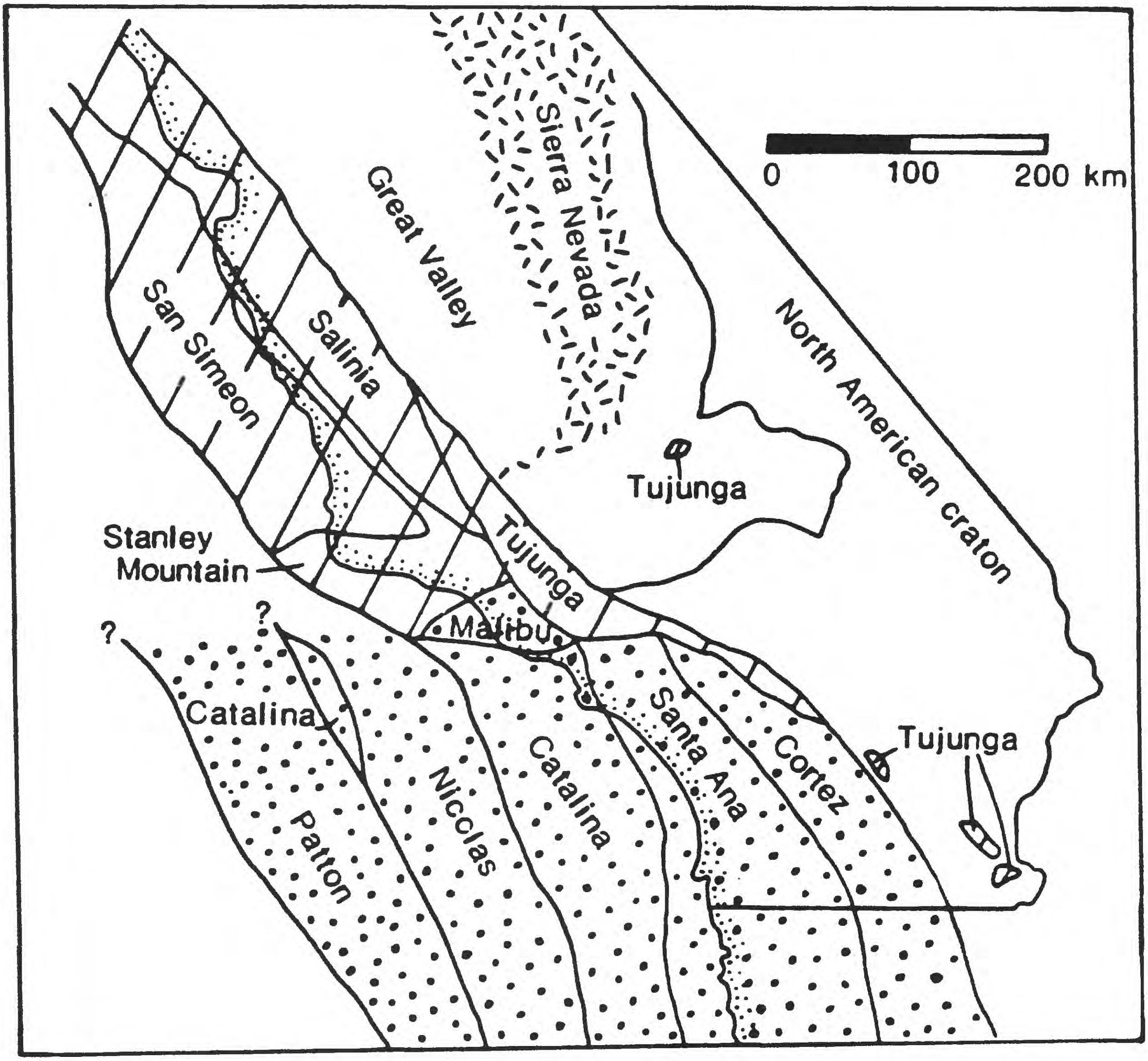


Figure 9. Terranes of southern California and northern Baja California. Diagonal lines indicate extent of the Santa Lucia-Orocopia allochthon, stippled pattern indicates Baja-borderland allochthon, and dashes indicate Mesozoic batholithic rocks of the Sierra Nevada that obscure older terrane boundaries. From Howell and others, 1987, p. 244, reprinted by permission of Prentice-Hall Inc., Englewood Cliffs, N.J. Originally published in: Howell/Champion/Vedder, "Terrane accretion, crustal kinematics, and basin evolution, southern California" in Cenozoic Basin Development of Coastal California, Ingersoll/Ernst, eds., ©1987, p. 244.

not known in outcrop or subcrop; however, three other basement assemblages are known in or near the province. On the northeast and eastern margins basement is granitic and metamorphic rocks of the Salinian terrane; in the Santa Monica Mountains it is a metamorphic complex called the Santa Monica Slate and granitic intrusives included in the Malibu terrane; and in the central Santa Ynez Mountains northeast of Santa Barbara one sliver along the Santa Ynez fault has been mapped as the Franciscan Formation (Fig. 7a) (Dibblee, 1966; 1988; Jennings and Strand, 1969; Vedder and others, 1969) which is included in the San Simeon terrane (Fig. 9) (Vedder and others, 1983; Howell and others, 1987).

Howell and others (1987) also propose that rotation of the western Transverse Ranges occurred during the Neogene -- concurrently with the tectonic juxtaposition of the Santa Monica Mountains/Malibu terrane (part of a set of joined terranes called the Baja-Borderland Allochthon) against the Transverse Ranges/Stanley Mountain terrane (part of the Santa Lucia-Orocopia Allochthon) (Fig. 9). In the Sespe Formation (whose deposition preceded the hypothetical tectonic accretion of the Santa Monica Mountains/Malibu terrane to the Transverse Ranges/Stanley Mountain terrane), paleocurrents do not either refute or support the proposed 90 ° rotation (Howard, 1987). However, facies trends in the Sespe of the Santa Monica Mountains and the Transverse Ranges suggest that both areas were part of the same depositional system and, therefore, were connected during the deposition of the Sespe Formation (Howard, 1987). On the other hand, Sespe and pre-Sespe strata as well as pre-Monterey strata south of the Oak Ridge fault (a possible location for the suture between the Malibu and Stanley Mountain terranes) are lithologically different from their time-equivalent strata north of the fault (Figs. 3 and 5) (Yerkes and Campbell, 1979).

The physiographic features and west-trending structural grain of most of the assessment province (Fig. 7) are generally understood to be products of the most recent period of deformation, the Pasadenian orogeny, which began in Pleistocene time and continues to the present (Nagle and Parker, 1971; Yeats, 1983; Namson, 1987). For this period of major compression, Yeats (1983) documents north-south crustal shortening north of the Oak Ridge fault that was mainly taken up by reverse faults and flexural-slip folding of the Neogene sequence within the area of the Santa Clara trough and on the northern margin in the hanging wall of reverse faults (Fig. 10, a-c); he calculates rates of convergence as high as 23 mm/yr accross the Ventura basin. An alternative restoration by Namson (1987) for this Quaternary phase of compression indicates 35 km (22 mi) of total convergence taken up by thrust faults and folds, yielding a convergence rate of 27 mm/yr. These folds and related faults are the main petroleum traps of this province and include a major onshore and offshore anticlinal trend, the Rincon or Ventura-Rincon trend (Figs. 7a and 10a) (Nagle and Parker, 1971). This trend contains 5 giant oil fields greater than one hundred million barrels -- Ventura Avenue, Rincon, San Miguelito, Carpinteria, and Dos Cuadras -- the first four of which currently produce approximately half the hydrocarbons in the assessment province (California Division of Oil and Gas, 1984).

