U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

PETROLEUM GEOLOGY OF THE CENTRAL COASTAL BASINS ASSESSMENT PROVINCE, CALIFORNIA FOR THE 1987 NATIONAL ASSESSMENT OF UNDISCOVERED OIL AND GAS RESOURCES

by

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Open-File Report 89-450 D

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INTRODUCTION

This report presents a summary of the geology used as a basis for the U.S. Geological Survey's 1987 assessment of undiscovered oil and gas resources in the Central Coastal Basins assessment province. The petroleum geology was taken for the most part from published sources, principally Baldwin (1971) and California Division of Oil and Gas (1974).

The assessment was made on a base level of discovered oil and gas resources (cumulative production plus proved reserves) from the Nehring data base as of 12/31/83 (NRG Associates, 1984) which includes only fields exceeding 1 MMBOE (million barrels oil equivalent). These production and reserve figures correspond to those in California Division of Oil and Gas (1984) which includes fields of all sizes. Reserve additions due to field development or new discoveries declared after 12/31/83 by the California Division of Oil and Gas were for assessment purposes regarded as undiscovered resources.

Total baseline resources in the assessment province through 1983 were 884 MMBOE. These included cumulative production of 665 MMbbl (million barrels) oil and condensate and 343 Bcf (billion cubic feet) gas, for a province total of 722 MMBOE (California Division of Oil and Gas, 1984). Proved reserves totalled 161 MMbbl oil and condensate, and 7 Bcf gas, together representing 162 MMBOE (California Division of Oil and Gas, 1984).

PROVINCE LOCATION

The Central Coastal Basins assessment province is located in central coastal California. As defined (Figure 1A), the province is bounded on the south by the Big Pine fault, on the northeast by the San Andreas fault, and on the west (offshore) by the western limit of state waters within 3 miles of shore from Monterey (at the south) to San Francisco (at the north). The southwest boundary of the assessment province generally follows the Sur-Nacimiento fault but north of 36°N excludes the approximate extent of exposed pre-Cretaceous metamorphic basement rocks.

Geologically speaking, the assessment province includes the Neogene Cuyama, Salinas, and La Honda Basins (Figure 1B), together with slivers of the Neogene outer Santa Cruz and Bodega Basins in the offshore (Figure 1C).

STRUCTURAL SETTING

The Central Coastal Basins assessment province is bounded by two major northwest-southeast trending faults, the San Andreas and Sur-Nacimiento faults, and includes the onshore portion of the Salinian block together with adjacent nearshore areas (Figure 1D). Basement rocks in the Salinian block consist of Cretaceous granites and metamorphic r rocks distinct from the basement rocks of adjacent structural blocks to the east and west (Figure 2A).

The onshore part of the assessment province generally consists of low-lying areas of Neogene and younger deposits (including the Neogene Cuyama, Salinas, and La Honda Basins), located more or less between northwest-southeast trending mountains of the Coast Ranges that expose pre-Neogene strata and basement rocks. The offshore part of the assessment province lies at a complex tectonic juncture of the San Gregorio-Hosgri and Sur-Nacimiento fault systems (Figure 1D) near the edges of the Neogene outer Santa Cruz and Bodega Basins (Figure 1C).

Prevailing views of the formation of west coast Neogene basins are based on modifications of Atwater's (1970) and Atwater and Molnar's (1973) plate tectonic model for the west coast of North America. In this model, Neogene basins were formed at a triple junction (between the North American, Pacific, and Farallon Plates) that migrated north and south from the vicinity of southern California between 29 Ma and present (Figure 2C). Various summaries address the formation of basins within this setting (e.g. Blake and others, 1978; Howell and others, 1980), and a diagrammatic representation of the development of the central California margin is given in Figure 2D. Cross-sections of the assessment province are shown in Figure 3.

The Miocene and younger structural style of the assessment province has generally been regarded as dominated by wrench tectonics and associated vertical strike-slip faulting (e.g., Howell and others, 1980). However, compressional tectonics and associated thrust and high-angle reverse faulting were more recently advocated as the dominant structural style in the development of nearby offshore areas (Crouch and others, 1984). Subsequent to the assessment, major anticlinal structures in the Cuyama district and adjacent areas in the southern Coast Ranges and Transverse Ranges have been related to fault-bend and fault-propagation folds in a Pliocene and younger fold and thrust belt (Davis and Namson, 1987; Namson and Davis, 1990).

STRATIGRAPHY

The Central Coastal Basins assessment province is included in the Salinian composite terrane of Vedder and others (1983). Basement rocks in this terrane consist of Cretaceous or older granitic rocks and (locally) high temperature metamorphic rocks (Vedder and others, 1983, and references therein). The overlying Upper Cretaceous and lowermost Paleocene strata for the most part are sequences of clastic marine sedimentary rocks (Pigeon Point, Locatelli, Merle, Dip Creek, Asuncion, and Pattiway Formations together with various other including unnamed strata; see Figure 4A). These sequences are overlain throughout the assessment province by an unconformity representing most of Paleocene time (Figure 4A; Vedder and others, 1983). According to Vedder and others' (1983) terrane model, pre-Eocene strata were deposited far distant from the present California margin and sutured to the North American craton about 40 Ma (Figure 2A).

During the Eocene, a series of marine basins developed along the California continental borderland (Figure 2B; Nilsen and Clarke, 1975). Included within the assessment province are the Sierra Madre, Northern Santa Lucia, Point Lobos, La Honda, and Point San Pedro basins (or parts thereof; Figure 2B). Strata deposited in these basins were largely submarine fan deposits represented by thick marine sequences for the most part composed of sandstone, conglomerate, and mudstone (Matilija Sandstone, Juncal Formation, Church Creek Formation, Reliz Canyon Formation, Pinecate Formation, San Juan Bautista Formation, Butano Sandstone, and various other including unnamed strata; see Figure 4A). Locally, mudstone is also predominant as in the Cozy Dell Shale in the southeastern part of the assessment area (Figure 4A) and the Two Bar Shale and Rices Mudstone in La Honda district (Figure 4F). The Oligocene to early Miocene period in the La Honda basin is represented by a marine sequence generally deposited at bathyal or even abyssal depths (Stanley, 1984; Figure 4F).

In the Cuyama and Salinas districts, by contrast, Eocene deposits are unconformably overlain by nonmarine conglomerates and sandstones of probable late Oligocene or early Miocene age including the Simmler, Caliente, and Plush Ranch Formations (Figure 4A) and Berry Formation (Figures 4D and 4E). These strata mark the beginning about 20 Ma of Neogene basin formation (Figure 2C) represented by a major episode of basin subsidence and filling in the Salinas district (Graham, 1976; Figure 5B) and two such episodes in the Cuyama district (Lagoe, 1987a, 1987b; Figure 5A). Strata deposited during these episodes include shallow - and, in the Cuyama basin, partly bathyal - marine deposits of sandstone and mudrock (early Miocene Vaqueros Formation), overlain by mainly bathyal fine-grained calcareous and biosiliceous mudrocks (late early to late Miocene Monterey Formation), in turn locally overlain by bathyal to neritic sandstones and mudrocks (late Miocene Santa Margarita Formation). In the Cuyama district, the Monterey Formation is very localized, interfingers with inner shelf marine sandstones of the Branch Canyon Sandstone, and is partly coeval with nonmarine strata of the Caliente Formation (Lagoe, 1984, 1987; Figure 4C). In the Salinas district, the Monterey Formation is generally much thicker (max, 8600 ft; see Figure 4D) and more widespread, but locally interfingers with marine shelf sandstones of the Tierra Redonda and Santa Margarita Formations (Figures 4D, 4E, and 5B). Overlying Pliocene and younger nonmarine strata include the Qatal and Morales Formations in the Cuyama district, and the Paso Robles Formation in the Salinas district.

In the La Honda district, early Miocene strata included in the Vaqueros Formation are bathyal turbidite sandstones overlain by locally varying strata (including in places the Monterey Formation, Santa Cruz Mudstone, etc.) deposited in periods interrupted by several episodes of uplift and erosion during the Miocene (Figure 4F). A thick Pliocene mudrock (Purisima Formation) locally caps the Neogene stratigraphic sequence in this area.

Many studies describe the detailed stratigraphy and structure in the assessment province. For the Cuyama district, included are Carman (1964), Hill and others (1958), Vedder and Repenning (1965, 1975), Vedder (1968, 1970), Vedder and others (1973), Bohannon (1975), and Dibblee (1982). For the Salinas district are Durham (1963, 1964,

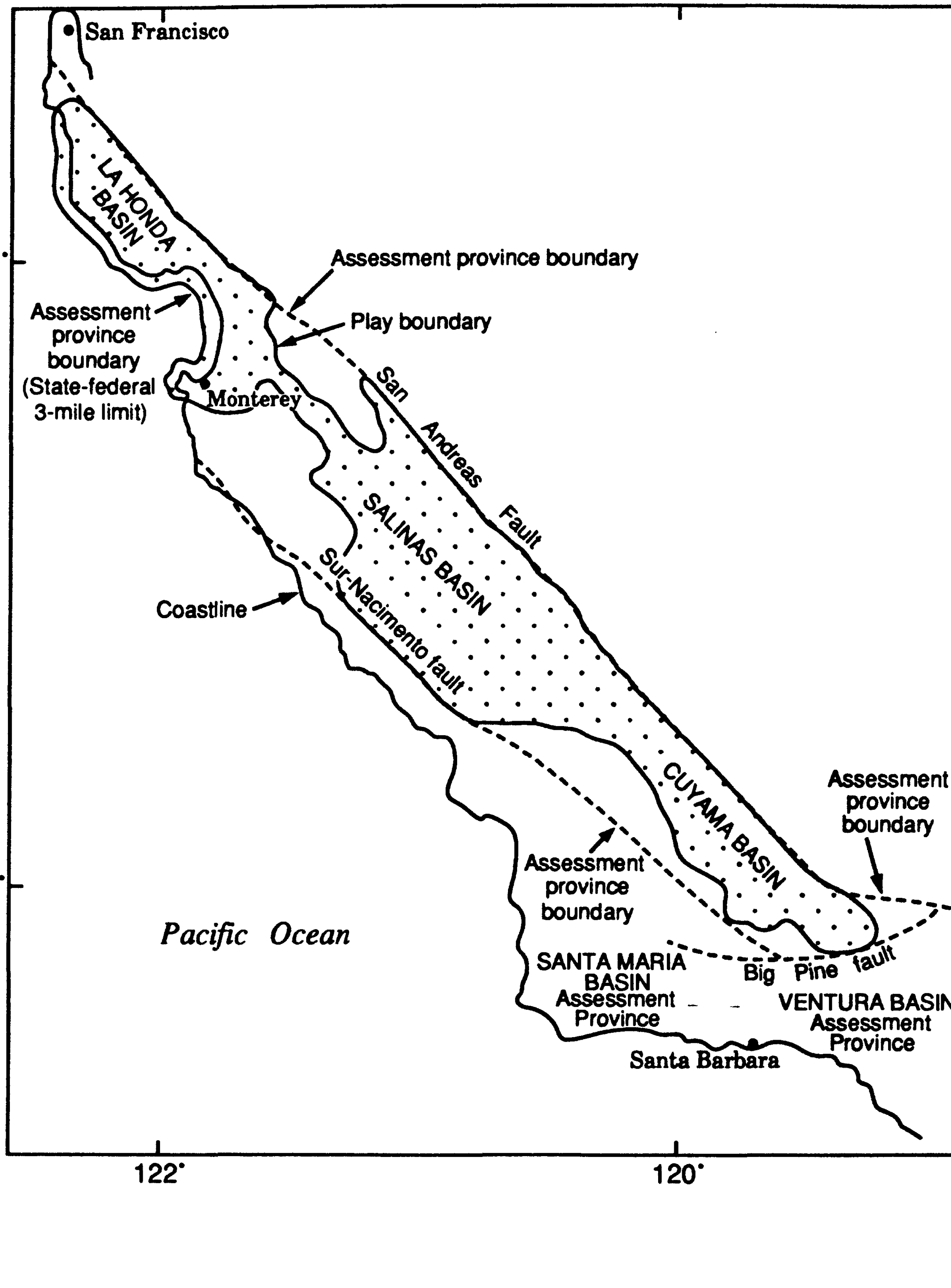


Figure 1A. Location of the Central Coastal Basins assessment province and Neogene play boundary.