Because of the recency and magnitude of the Pasadenian orogeny, earlier tectonism is incompletely known and is controversial. For example, Nagle and Parker (1971) document one other important period of deformation -- early middle Miocene -- in addition to the Pasadenian orogeny. This event was characterized by tensional stresses and large vertical movements -- mainly

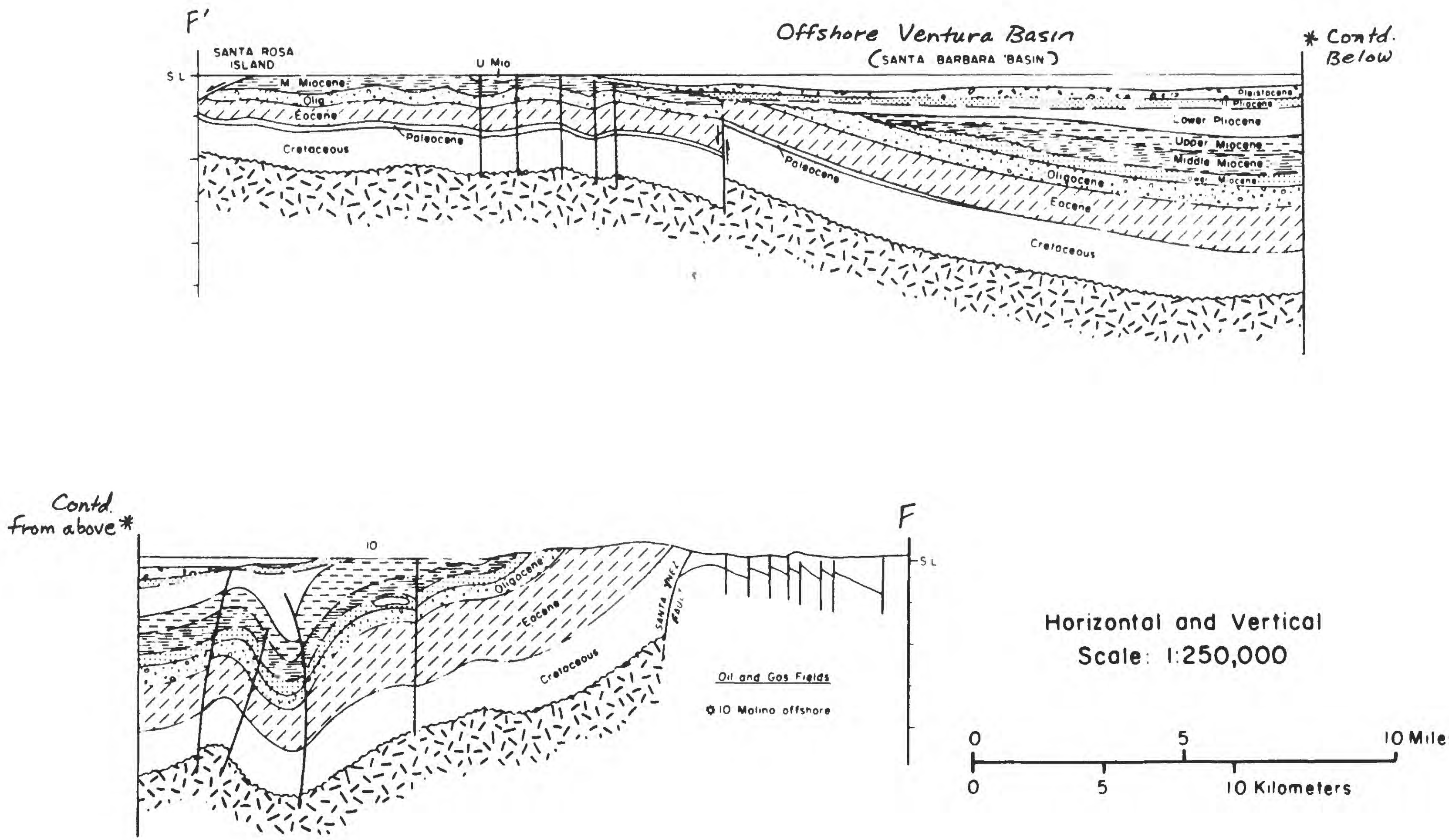
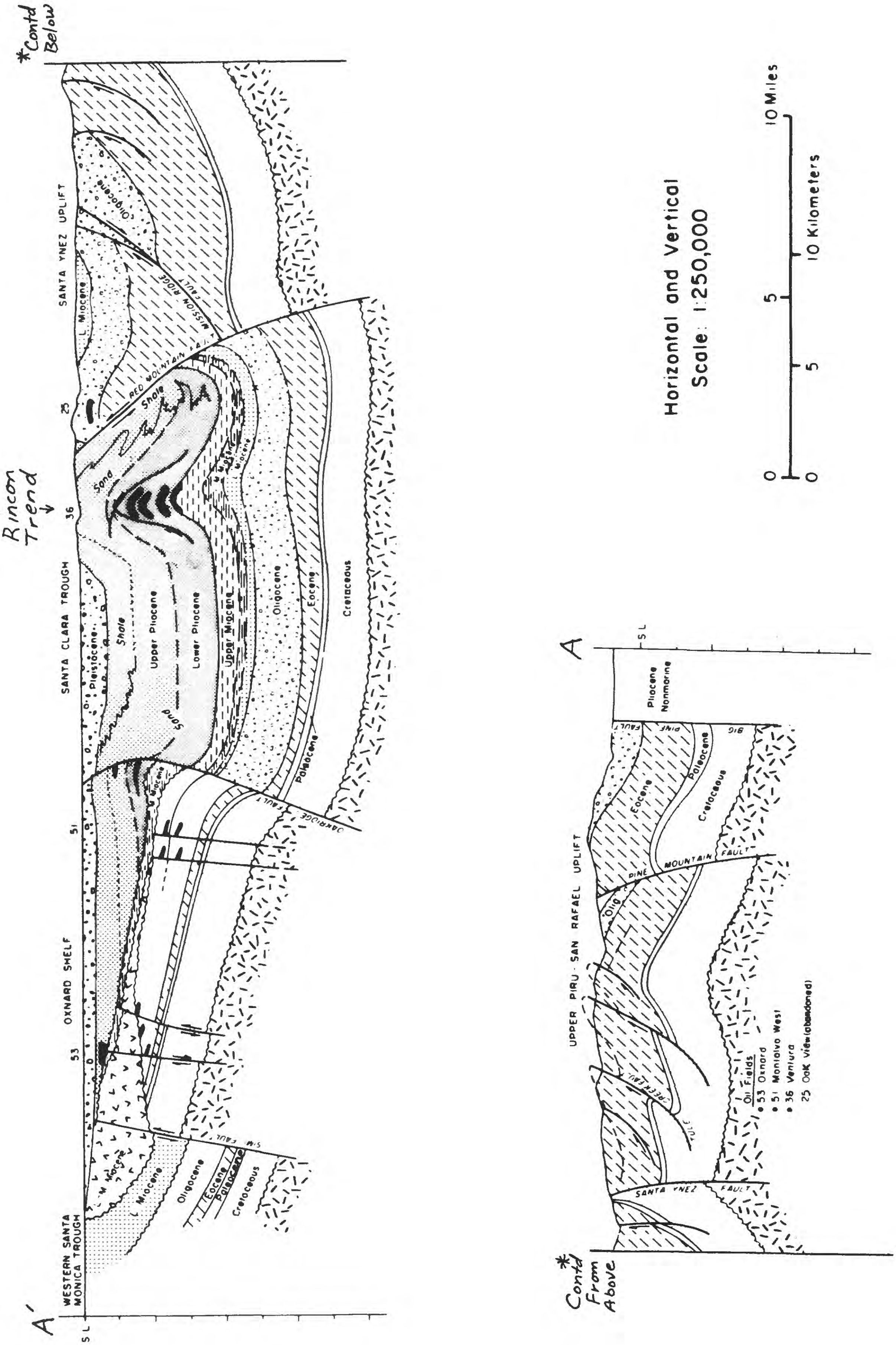
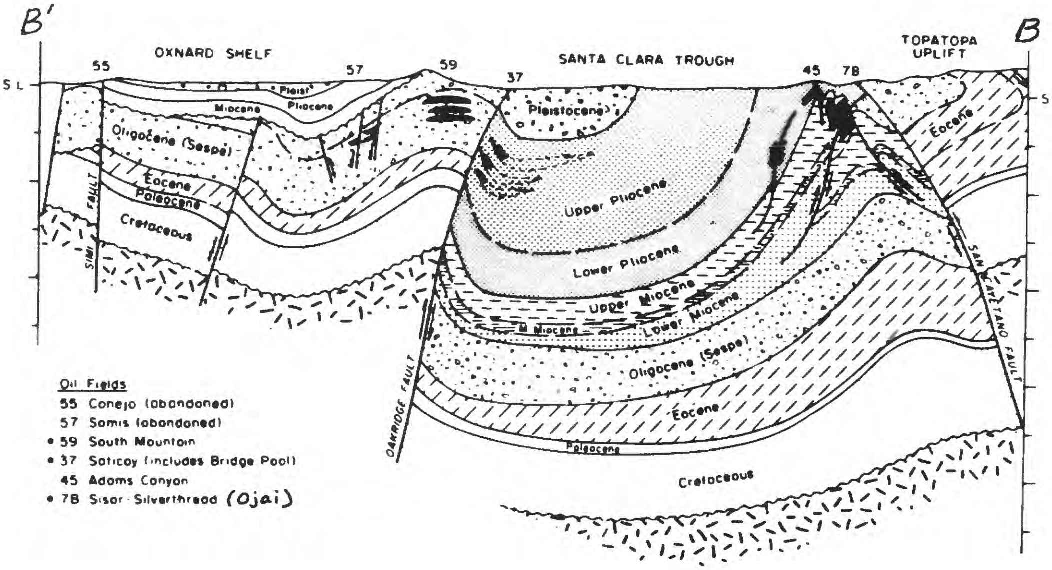
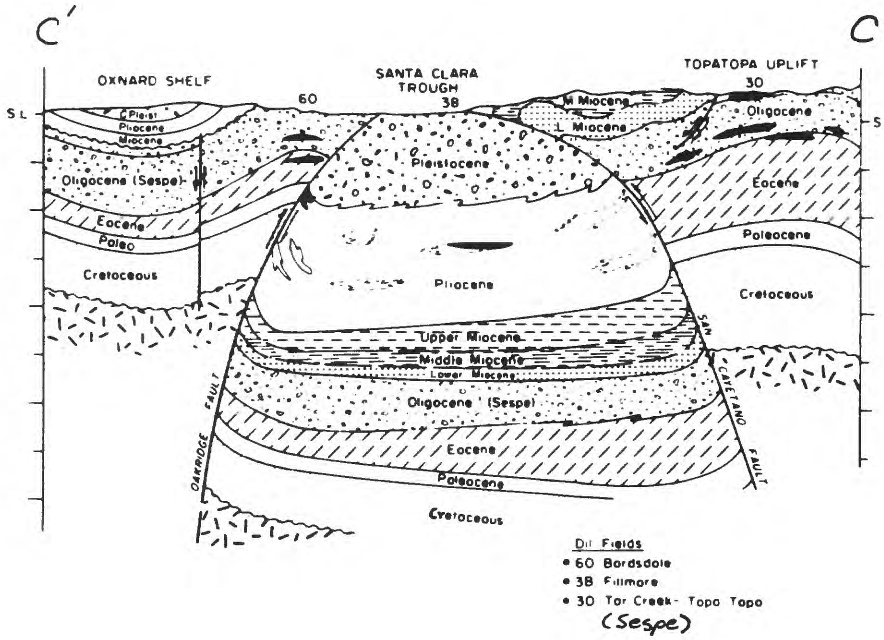


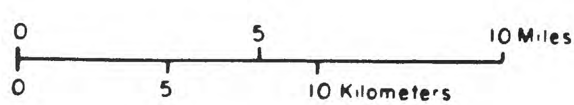
Figure 10. Diagrammatic structural cross sections of the Ventura Basin assessment province. From Taylor and Magoon /unpub. data, 1976; A'-A-E'-E as modified from Nagle and Parker (1971). F'-F as modified from Campbell and others (1975)/. Locations shown in Fig. 7b (A-E) and 4a (F).

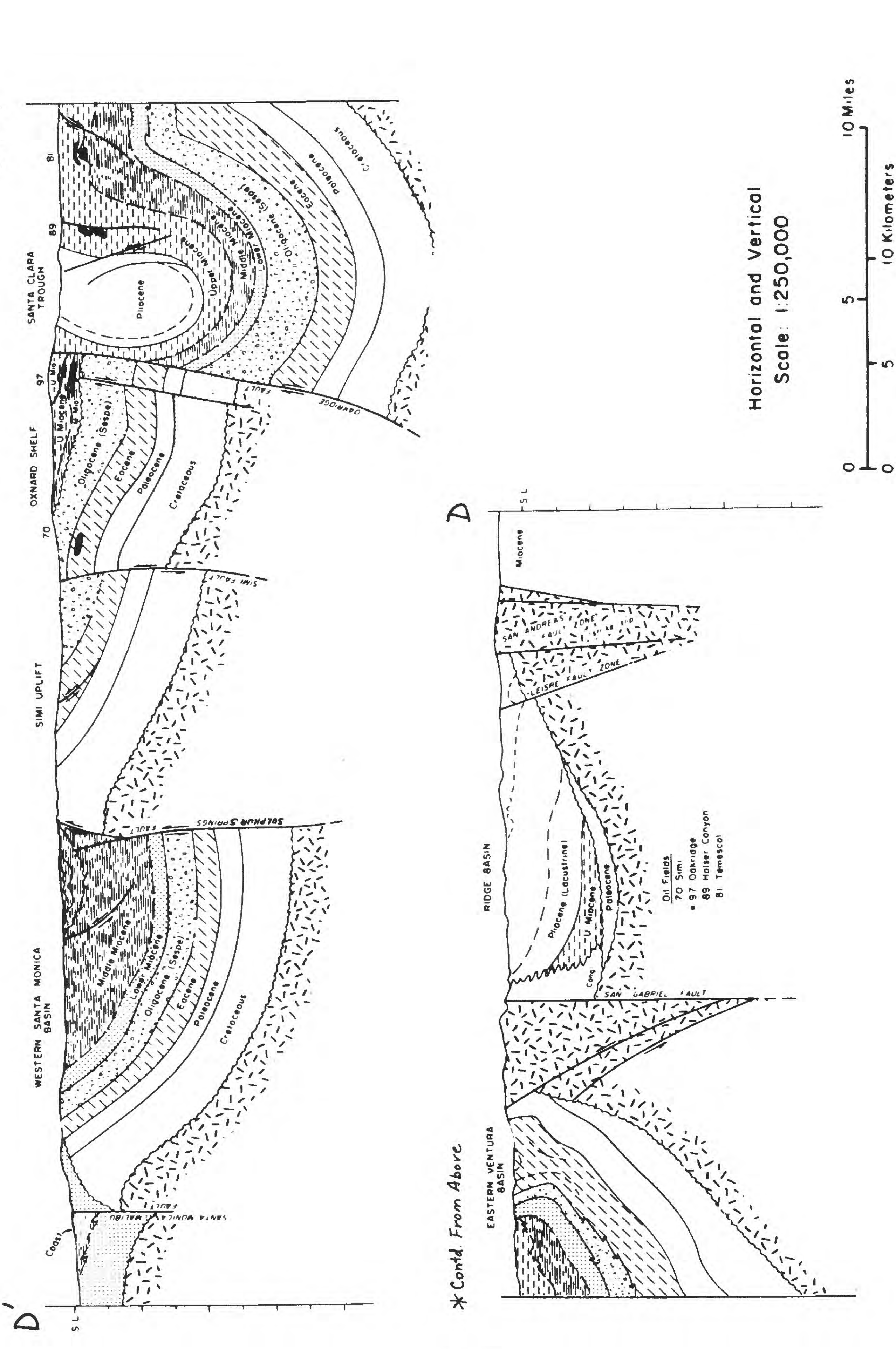

A'
SL
WESTERN SANTA MONICA TROUGH
53
OXNARD SHELF
51
SANTA CLARA TROUGH
Rincon Trend
36
25
SANTA YNEZ UPLIFT
*Contd Below
M Miocene
L Miocene
Oligocene
Eocene
Paleocene
Cretaceous
S.M. FAULT
Pleistocene
Shale
Upper Pliocene
Lower Pliocene
Upper Miocene
Sand
Oligocene
Eocene
Paleocene
Cretaceous
OAKRIDGE FAULT
RED MOUNTAIN FAULT
MISSION RIDGE FAULT
L. Miocene
Oligocene
Horizontal and Vertical
Scale: 1:250,000
0 5 10 Miles
0 5 10 Kilometers
A
SL
Pliocene Nonmarine
BIG PINE FAULT
Eocene
Paleocene
Cretaceous
PINE MOUNTAIN FAULT
Olig
UPPER PIRU - SAN RAFAEL UPLIFT
TULE CREEK FAULT
Oil Fields
• 53 Oxnard
• 51 Montalvo West
• 36 Ventura
25 Oak View (abandoned)
SANTA YNEZ FAULT
*Contd From Above

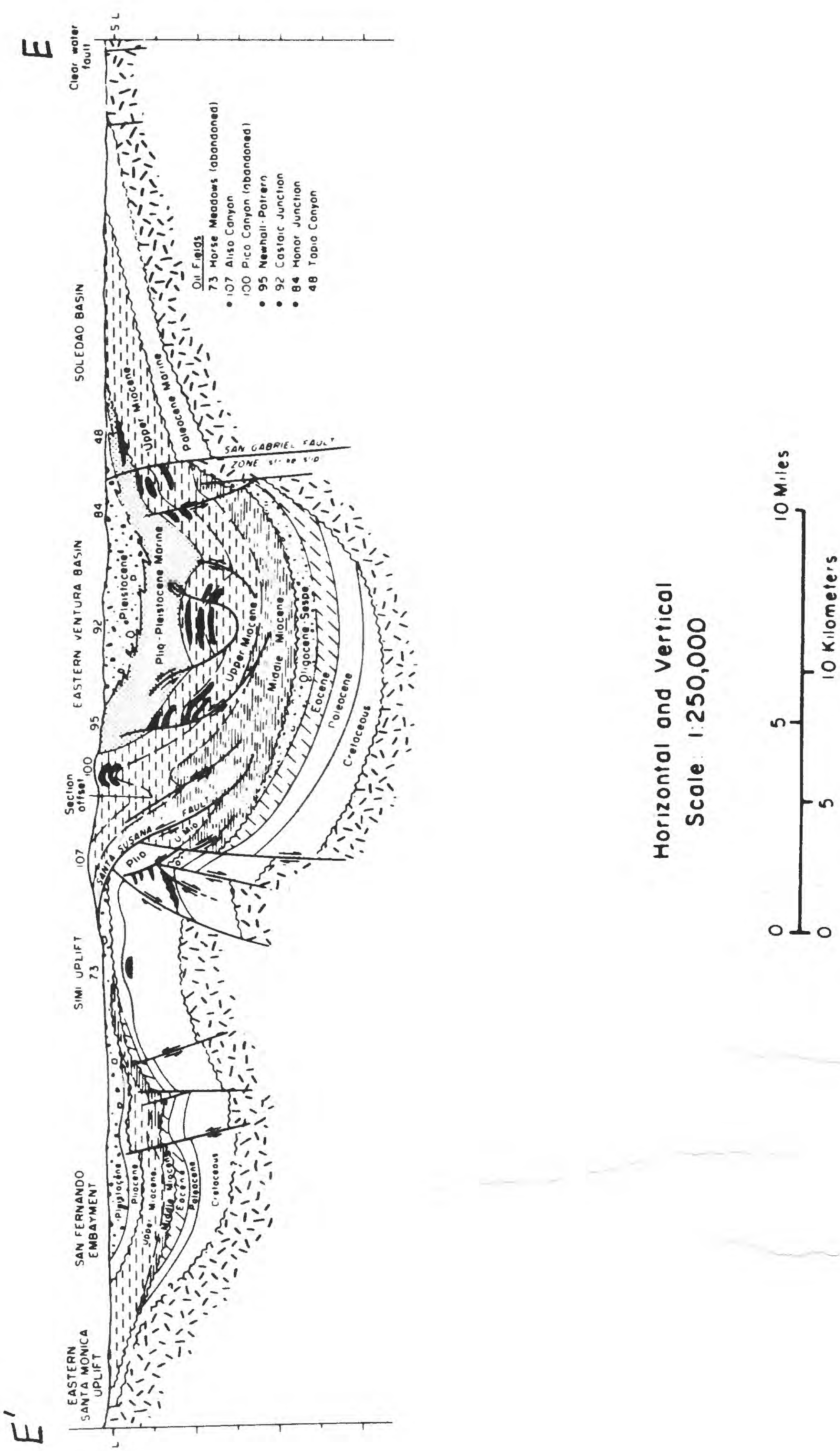




Horizontal and Vertical
Scale 1:250,000




D'
S L
Coast
SANTA MONICA - MALIBU FAULT
WESTERN SANTA MONICA BASIN
Middle Miocene
Lower Miocene
Oligocene (Sespe)
Eocene
Paleocene
Cretaceous
SULPHUR SPRINGS FAULT
SIMI UPLIFT
SIMI FAULT
70
OXNARD SHELF
U Miocene
Oligocene (Sespe)
Eocene
Paleocene
Cretaceous
97
OAKRIDGE FAULT
SANTA CLARA TROUGH
Pliocene
Upper Miocene
Middle Miocene
Oligocene (Sespe)
Eocene
Paleocene
Cretaceous