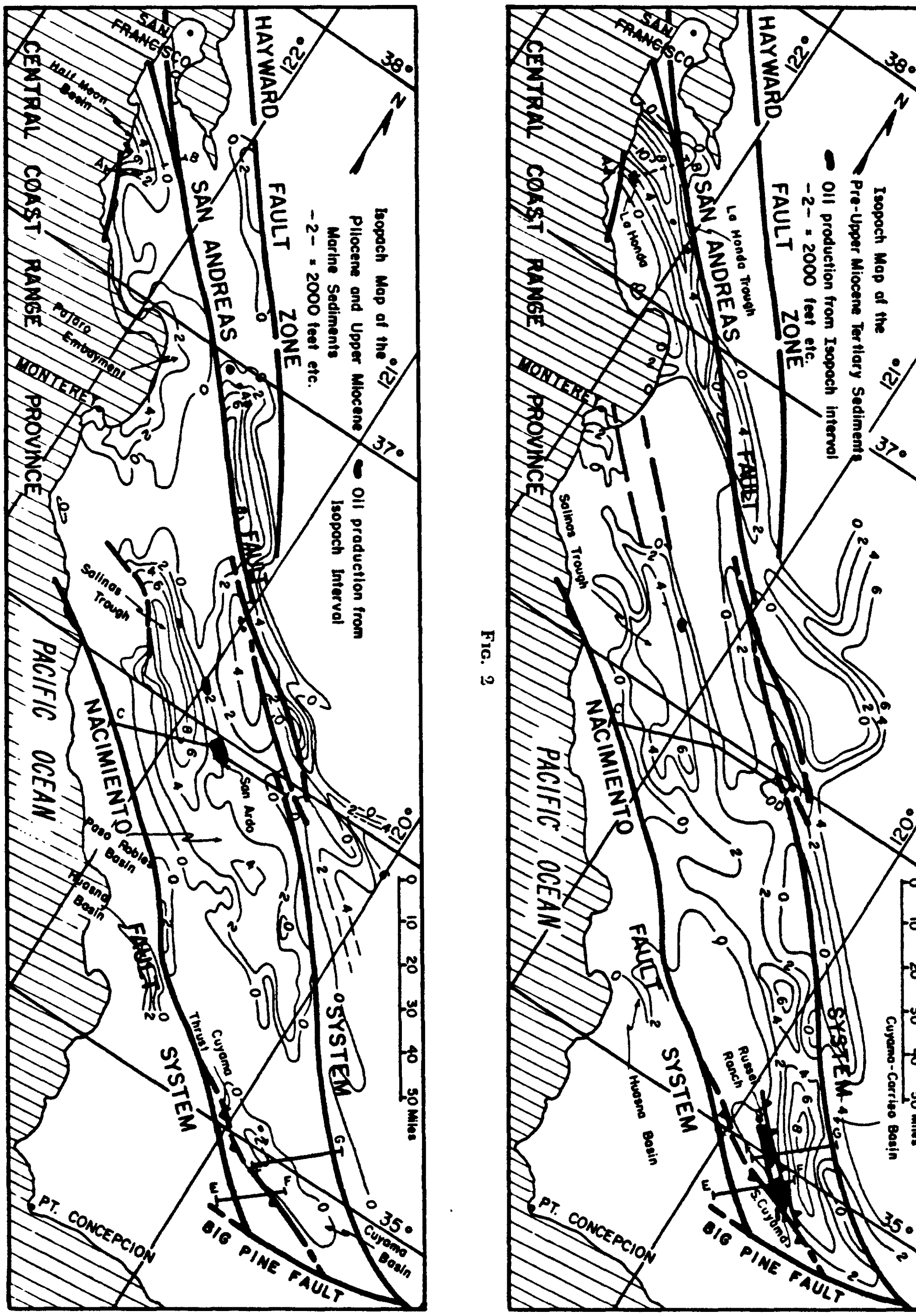


Figure 1B. Tertiary isopach maps. Reprinted from Baldwin (1971) by permission.

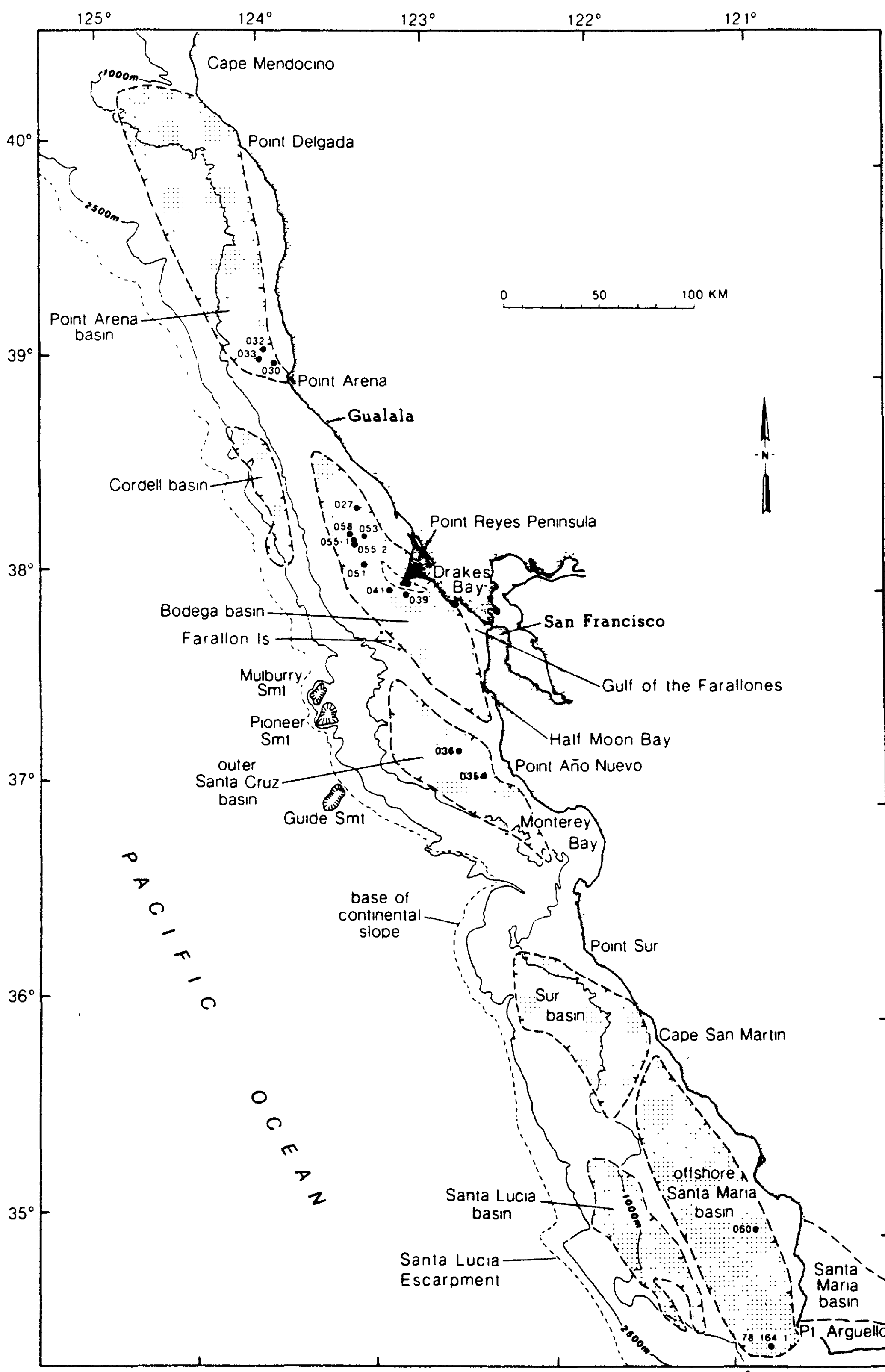


Figure 1C. Generalized boundaries of late Tertiary shelf and slope basins and locations of offshore exploratory wells on the central California continental margin (from McCulloch, 1989).