89
81
Contd. Below *
* Contd. From Above
EASTERN VENTURA BASIN
SAN GABRIEL FAULT
RIDGE BASIN
Pliocene (Lacustrine)
U Miocene
Paleocene
Cong
Oil Fields
70 Simi
• 97 Oakridge
89 Holser Canyon
81 Temescal
LEISRE FAULT ZONE
SAN ANDREAS FAULT ZONE
Miocene
D
S L
Horizontal and Vertical
Scale: 1:250,000
0
5
10 Miles
0
5
10 Kilometers


E'
E
S L
EASTERN SANTA MONICA UPLIFT
SAN FERNANDO EMBAYMENT
SIMI UPLIFT
73
107
Section offset
100
95
EASTERN VENTURA BASIN
92
84
48
SOLEDAD BASIN
Clear water fault
Pleistocene
Pliocene
Upper Miocene
Middle Miocene
Eocene
Paleocene
Cretaceous
SANTA SUSANA FAULT
Plio
U. Mio
Plio-Pleistocene Marine
Oligocene Sespe
Paleocene Marine
SAN GABRIEL FAULT ZONE
Oil Fields
73 Horse Meadows (abandoned)
• 107 Aliso Canyon
100 Pico Canyon (abandoned)
• 95 Newhall-Potrero
• 92 Castaic Junction
• 84 Honor Junction
• 48 Tapia Canyon
Horizontal and Vertical
Scale 1:250,000
0
5
10 Miles
0
5
10 Kilometers

south of the Oak Ridge fault, the major southern boundary fault of the Santa Clara trough. Namson (1987), however, documents two other major deformational periods, Oligocene compression and late Miocene through Pliocene normal faulting and activity on the Oak Ridge fault. In any case, the Oak Ridge fault is a prominent structure that separates areas with differences in pre-middle Miocene stratigraphy (Figs. 3 and 5). For further discussion of the origin of the Santa Clara trough/Ventura basin and the deep structure of the basin see Crowell (1976) and the gravity modeling of Jachens and Griscom (1985).

Hydrocarbon Occurrence

Nagle and Parker's (1971) nine tectonic subprovinces (Fig. 2) provide a useful framework for understanding the petroleum geology and structure of the assessment province. Each subprovince is characterized by a unique combination of stratigraphy, structure, modes of oil occurrence, and future oil and gas potential discussed thoroughly by Nagle and Parker (1971). The generalized structural and stratigraphic configuration of typical hydrocarbon occurrences in the nine subprovinces are shown in six north-south cross sections of the assessment province (Fig. 10).

The Ventura Basin assessment province is an active area for petroleum exploration and development, including all of district 2 and part of district 3 of the California Division of Oil and Gas (1984) (Fig. 11). Most hydrocarbons produced in the province are oil and associated gas and condensate; approximately 75 percent of the 95 oil and gas fields discovered are currently producing (California Division of Oil and Gas, 1984) (Table 1). Sixty-five of the fields are estimated to have ultimate production greater than one million barrels of oil or six billion cubic feet of gas (Table 1) (NRG Associates, 1984). Cumulative production through 1983 for the province is approximately 2.07 billion barrels of oil and 4.34 Tcf total gas, including 468 Bcf dry gas (California Division of Oil and Gas, 1984). Yearly production for 1983 was approximately 24 million barrels of oil and 27.9 Bcf total gas, including one Bcf dry gas (California Division of Oil and Gas, 1984).

Hydrocarbons have been produced in the province from reservoirs of all ages from Late Cretaceous to Pleistocene (Fig. 5) (California Division of Oil and Gas, 1974). As many as a dozen formations provide multiple exploration prospects which have stimulated exploration for over 100 years and may continue to do so for many years to come; in contrast, exploration prospects and reservoirs in existing fields in the adjacent Santa Maria basin (Fig. 1) are fewer and mainly restricted to the Miocene Monterey Formation (Dainty and Woltz, 1984).

In the Ventura Basin assessment province, approximately ninety-nine percent of the hydrocarbon production is from the post-Eocene section, of which 12 percent is from the Sespe Formation, 12 percent is from the lower and middle Miocene section, and approximately 75 percent is from the upper Miocene and younger section (Taylor, 1976, Table 2). Thus, approximately 87 percent of the hydrocarbon production in the province is from the Neogene section in which excellent petroleum reservoir and source rocks were deposited (Taylor, 1976). Most production from the Neogene is from faulted anticlines and other structural and stratigraphic traps in the Santa Clara trough, its offshore

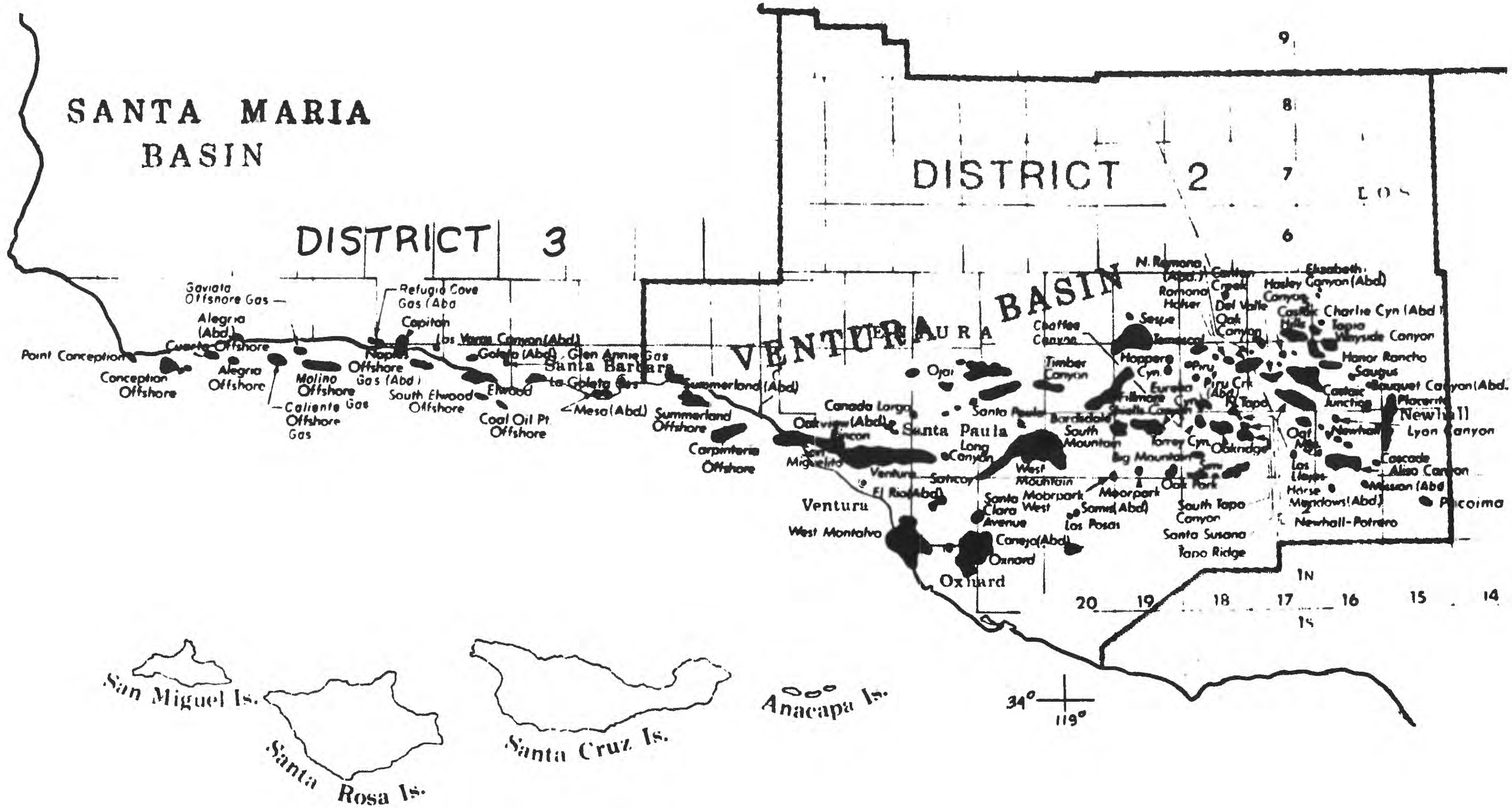


Figure 11. Oil and gas fields in the Ventura Basin assessment province. From California Division of Oil and Gas as reprinted by Conservation Committee of California Oil Producers (1987).