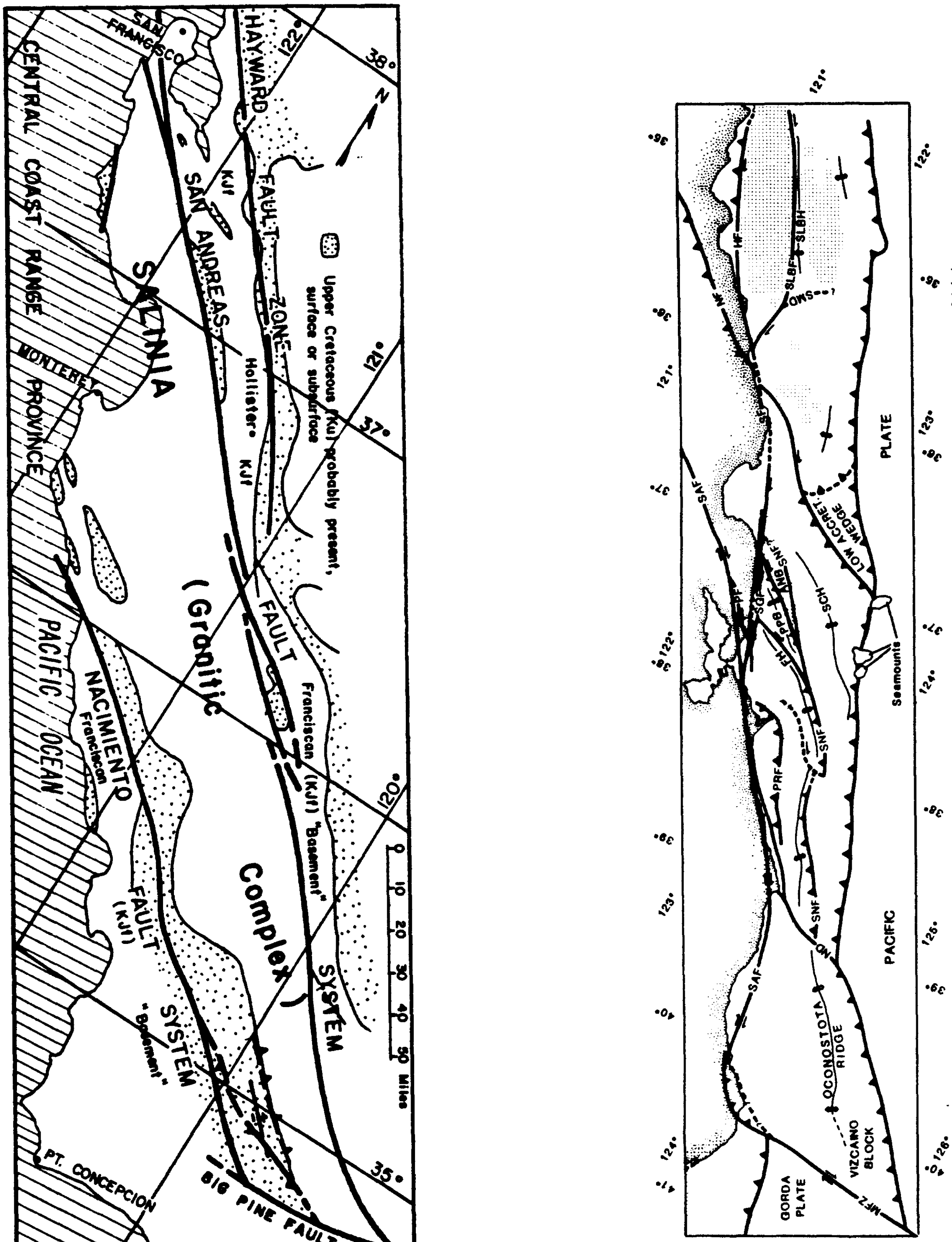
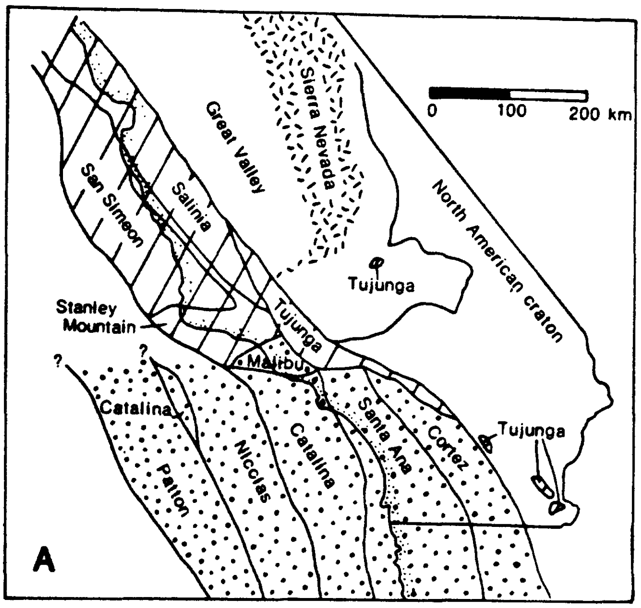
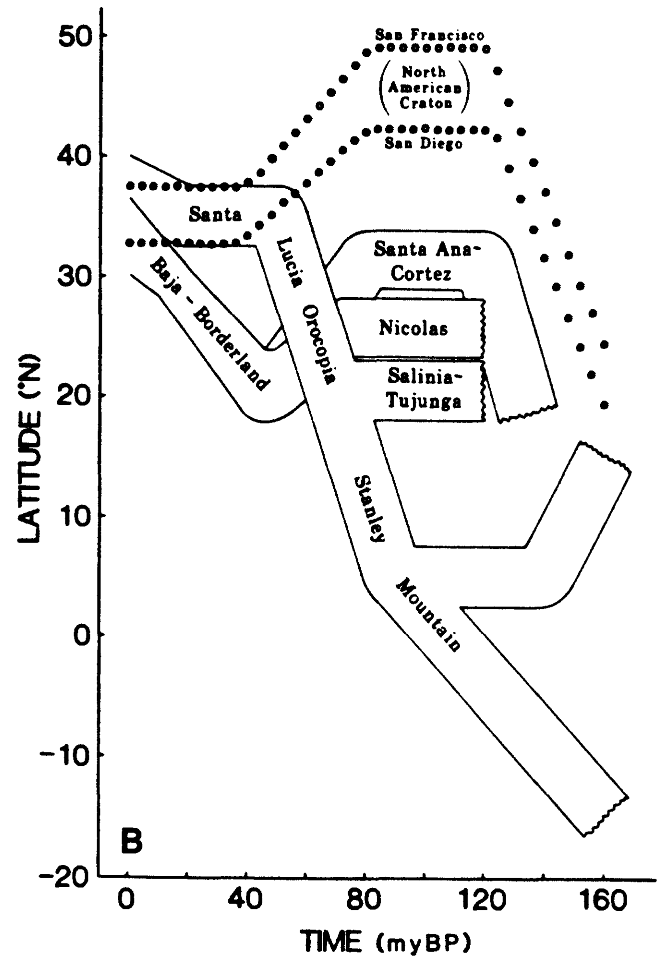


Figure 1D. Major structural features onshore (left; reprinted from Baldwin, 1971, by permission) and offshore (right; from McCulloch, 1987, 1989). On right diagram, teeth are shown on up-thrown side of high-angle reverse faults or upper plate of thrust faults, and shaded offshore areas are late Tertiary basins. Abbreviations for faults (near the assessment province) are: SAF - San Andreas, SF - Sur, NF - Nacimiento, SNF - Sur-Nacimiento, SGF - San Gregorio, HF - Hosgri, SLBF - Santa Lucia Bank, PF - Pilarcitos. Structural highs: SCH - Santa Cruz, FH - Farallon. Blocks: PPB - Pigeon Point, ANB-Año Nuevo.





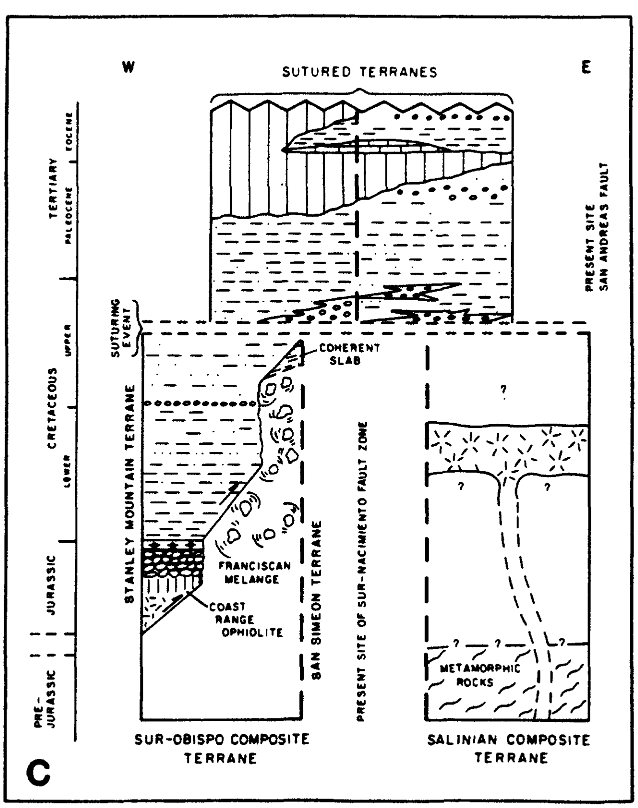


Figure 2A. Pre-Eocene geologic history of the Santa Maria and Santa Barbara-Ventura basins. (A) Terranes of Southern California and northern Baja California showing the Santa Lucia-Orocopia allochthon (diagonal lines) and the Baja Borderland allochthon (stippled pattern). From Howell and others (1987). (B) Proposed latitude trajectories of the allochthons (and their constituent terranes) shown in A. From Howell and others (1987). (C) Generalized pre-Eocene stratigraphic column for the Salinian composite terrane, and the Sur-Obispo composite terrane (including the San Simeon terrane and the Stanley Mountain terrane). Modified slightly from Vedder and others (1983).

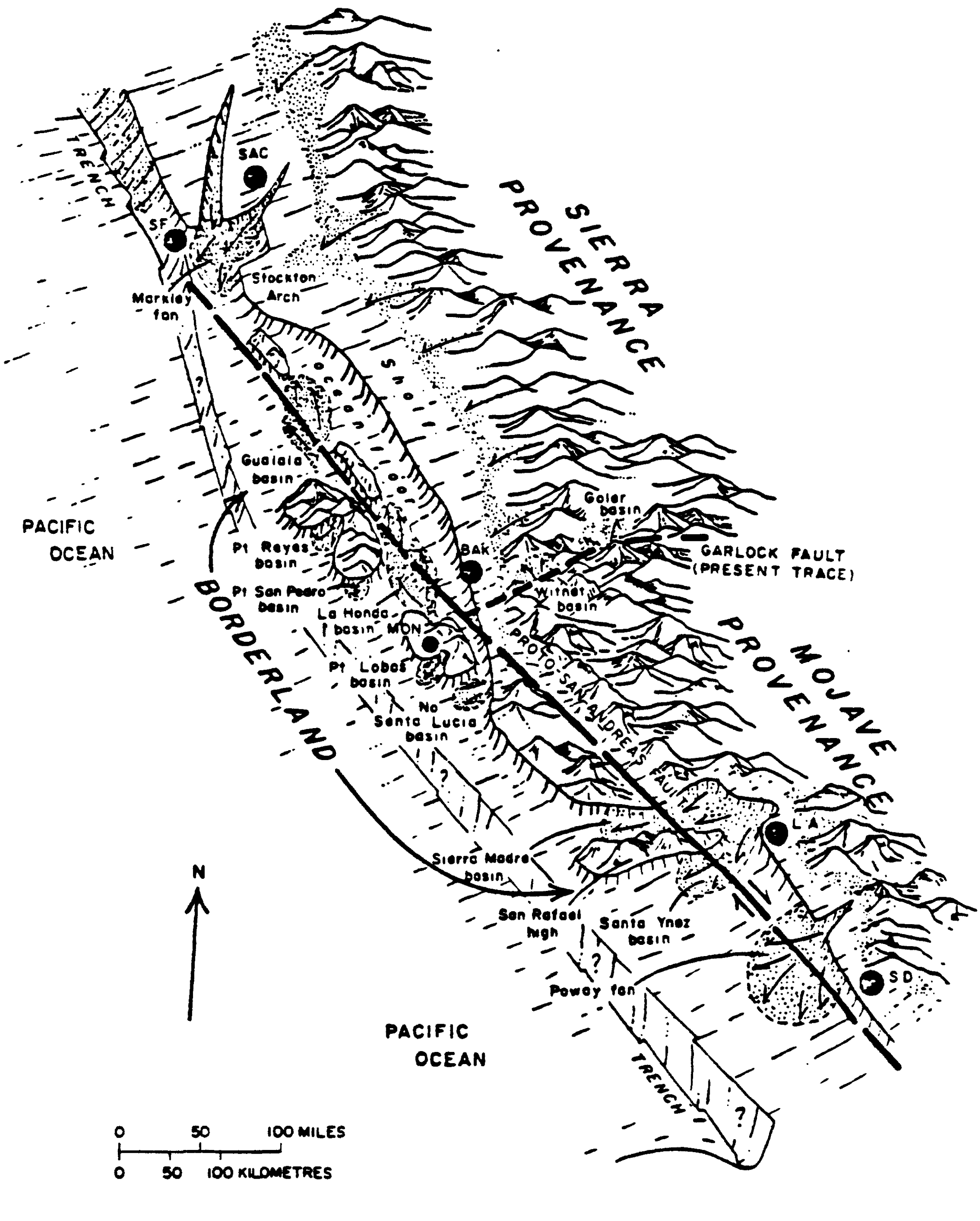


Figure 2B. Generalized paleogeographic map of early Tertiary California, restored for offset along the present San Andreas fault. City abbreviations: SAC-Sacramento; SF-San Francisco; BAK-Bakersfield; MON-Monterey; LA-Los Angeles; SD-San Diego. From Nilsen and Clarke (1975).

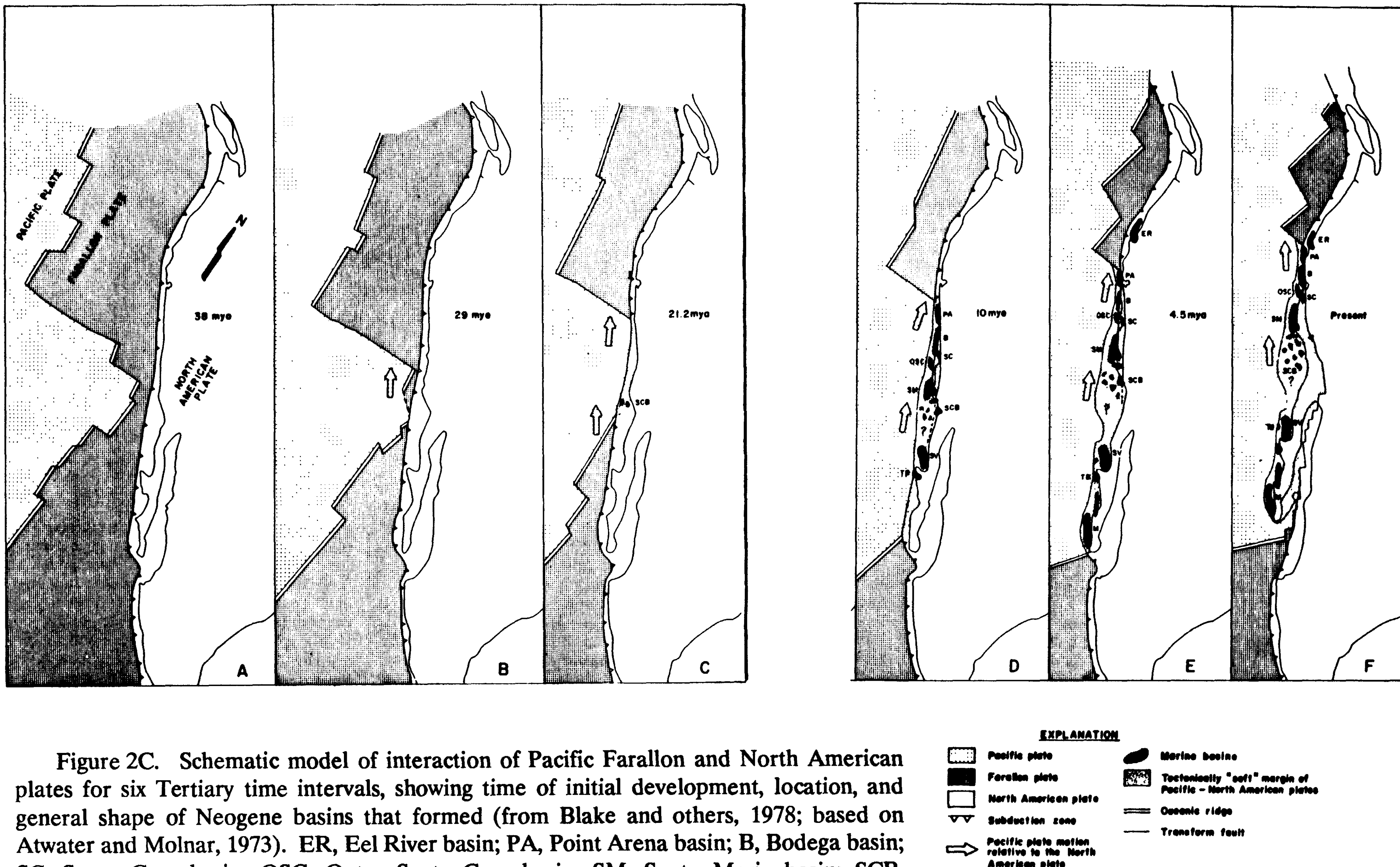


Figure 2C. Schematic model of interaction of Pacific Farallon and North American plates for six Tertiary time intervals, showing time of initial development, location, and general shape of Neogene basins that formed (from Blake and others, 1978; based on Atwater and Molnar, 1973). ER, Eel River basin; PA, Point Arena basin; B, Bodega basin; SC, Santa Cruz basin; OSC, Outer Santa Cruz basin; SM, Santa Maria basin; SCB, Southern California basin; SV, Sebasian Vizcaino basin; TB, Tortugas basin; and M, Magdalena borderland.

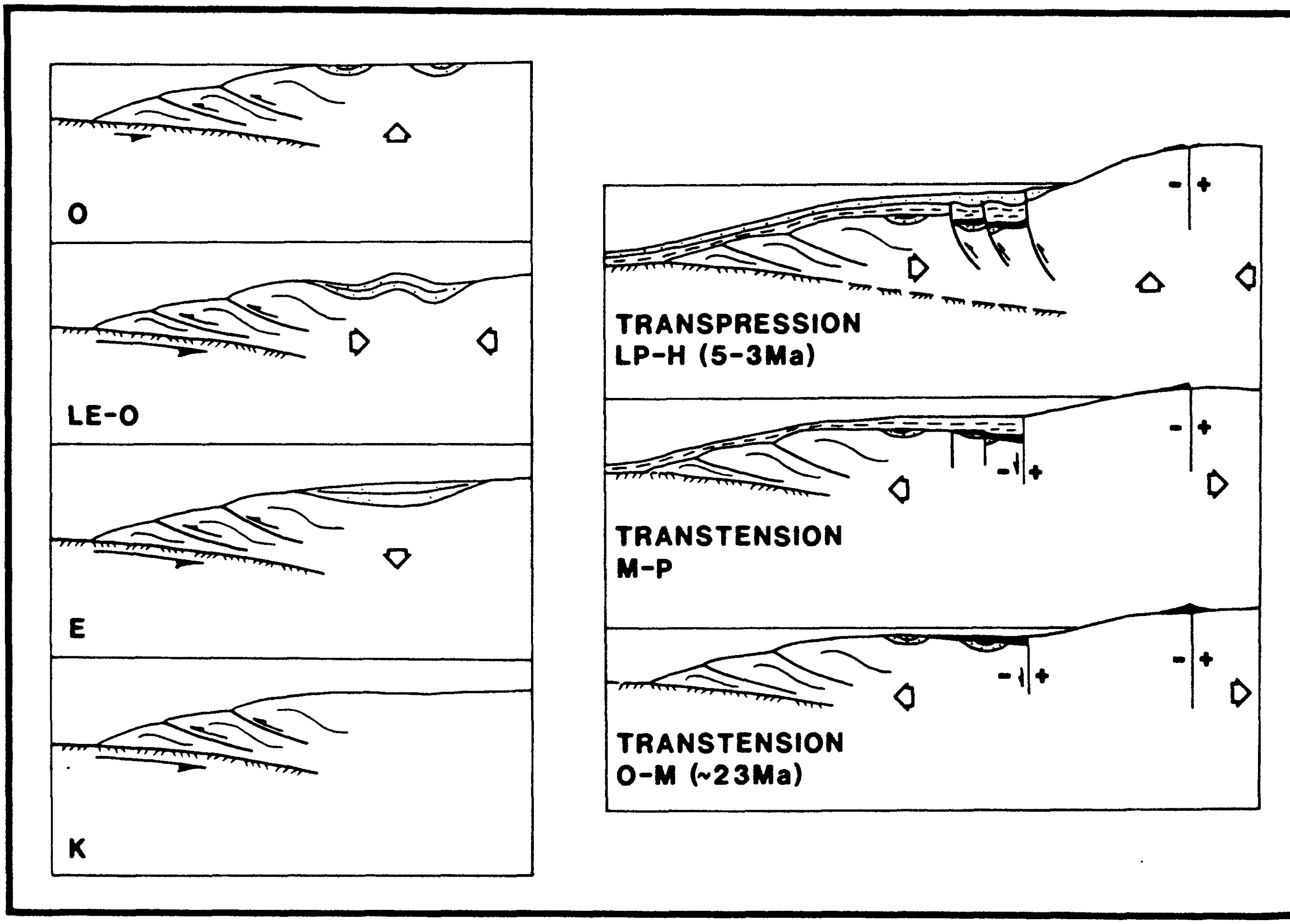


Figure 2D. Diagrammatic representation of the development of the offshore central California margin (from McCulloch, 1989). K, Cretaceous; E, Eocene; O, Oligocene; M, Miocene, P, Pliocene; H, Holocene.

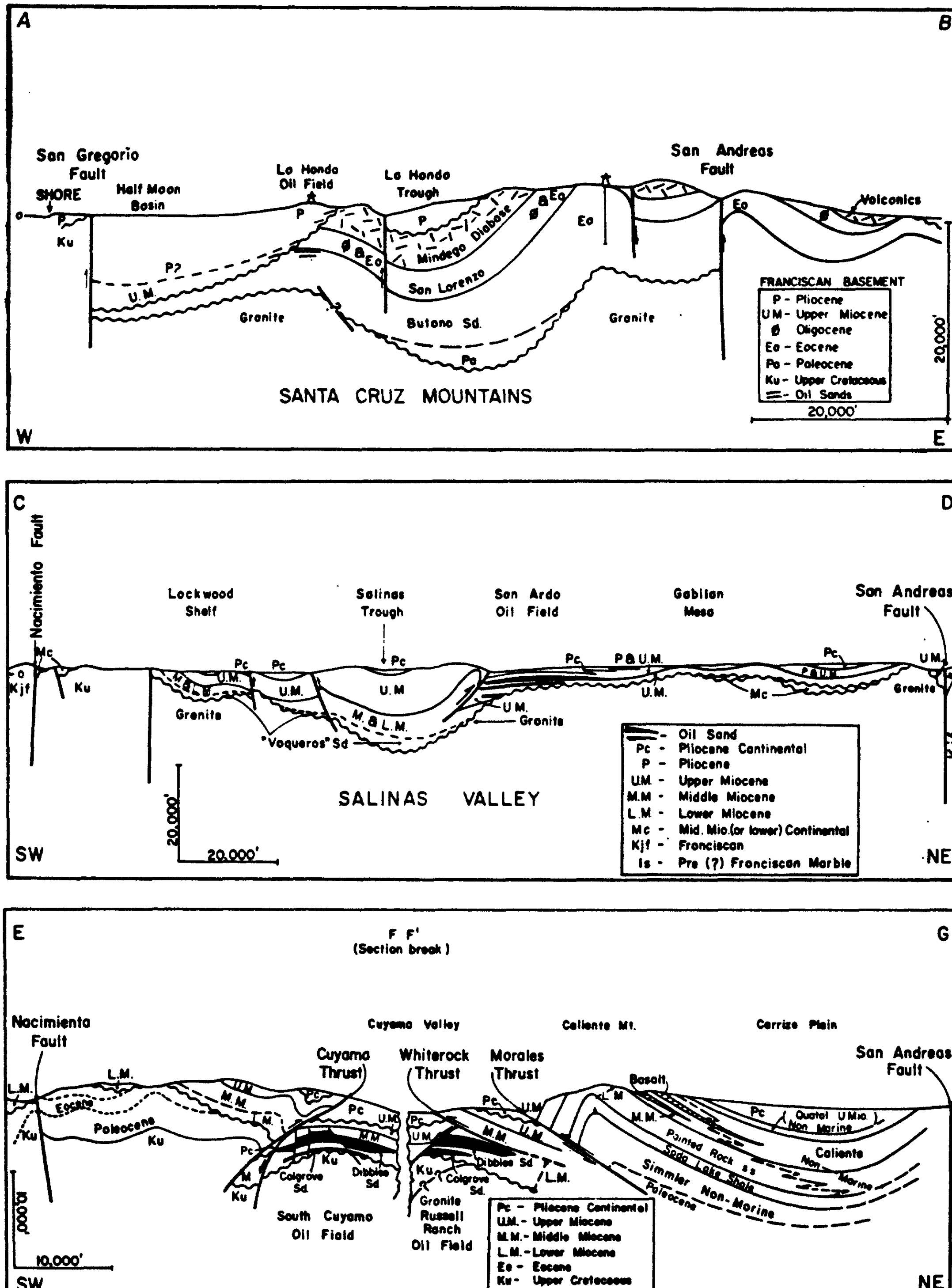


Figure 3. Cross sections in the Central Coastal Basins assessment province. A-B across northern Santa Cruz Mountains. C-D across Salinas Valley. E-F-F'-G across Cuyama basin area. Locations of the sections are shown in Figure 1B. Reprinted from Baldwin (1971) by permission.