TABLE 1. Oil and Gas Field Data for Ventura Basin Assessment Province*

SIGNIFICANT FIELDS[1]	DISCOVERY DATE	PLAY[2]	ULTIMATE RECOVERY[3] OIL	GAS	NGL
Alegria Offshore	1962	P	925	3,990	--
Aliso Canyon: Main[4]	1938	N	57,500	180,000	706
Bardsdale	1892	P	14,100	80,400	--
Big Mountain	1966	P	1,550	1,710	--
Caliente Offshore Gas	1962	P	0	33,000	--
Capitan	1929	P	20,700	14,778	2
Carpinteria Offshore	1966	N	100,000	113,400	1,975
Cascade	1954	N	2,000	450	--
Castaic Hills	1951	N	8,900	18,900	390
Castaic Junction	1950	N	33,000	56,400	1,480
Chaffee Canyon	1957	P	225	6,900	300
Coal Oil Point Offshore	1961	B	79,500	92,400	2,100
Conception Offshore	1961	P	20,933	12,326	--
Cuarta Offshore Gas	1959	P	613	18,767	--
Del Valle: Main[4]	1940	N	26,000	89,400	5,230
Del Valle: South[4]	1944	N	1,100	2,100	80
Elwood	1928	P	104,874	96,349	2,257
Elwood, South, Offshore	1965	B	67,000	45,000	--
Fillmore	1954	N	13,000	19,800	610
Gaviota Offshore Gas	1958	P	0	64,158	2,798
Hasley Canyon	1944	N	1,900	240	--
Holser	1942	N	1,200	810	--
Honor Rancho: Main[4]	1950	N	11,900	12,000	505
Honor Rancho: Southeast[4]	1956	N	18,000	28,176	1,180
Hopper Canyon: Main[4]	1884	N	2,900	3,600	150
La Goleta Gas	1929	P	0	47,293	--
Mesa: Main[4]	1930	P	3,704	8	--
Molino Offshore Gas	1961	P	0	330,000	10,750
Montalvo West: Colonia[4]	1951	P	33,700	24,012	620
Montalvo West: McGrath[4]	1947	N	4,400	34,500	1,070
Naples Offshore Gas	1960	P	0	20,815	--
Newhall-Potrero	1937	N	76,000	145,500	3,200
Newhall: Pico Canyon[4]	1876	N	3,330	3,060	--
Newhall: Tunnel[4]	1900	N	2,360	1,083	--
Oak Canyon	1941	N	16,800	25,200	650
Oak Park	1969	P	1,600	330	--
Oakridge	1952	N	14,500	8,400	350
Oat Mountain	1946	P	1,600	960	25
Ojai: Silverthread[4]	1866	N	17,000	25,200	250
Ojai: Sisar Creek[4]	1900	N	3,000	660	--
Ojai: Sulphur Crest[4]	1979	N	2,000	4,800	80
Ojai: Sulphur Mtn. North[4]	1912	N	8,500	21,000	340
Ojai: Weldon Canyon[4]	1951	N	950	1,080	10
Oxnard	1937	B	41,000	23,100	720
Pacoima[5]	1975	N	5,600	61,000	--
Placerita[5]	1920	N	46,536	6,080	--
Point Conception[5]	1965	P	1,405	751	--

TABLE 1. Oil and Gas Field Data for Ventura Basin Assessment Province*--Continued

SIGNIFICANT FIELDS[1]	DISCOVERY DATE	PLAY[2]	ULTIMATE RECOVERY[3] OIL	GAS	NGL
Ramona	1943	N	22,250	40,500	1,260
Santa Clara Ave.	1972	P	5,700	3,900	120
Santa Paula	1861	N	2,320	648	--
Santa Susana-Tapo Canyon South[4]	1953	B	13,500	15,000	630
Sespe	1887	P	40,000	43,500	1,920
Shiells Canyon	1911	B	28,000	60,000	2,500
Simi: Canada De La Brea[4]	1910	P	1,170	480	--
Simi: Old[4]	1901	P	2,800	1,098	--
South Mountain Area[4]	1915	B	185,000	345,000	10,700
Summerland	1891	B	3,224	1,704	--
Summerland Offshore	1958	P	27,000	99,900	2,230
Tapia	1957	N	1,600	--	--
Tapo, North	1882	N	1,230	159	--
Temescal	1924	N	7,600	5,760	--
Timber Canyon: Main[4]	1889	N	6,970	12,900	--
Torrey Canyon	1889	P	21,800	34,500	1,070
Ventura-Rincon[4]	1918	N	1,240,000	2,295,000	132,530
Wayside Canyon	1962	N	2,740	9	--

SMALL FIELDS*[5,6]	DISCOVERY DATE	PLAY	ULTIMATE RECOVERY OIL	GAS
Alegria	1959	N	7	13
Boquet Canyon	1958	N	9	0
Canada Larga	1955	N	100	76
Canoga Park	1952	N	1	0
Canton Creek	1957	N	19	0
Charlie Canyon	1958	N	0.2	0
Conejo	1892	N	110	12
El Rio	1958	P	368	195
Elizabeth Canyon	1950	N	1	2
Eureka Canyon	1893	N	849	75
Glen Annie Gas	1958	P	0	491
Goleta	1927	P	136	56
Horse Meadows	1952	P	137	87
Las Llajas	1945	P	75	51
Las Posas	1967	P	26	2
Las Varas	1958	P	5	287
Long Canyon	1956	N	17	39
Lyon Canyon	1969	N	125	0
Mission	1953	B	537	301
Moorpark	1955	P	29	0
Moorpark West	1976	P	115	6

TABLE 1. Oil and Gas Field Data for Ventura Basin Assessment Province*--Continued

SMALL FIELDS*[5,6]	DISCOVERY DATE	PLAY	ULTIMATE RECOVERY OIL	GAS
Oakview	1955	P	1	0
Piru	1897	N	459	156
Piru Creek Area	1956	N	12	4
Ramona North	1946	N	2	0
Refugio Cove Gas	1946	P	3	990
Rincon Creek	1982	P	26	104
Saugus	1957	N	561	784
Somis	1955	P	2	1
Tapo Ridge	1974	P	41	9

*Data is from NRG Associates (1984) except for all small fields and where noted otherwise.

1 = field with ultimate recovery greater than one million barrels oil or six billion cubic feet gas.

2 = Neogene=N, Paleogene=P, and both=B.

3 = ultimate recovery (cumulative production plus reserves) for oil and NGL (natural gas liquids) is $x10^3$ barrels and for gas $x10^6$ ft^3.

4 = field or area of field grouped differently by NRG Associates (1984) and the Calif. Div. of Oil and Gas (1984). For example, Ventura-Rincon of NRG Associates (1984) is three separate fields--Ventura Avenue, Rincon, and San Miguelito--by the Calif. Div. of Oil and Gas (1984), and 5 of 8 areas of the Ojai field of the Calif. Div. of Oil and Gas (1984) are five different fields by NRG Associates (1984).

5 = data from Calif. Div. of Oil and Gas (1974; 1984). The Calif. Div. of Oil and Gas does not indicate reserves for many fields --particularly the small ones--thus, ultimate recovery may reflect only cumulative production.

6 = some data is from the Conservation Committee of California Oil Producers (1987).

extension, and the eastern Ventura basin. The Rincon or Ventura-Rincon anticlinal trend (Fig. 7a) is the major producing structure in this part of the province. Other important Neogene production, as well as Paleogene production, is from the adjacent and structurally higher areas of the Santa Ynez-Topatopa uplift (north of the Santa Clara trough) and the Oxnard shelf to the south. In the Oxnard shelf, the Montalvo anticlinal trend and the Oak Ridge uplift trend are areas of major production from the Sespe Formation (Fig. 7a).