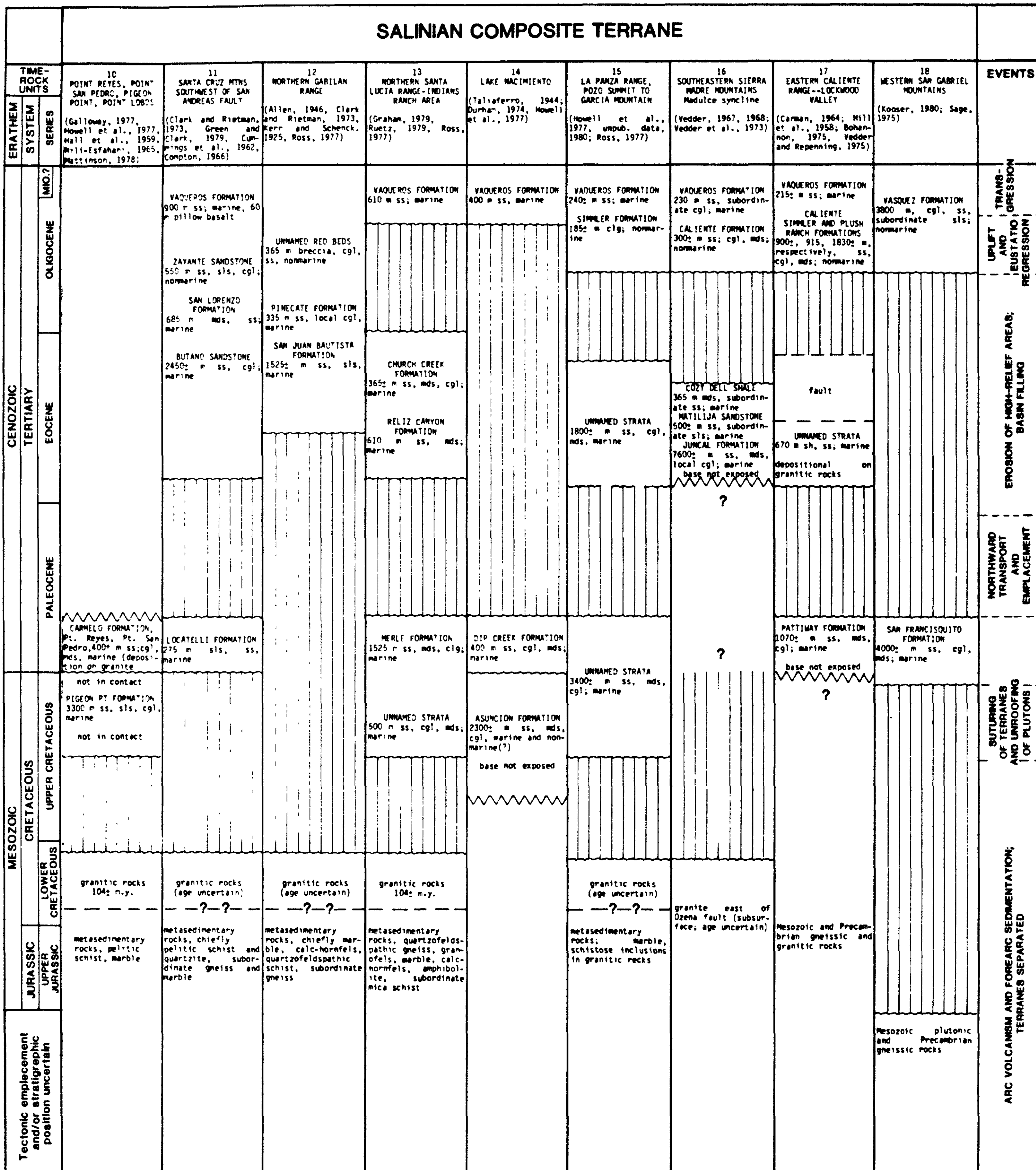


Figure 4A. Pre-Neogene correlation chart illustrating known and inferred stratigraphic and structural discontinuities in the Salinian composite terrane. Stratigraphic units, maximum or aggregated thicknesses, and predominant rock types are shown for localities 10-18 shown in Figure 4B. From Vedder and others (1983); not all references given are included in this report.

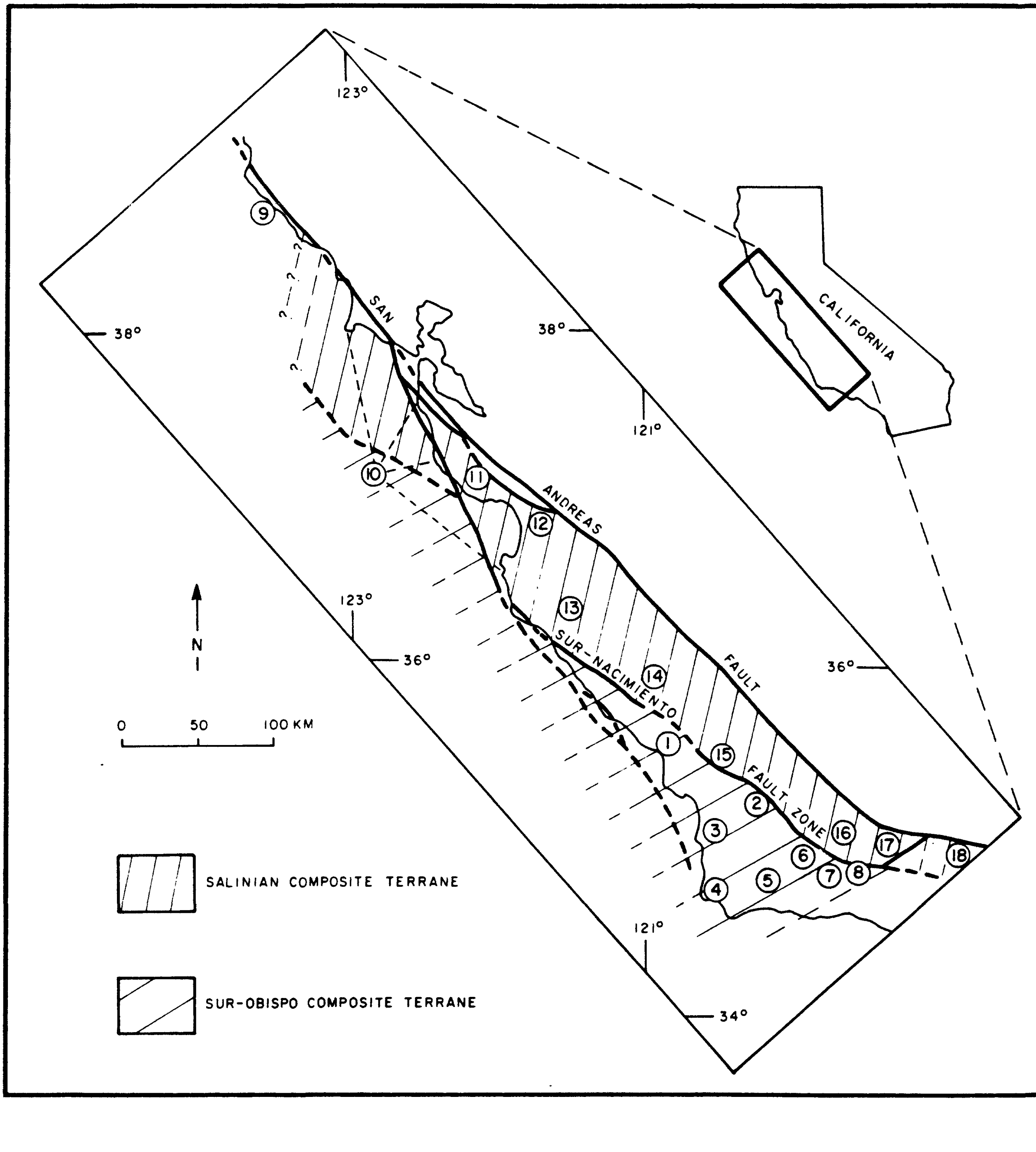
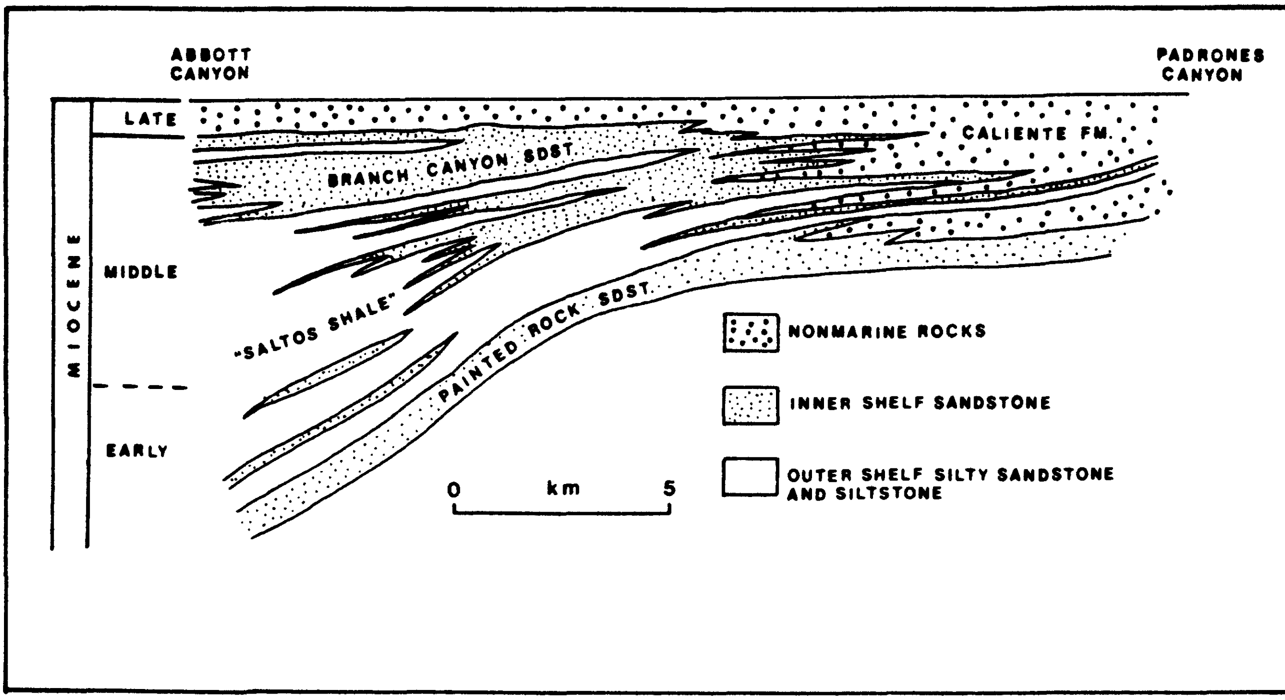


Figure 4B. Location of stratigraphic columns in pre-Neogene correlation chart (Figure 4A). From Vedder and others (1983).