Source Rocks: Burial, Maturity, and Migration

For a mature province with a long and successful period of hydrocarbon exploration and development, very few data are available on geochemistry and thermal maturity of possible source rocks in the Ventura Basin assessment province. However, the results of a recent oil/source correlation study by Fuex (1987) are supportive of two sources of oil -- Miocene and Eocene -- in the Ventura Basin assessment province. In this study of carbon isotopes in oils and source rocks, the delta C_{13} values for Ventura basin oils cluster between -22 and -24, within the -20 to -24 range for ten Miocene source rocks; whereas, eight of nine oils from the western coastal Santa Barbara Channel (including the Capitan field) cluster between -25 and -28, the same range as sixteen Eocene rock samples (Fuex, 1987).

Within the Neogene section, "the Miocene and in particular the middle to late Miocene shales have long been considered one of the most likely sources of the prolific oil production in the onshore coastal basins" (Taylor, 1976, p. 21). Isaacs and Petersen (1987), in describing the petroleum source potential of the Miocene Monterey Formation, report that the Monterey of the coastal area between Point Conception and Ventura and the onshore Santa Maria basin has an average of greater than 5 percent organic carbon with a maximum of 23 percent organic carbon in some beds. In the same areas the underlying Rincon Formation has a mean organic carbon content of 3.3 percent and the Sisquoc Formation, overlying the Monterey, has a mean of 1.5 percent (Isaacs and Petersen, 1987).

Other potential hydrocarbon source rocks in the Ventura Basin assessment province include marine shales from the Cretaceous and Paleogene sections (Nagle and Parker, 1971). An overview for the northern part of the province where most of the Neogene sequence and its excellent source rocks are absent is provided by Frizzell and Claypool's (1983) reconnaissance study of the petroleum potential of Mesozoic and Cenozoic rocks in the Los Padres National Forest. Their data indicate that most pre-Miocene rocks sampled contain less than 1% total organic matter, most of which has little capacity to generate oil, although it may generate natural gas. Inasmuch as their study represents a reconnaissance evaluation of only a small part of the whole region, the hydrocarbon potential of the pre-Miocene section may be more favorable in other areas of the assessment province.

Bailey (1947, p. 1935) presents a good case, though largely speculative, for origin and migration of Eocene oil into the Sespe Formation in several areas of the assessment province: in the fields north of the Santa Clara River ("Sespe Creek to Capitan inclusive"), in the Simi Valley district, and in the South-Mountain Oak Ridge group of fields (though "possible that some of it migrated from Miocene or Pliocene accross the Oak Ridge fault"). For the Eocene rocks south of the Oak Ridge fault, Nagle and Parker (1971) report that dark marine shale of the Llajas Formation appears to be a suitable source rock, and in this area oil is produced from interbedded sands in the Llajas. In a description of the only oil indigenous to the Ridge basin, Stitt (1987, p. 44) states that "such high gravity oils and high GOR's are commonly generated by Eocene source rocks within the adjacent Ventura Basin".

Most oil and gas in the assessment province was probably generated from Miocene source rocks in the Santa Clara trough and other deep areas of the basin where, in places, the overlying Pliocene and Pleistocene sequence reaches a thickness of approximately 20,000 ft (6,096 m) (Fig. 6). The thermal gradient in the central trough of the basin is low (approximately 24°C/km, 1.3°F/100 ft) (Bostick and others, 1978) relative to the adjacent north and south basin margins (McCulloh and others, 1978), probably due to the rapid deposition of the thick Pliocene and Pleistocene sequence. Oil is thought to have generated only at burial depths greater than 3,810 m (12,500 ft) based on organic geochemical analyses (Philippi, 1975). Data from two of the deeper wells in the central area of the Santa Clara trough that penetrated the lower Pliocene suggest that the underlying Miocene sequence may be generating oil; in one of these wells, Bostick and others (1978) report an equilibrium temperature of 150°C (302°F) and a vitrinite reflectance value of approximately 0.3 at about 18,000 ft (5500 m).

Migration from Miocene source rocks probably took place, for the most part, after the onset of Pleistocene tectonism which formed most of the structural traps for hydrocarbons in this province. Geologic and structural relations in the Ventura Avenue field indicate that oil migration into the Ventura Avenue reservoir took place after formation of the Taylor fault set (1.3-0.6 my) and before formation of the Barnard fault set which displaces these oil accumulations (Yeats, 1983).

Plays: Definition and Basis for Selection

In the Ventura Basin assessment province most crude oils are chemically similar based on Bureau of Mines analyses; most traps are anticlinal and modified to some degree by faults, although, combination and stratigraphic traps occur; and most reservoirs are sandstones with favorable porosity and permeability. Very few data are available to support major differences in these parameters throughout the basin. Furthermore, reservoirs are of all ages from Late Cretaceous to Pleistocene, and because of the magnitude of recent tectonism, reservoir age seems to closely correspond to tectonic subprovince and geographic area (Figs. 2 and 10). Thus, primarily on the basis of reservoir age, the Ventura Basin assessment province is divided into two plays -- a Paleogene play and a Neogene play (Fig. 12). The Paleogene play consists of oil plus associated gas and dry (non-associated) gas trapped by structure, stratigraphy, or a combination of both in sandstone reservoirs of Late Cretaceous to early Miocene age. The Neogene play consists of oil and associated gas trapped by structure, stratigraphy, or a combination of both in sandstone reservoirs of middle Miocene to Pleistocene age.