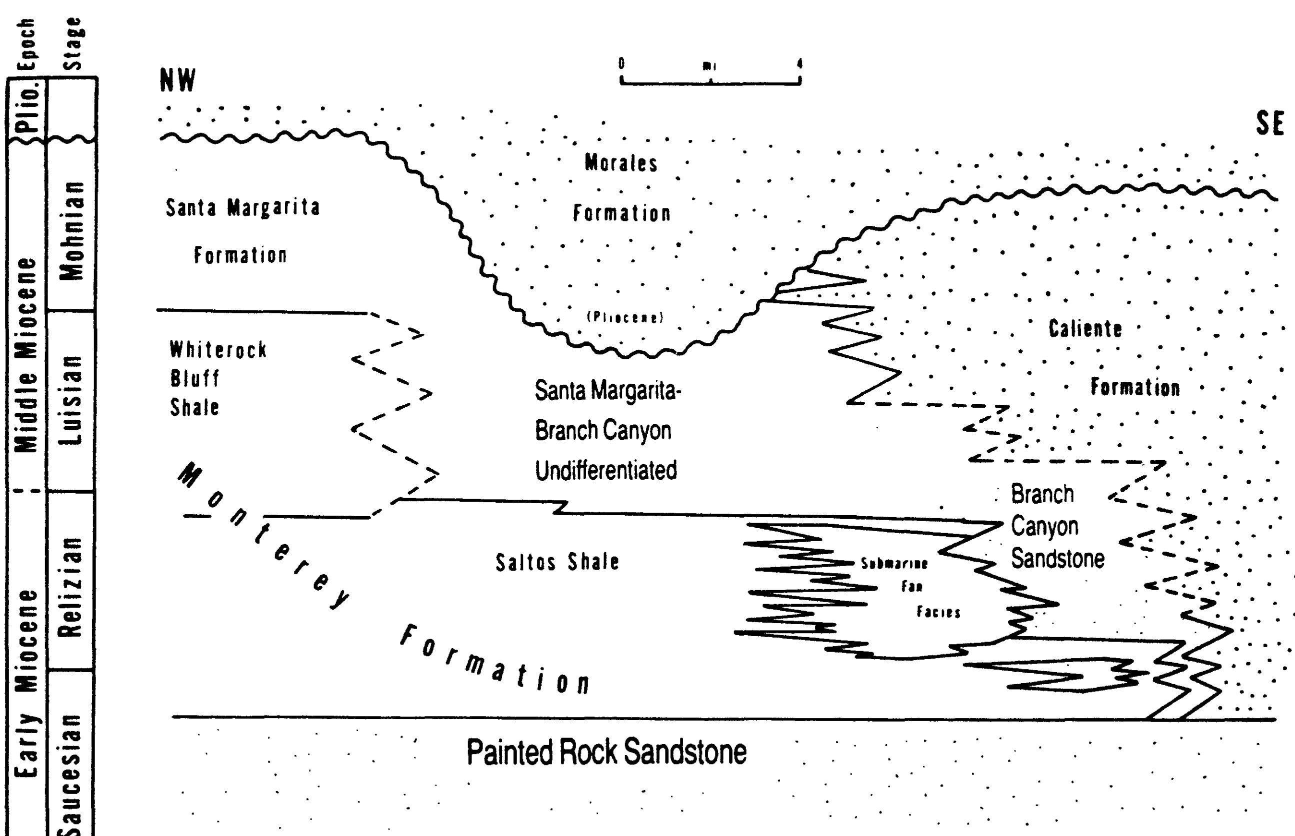


Figure 4C. Summary Miocene stratigraphic section of southeast Caliente area (above); from Lagoe (1984) after Clifton (1981). Summary Neogene stratigraphic section beneath Cuyama Valley (below) from Lagoe (1984). For the pre-Neogene section in this area, see Figure 4A.

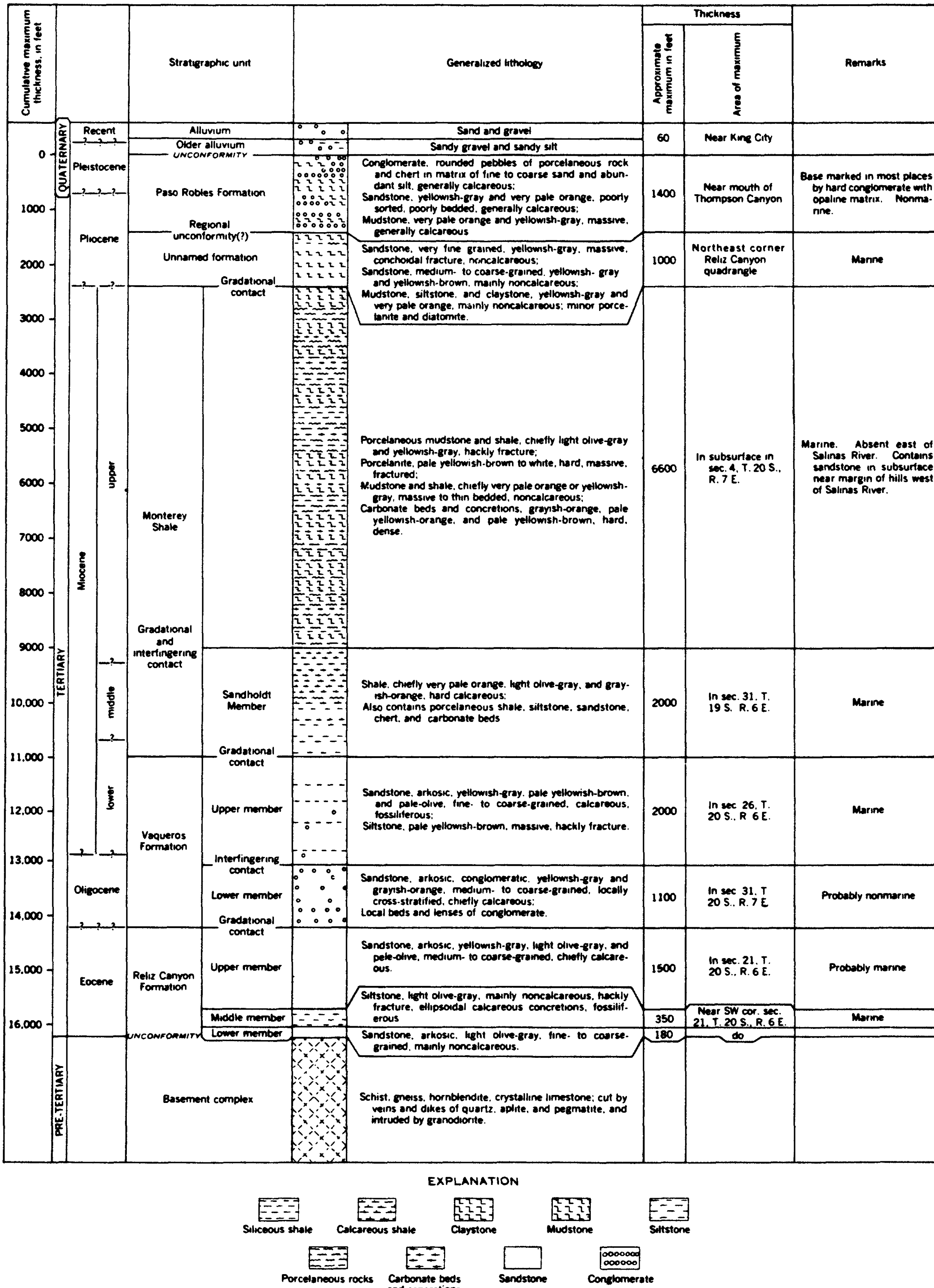


Figure 4D. Stratigraphic column in the Reliz Canyon area. From Durham (1963).

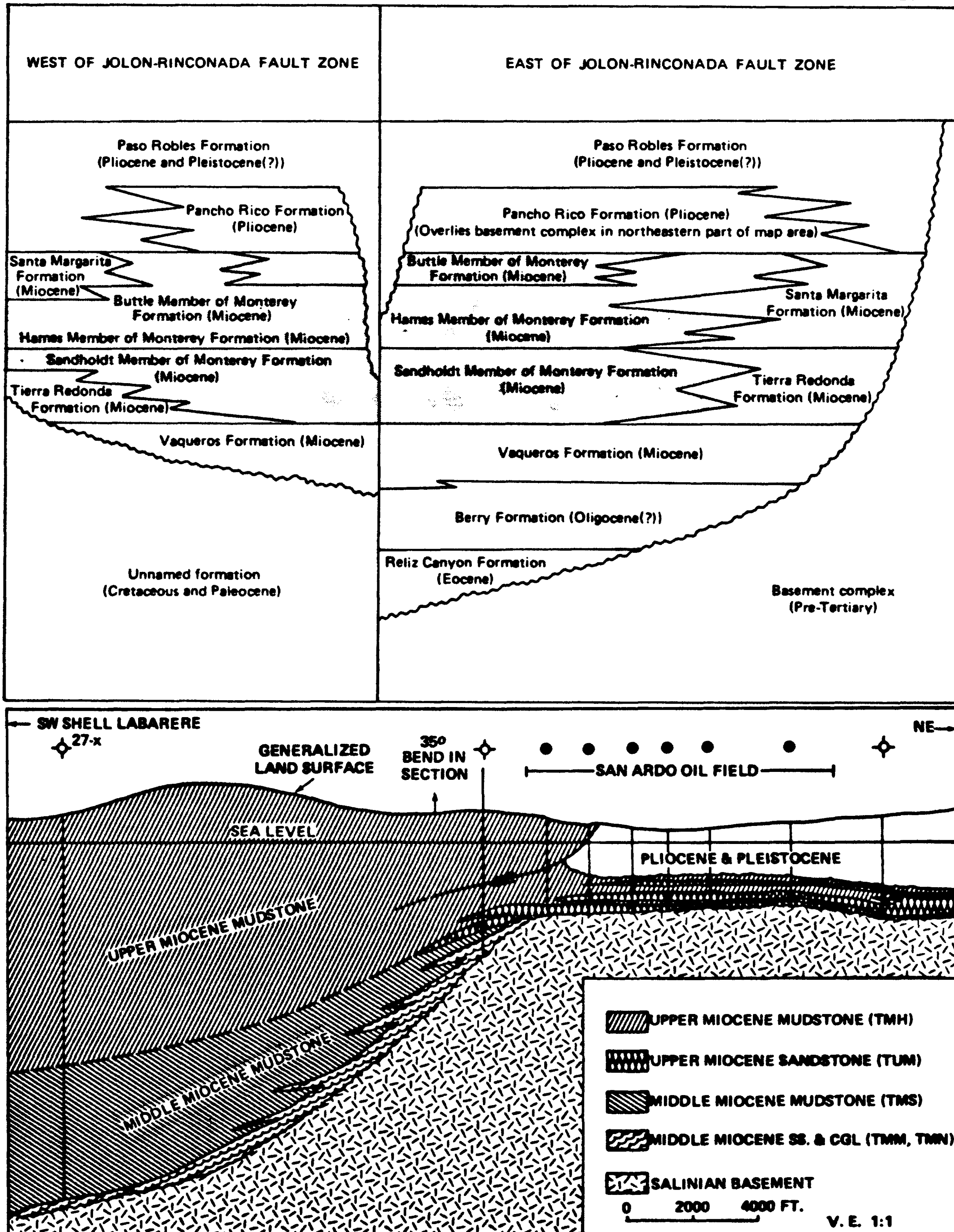


Figure 4E. Lateral relations (above) among formations in the southern Salinas Valley; from Durham (1974). Geologic cross-section (below) in the San Ardo oil field area; reprinted from Graham (1976) by permission (in part after Colvin, 1963).

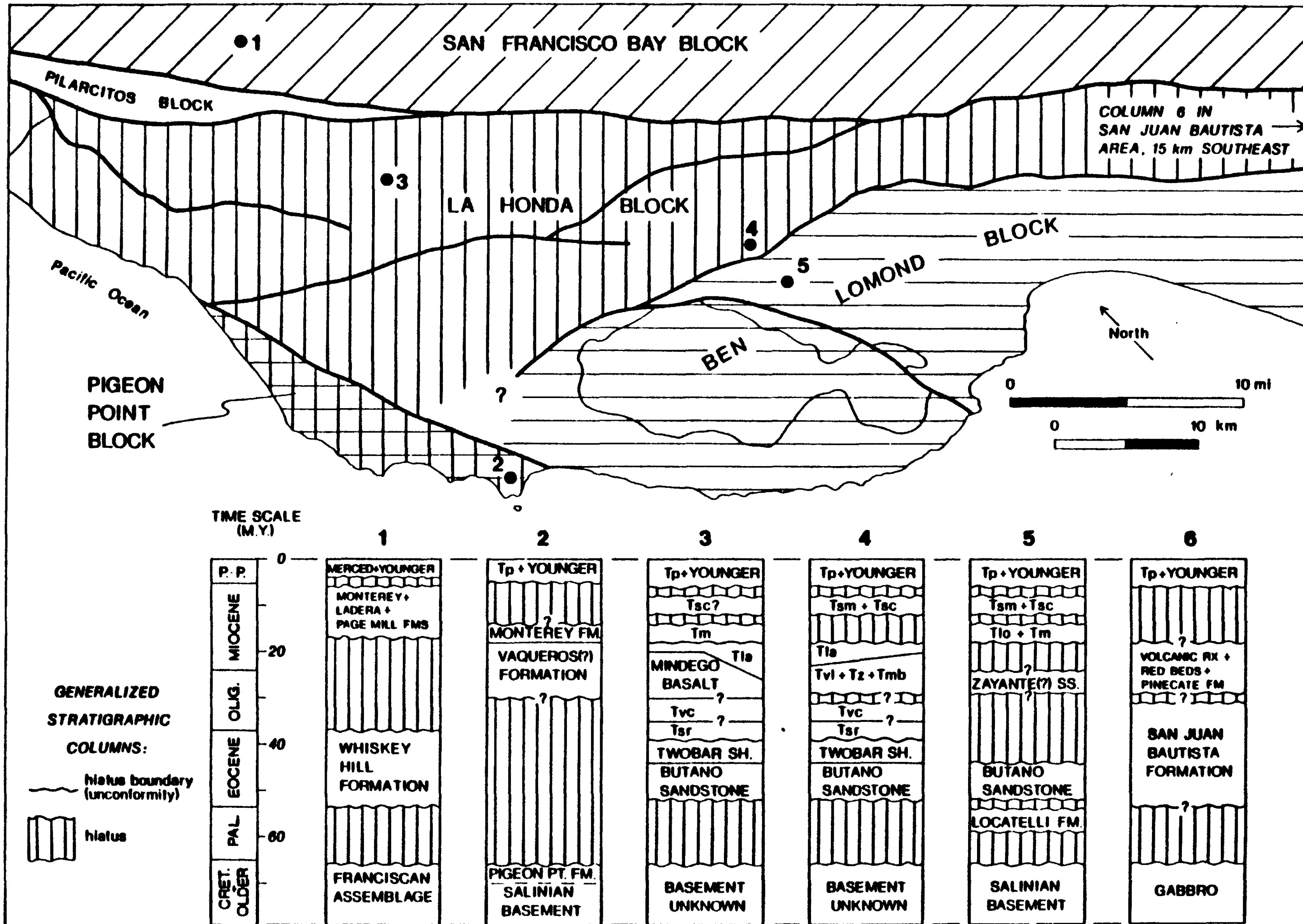


Figure 4F. Representative stratigraphic columns in the La Honda basin area (section 1 is outside the assessment province). Tp, Purisima Formation; Tsc, Santa Cruz Mudstone; Tsm, Santa Margarita Sandstone; Tm, Monterey Formation, Tlo, Lompico Sandstone; Tla, Lambert Shale; Tvl and Tvc, Vaqueros Sandstone; Tz, Zayante Sandstone; Tmb, Mindego Basalt, Tsr, Rices Mudstone. Reprinted from Stanley (1984) by permission.

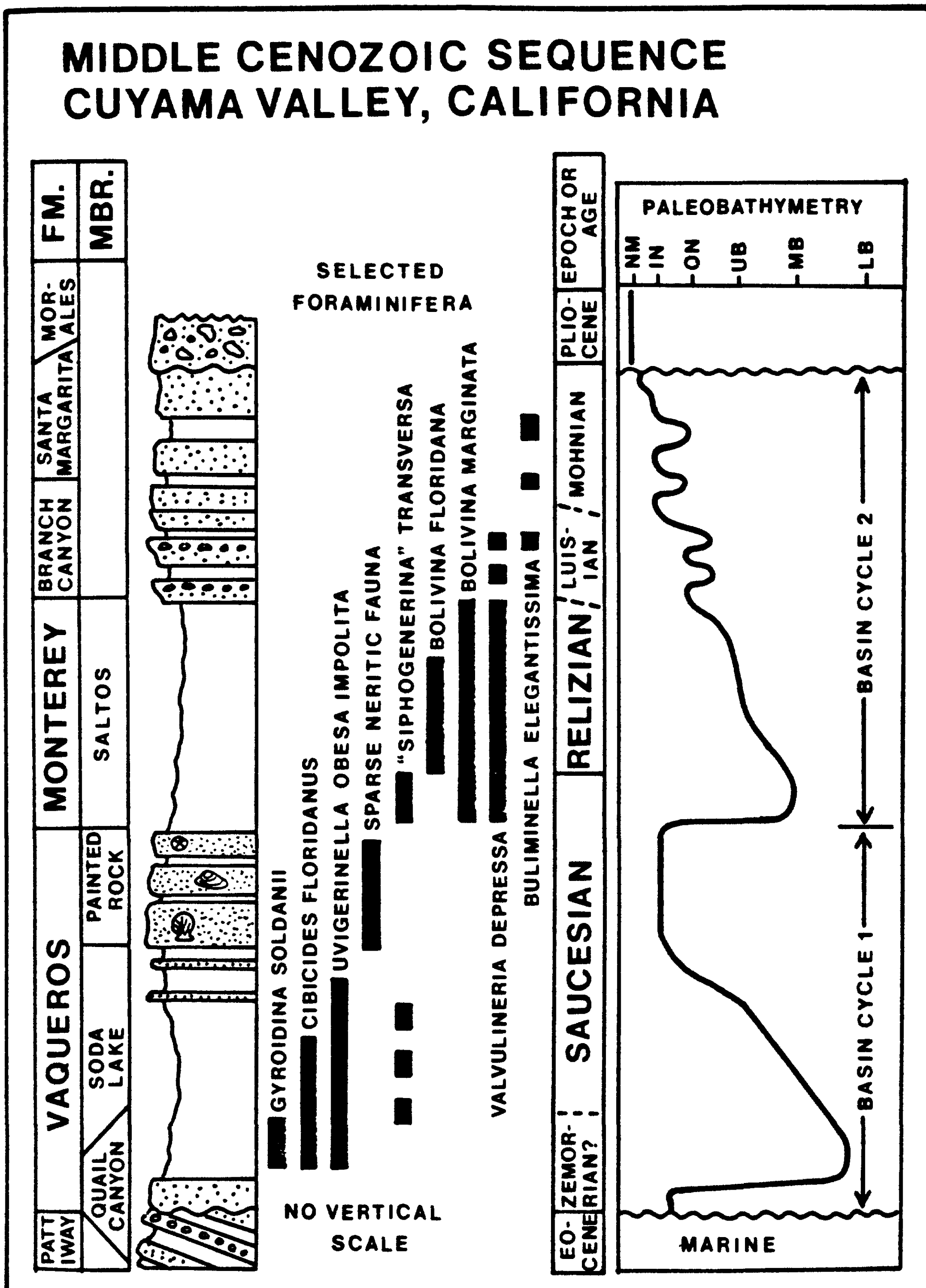


Figure 5A. Paleobathymetry of middle Cenozoic rocks beneath Cuyama Valley, showing two distinct episodes of basin subsidence and filling. Paleobathymetric abbreviations: NM-nonmarine; IN-inner neritic; ON-outer neritic; UB-upper bathyal; MB-upper middle bathyal; LB-lower middle bathyal. Reprinted from Lagoe (1987a).