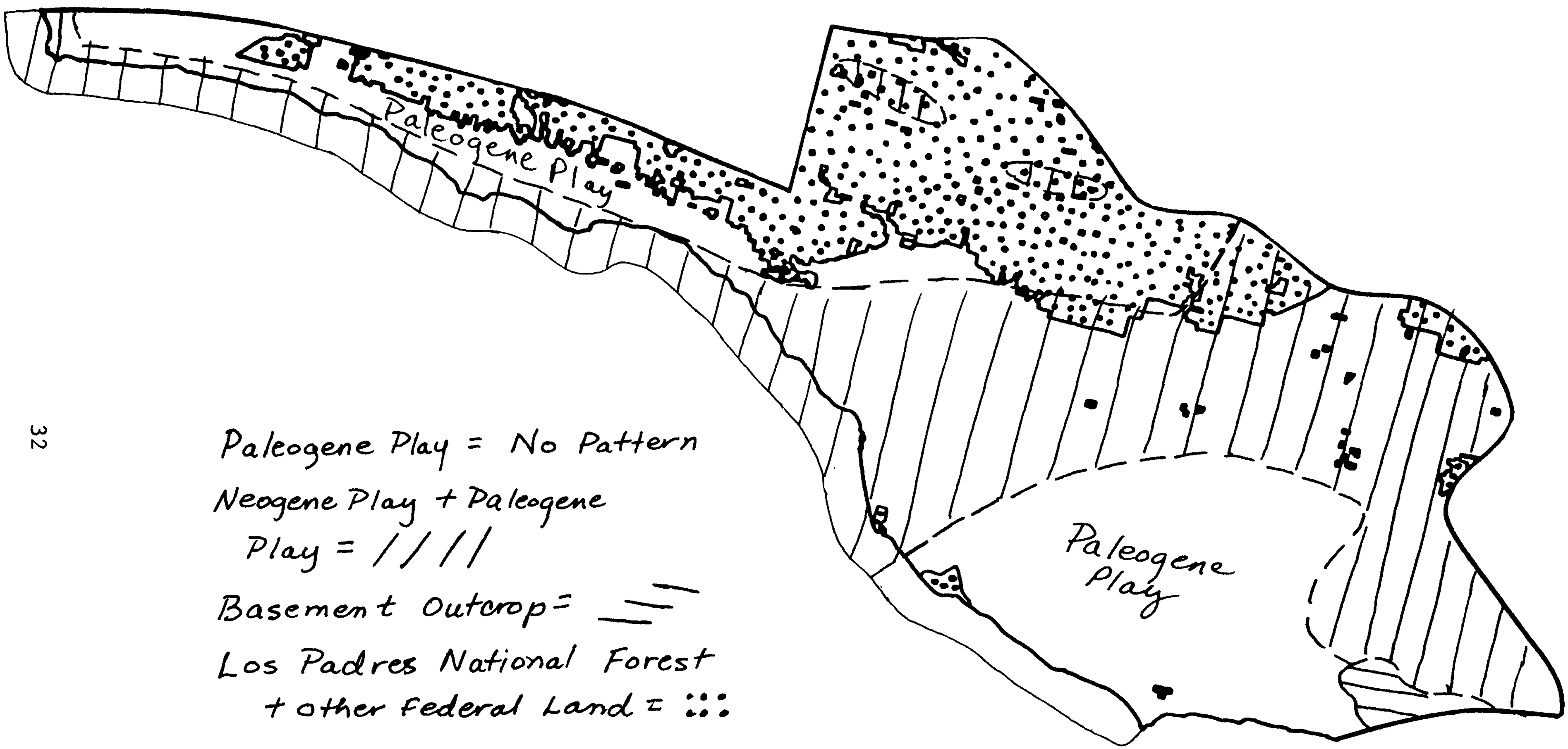


Figure 12. Map of Neogene and Paleogene hydrocarbon plays in the Ventura Basin assessment province.

Paleogene Play

The Paleogene play consists primarily of oil and associated gas-condensate trapped by structure, stratigraphy, or a combination of both in siliciclastic reservoirs of Late Cretaceous to early Miocene age; dry (non-associated) gas is also found in the province, mostly in five fields located in state waters off the Santa Barbara Coast (Caliente, Cuarta, Gaviota, Molino, and Naples offshore gas fields) (Fig. 11). Of the 31 fields having ultimate production (cumulative production plus reserves) greater than one million barrels of oil or six Bcf gas in this play, 24 are oil fields (7 of which also produce from the Neogene) and 7 are gas fields (Fig. 11) (Table 1) (California Division of Oil and Gas, 1984; NRG Associates, 1984).

The most important reservoir in the play is the nonmarine Sespe Formation in the areas both north and south of the Santa Clara trough (Fig. 10A-E). The Sespe Formation commonly has good to excellent reservoir properties, is up to 7000 ft (2130 m) thick in the subsurface of the Oak Ridge uplift (Nagle and Parker, 1971), and accounts for approximately 12 percent of total production in the Ventura Basin assessment province (Taylor, 1976). Another important reservoir in this play, and commonly produced with the Sespe, is the overlying Vaqueros Formation. The Vaqueros is up to 300 ft (91 m) thick and in places has excellent reservoir properties (Nagle and Parker, 1971). Other important reservoirs, where favorable porosity and permeability exist and laumontite is not widely developed, are the Matilija, Coldwater, and Llajas Formations of Eocene age (Frizzell and Claypool and references therein, 1983). Paleocene clastics south of the Santa Clara trough and Upper Cretaceous sandstones and conglomerates are less important reservoirs in the province; the small amount of Cretaceous production in the Simi Hills has been abandoned.

Traps in the Paleogene play are mainly anticlines and faulted anticlines. Along the Oak Ridge uplift, the major producing trend of the play, anticlinal accumulations in the Eocene and Sespe are found in numerous oil fields (e.g. South Mountain, Bardsdale, and Oakridge, Figs. 10 and 11). Less important traps include a homocline with a tar seal present in the Sespe field north of the basin trough (Fig. 10C), significant unconformities on the southern boundary of the Oak Ridge horst at the Oxnard field (Fig. 10A), and closure created by faults and dip reversals on the northern margin of this horst block (Fig. 10A-E) (Nagle and Parker, 1971). Marine shales within the Cretaceous, Paleogene, and Neogene sequences all provide seals in certain areas of the province.

Source rocks in the play are probably mainly the organic-rich early Miocene to early Pliocene fine-grained rocks of the Rincon, Monterey, Modelo, Sisquoc, and Santa Margarita Formations discussed above. Eocene marine shales are also potential hydrocarbon source rocks in certain areas of the province as discussed previously.

The play has been extensively explored in parts of the assessment province, but not in the rugged mountainous areas north of the Santa Clara River (mostly in the Los Padres National Forest) (Fig. 12), or in areas where the overlying Neogene sequence is productive (Munger, 1984). In the Los Padres National Forest of the Ventura Basin assessment province, most of the area is considered to have low to medium potential for undiscovered oil and gas, however, several BLM known geologic structures (KGS) are considered to have a high to very high potential (Hollis Record, written commmunication, 1987). In the area of the Santa Clara trough most reservoirs in this play may be too deep for favorable porosity and permeability; however this potential remains untested. Undiscovered resources may remain on the north and south margins of the Santa Clara trough, including their offshore extensions.

Neogene Play

The Neogene play consists of oil and associated gas trapped by structure, stratigraphy, or a combination of both in sandstone reservoirs of early Miocene to Pleistocene age. Forty-one fields (including 7 which also produce from the Paleogene) greater than one million barrels oil or six Bcf gas have produced in the play (Table 1), primarily in the area of the Santa Clara trough and eastern Ventura basin, but also in the subprovinces on the north and south margins of the trough and in its western extension offshore (Figs. 11 and 12).

The Neogene marine sequence consists of basal, shallow marine clastics (Vaqueros Formation) overlain by Miocene and lower Pliocene deep-marine organic-rich fine-grained rocks interbedded with and overlain by turbidite sandstones deposited within the Miocene sequence and in the Pliocene and Pleistocene. Coarse clastics of the Vaqueros Formation overlie and are commonly co-produced with the Sespe Formation and are included as a reservoir in the Paleogene play. The major reservoirs in the Neogene play are the turbidite sandstones of the Pliocene and Pleistocene Pico Formation. Other important reservoirs are Miocene and lower Pliocene sandstones and, to less extent in this province, fractured fine-grained rocks of the Rincon, Monterey, Modelo, Sisquoc, and Santa Margarita Formations. The fractured fine-grained rocks of the Monterey Formation are important reservoirs in the Santa Barbara Channel and in the Santa Maria basin, both onshore and offshore (Isaacs and Petersen, 1987).

Porosity measurements on Pliocene to Recent samples from deep wells in the Santa Clara trough range from 24 percent at 1000 m (3,281 ft) to 14 percent at 5,700 m (18,700 ft) in arenites and from 27 percent at 1000 m (3,281 ft) to 7 percent at 5,700 m (18,700 ft) in pelitic rocks (McCulloh and others, 1978).

Traps are anticlinal with associated faulting, but an important exception is the Fillmore field which is purely stratigraphic (Fig. 10C). Most production is from one main anticlinal trend --the Ventura-Rincon trend-- which contains 4 oil fields within the assessment province (Ventura Avenue, Rincon, San Miguelto, and Carpinteria) and one field, Dos Cuadras, outside the province in the Santa Barbara Channel (Figs. 10A and 11).

The Miocene and possibly the lower Pliocene organic-rich fine-grained rocks in the Santa Clara trough are probably the source rocks for this play.

The Neogene play has been extensively, but not exhaustively explored in the province (Munger, 1984). However, undiscovered petroleum resources may occur in the Santa Clara trough and its offshore extension, and also on the northern margin of the trough beneath the hanging wall of the San Cayetano fault (Yeats, 1983, figure 11, p.578). Small accumulations may also occur beneath the Pine Mountain fault (Fig. 10A) (Frizzell and Claypool, 1983; Namson, 1987) and in the areas adjacent to the Santa Clara trough.

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