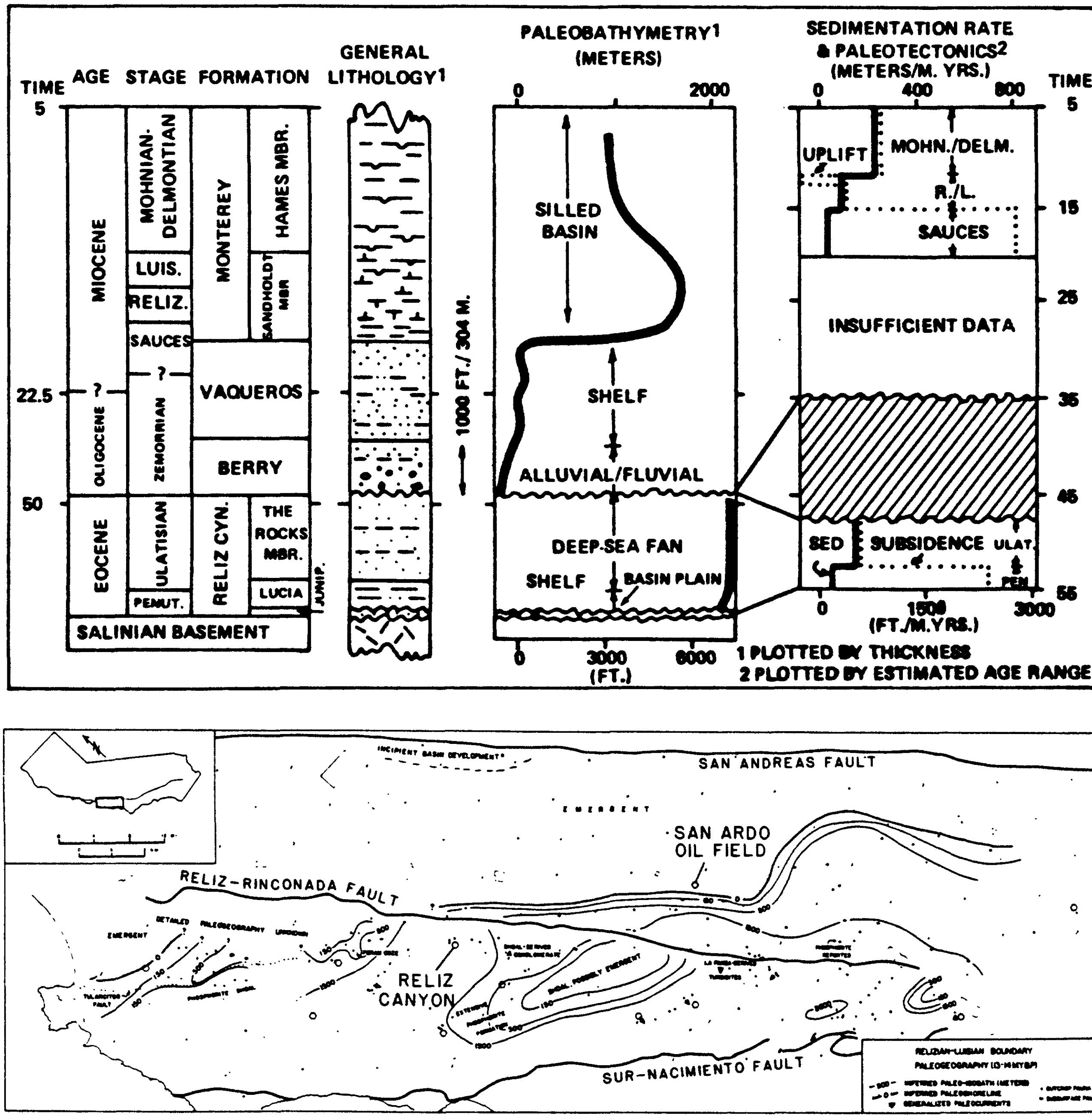


Figure 5B. Tertiary paleobathymetry (above) in the Reliz Canyon area and middle Miocene paleogeography (below) in the Salinas basin. Modified slightly from Graham (1976) and reprinted by permission.

1965, 1966, 1968a, 1968b, 1970, 1974), Durham and Addicott (1964, 1965), Graham (1976, 1979a, 1979b), and Ruetz (1979). For the Santa Cruz Mountains or La Honda district are Allen (1946), Cummings and others (1962), Clark and Reitman (1973), Greene and Clark (1979), and Stanley (1984). For adjacent offshore areas are Hoskins and Griffiths (1971) and McCulloch (1987, 1989). A more complete bibliography for the southern part of the area is given by Heilbrunn-Tomson (1988).

SOURCE ROCKS

The Central Coastal Basins assessment province contains a variety of potential source rocks from Cretaceous to Pliocene in age. At the time of the assessment, little research was available except data on the Monterey Formation which was generally presumed to be the principal source rock in the two major petroleum-producing districts (Salinas and Cuyama).

The main source-rock study available was Kablanow (1986) who evaluated subsurface Monterey samples (mainly cuttings) from 8 wells in the central part of the Salinas Basin. Samples yielded TOC (total organic carbon) values in the range 0.8-5.5% (av 2.6%), with the organic matter generally type II or intermediate type II-III (as shown by elemental composition). Similar values of TOC (average lithotype values in the range 0.2-4.6%) and kerogen types were documented by Mertz (1984) for mainly surface samples from the lower part of the Monterey Formation (Sandholdt Member) in the area. A few samples of Eocene Juncal Formation in the mountains along the western boundary of the assessment province near the Cuyama district had TOC in the range 0.4-6.8% and type III kerogens (interpreted from Rock-Eval pyrolysis) (Frizzell and Claypool, 1983).

Subsequent to the assessment, several source-rock studies were published or presented for the Cuyama basin. These generally concluded that the most probable major petroleum source in the Cuyama district is not the Monterey Formation but the early Miocene Soda Lake Shale Member of the Vaqueros Formation (Kornacki, 1988; Lillis, 1988; Lundell and Gordon, 1988), a unit sedimentologically similar to and more or less coeval with the Rincon Shale of the Ventura basin (Lagoe, 1987a).

BURIAL HISTORY, THERMAL MATURITY, AND TIMING OF MIGRATION

Because the major source rocks in the assessment province are Miocene in age, Neogene and especially late Neogene burial histories are of principal importance in evaluating oil generation and migration histories. Each district in the province has somewhat different characteristic burial histories. In the Cuyama district, the thickness of pre-upper Miocene Tertiary sediments in places exceeds 8000 ft (Figure 1B) but younger strata were not rapidly deposited and are not today particularly thick, nowhere exceeding more than about 2000 ft (Figure 1B). In the Salinas district, by contrast, upper Miocene and younger strata are as much as 8000 ft thick (Figure 1B; Baldwin, 1971) and the

Monterey Formation as a whole in places exceeds 13,000 ft in thickness (Kablanow, 1986). In the Santa Cruz Mountain district, episodes of uplift and erosion occurred during parts of middle and late Miocene time (Stanley, 1984), and upper Miocene and younger strata exceed 4000 ft thickness mainly in the Half Moon Basin (Baldwin, 1971; Figure 1B) which is filled for the most part with Pliocene sandstone and mudrocks of the Purisima Formation (Baldwin, 1971; Figure 3).

The only thermal maturation model available at the time of the assessment was Kablanow's (1986) study of the Monterey Formation in the central part of the Salinas basin. This study contains much valuable data on maturation of Monterey organic matter, including subsurface values for extractable hydrocarbon, some chromatographic parameters, and Rock-Eval pyrolysis corrected by extraction. (This latter correction adjusts for the heavy hydrocarbons and nitrogen-sulfur-oxygen compounds abundant in Monterey bitumen; see Kruge, 1983; Orr, 1983; Kablanow, 1986; Petersen and Hickey, 1987). By these criteria, mature (oil-generating) organic matter was considered to be present below 4500 ft (1.4 km) present-day depths in the center of the Salinas Trough (Kablanow, 1986).

Kablanow's (1986) study also addressed the history of oil generation and migration in the area. According to his model, in the lower part of the Monterey Formation in the central basin trough, sulfur-rich kerogen would have generated oil from about 8 to 6 Ma (in the temperature range 100-135 ^{o}C) with expulsion at 6000 ft of burial, and sulfur-poor kerogen would have generated oil from 5 Ma to the present (at temperatures exceeding 125 ^{o}C) with expulsion at 8000 ft. However, these conclusions are sensitive to many assumptions, for example assumptions regarding paleo heat flows (assumed to be high in the early Miocene, based on Hall's 1981 tectonic model of the Coast Ranges), thermal conductivity patterns in diatomaceous rocks (not well-known), present-day temperature gradients (not measured in equilibrium), etc. Other major unknowns were (1) whether the source kerogen is in fact sulfur-rich, sulfur-poor, or some combination; and (2) whether the heavy oils in the area are early-generated primary oils or biodegraded "normal" oils. (For a summary on early generation in the Monterey Formation, see Petersen and Hickey, 1987; Isaacs and Petersen, 1987.) Because of these uncertainties, models of the history of oil generation and migration were not considered sufficiently conclusive to be of particular value at the time of the assessment.

HYDROCARBON OCCURRENCE

Geographic Distribution

Discovered oil and gas resources (cumulative production plus proved reserves through 1983) in the assessment province total 884 MMBOE, including 826 MMbbl oil (93% of total province resources). Most resources are in the Salinas district with 545 MMBOE (62% of total province resources) and Cuyama district with 338 MMBOE oil (38% of total province resources), but most gas resources (≈80% of province gas resources) are in the

Cuyama district. Additional resources of about 1.7 MMBOE oil (≈0.2% of total province resources) are located in the La Honda district.

Of total resources in the Salinas district, the vast majority (>99%) are in the Main area of the giant San Ardo field with remaining resources scattered among 9 other small fields or field areas (Tables 1-3). Resources in the Cuyama district are largely in the Main area of the South Cuyama field with 258 MMBOE (76% of the district total) and the Main area of the Russell Ranch field with 77 MMBOE (23% of the district total); another 3 MMbbl oil (≈1% of the district total) is scattered among 7 small fields and field areas (Tables 1-3).

Stratigraphic and structural habitat of petroleum

Most hydrocarbons in the Central Coastal Basins assessment province accumulated in permeable Miocene sandstones. In the Cuyama district, most oil is produced from shelfal marine sandstones of the Vaqueros Formation, principally the Dibblee sand of the Painted Rock Sandstone Member and the Colgrove sand of the Soda Lake Shale Member (Figure 4C; Table 3). Minor oil and gas are also produced from nonmarine sandstones in the Pliocene Morales Formation (≈1 MMbbl oil), the shelfal Miocene sandstones of the Branch Canyon Sandstone (≈1.5 MMbbl oil) and Santa Margarita Formation (≈2.5 MMbbl oil), and possibly the Soda Lake Shale Member of the Vaqueros Formation (≈1.4 MMbbl oil) (Table 3; Conservation Committee of California Oil and Gas Producers, 1986). Traps in the Cuyama district are mainly structural - complexly faulted anticlines, homoclines, and noses (Table 3; Figure 7A-7C). Some small traps are in subthrust structures sealed by overlying impermeable shale (Figure 7C).

In the Salinas district, the vast majority of oil is produced from the San Ardo field, where reservoirs are upper Miocene sandstones in the Monterey Formation (California Division of Oil and Gas, 1991) or Santa Margarita Formation (Durham, 1974) which intertongue with fine-grained rocks near the Miocene shoreline along the eastern edge of the Salinas Trough (Baldwin, 1971; Durham, 1974; Figure 4E). Several other smaller oil fields also produce from the "basinward shale edge" of upper Miocene Monterey-Santa Margarita sandstones, and one field (the King City field) produces from the "basinward shale edge" of middle Miocene Monterey-Tierra Redonda sandstones (Baldwin, 1971; Durham, 1974). Traps in the Salinas district are mainly stratigraphic or combination stratigraphic-structural traps (Figures 7D-7F).

Basis for play definition

A variety of more or less stratigraphically defined plays were early considered for the Central Coastal basins assessment province. These included fractured reservoirs in the Monterey Formation (a speculative play); Miocene-Pliocene sandstones of the Monterey Formation together with subjacent and superjacent strata; sandstone reservoirs of the Vaqueros Formation (the main reservoir in Cuyama district, a speculative play for the Salinas district); nonmarine sandstones of the Simmler, Caliente and other Formations (a speculative play); Eocene sandstones of various formations (the main reservoir in the La

Honda district, a speculative play in other districts); Cretaceous sandstones and basement rocks (a speculative play); etc.

Because of the small number of fields (7 major fields as classed by the Nehring data base; see Table 1), however, and because reservoirs in all major discovered fields are Miocene-Pliocene sandstones, all fields in the assessment area were grouped together in a single play termed the Neogene play.

NEOGENE PLAY

Play Definition

The Neogene play is characterized by oil accumulations in Neogene sandstone reservoirs, trapped in structural, stratigraphic, and combination structural-stratigraphic traps. The play includes the entire area of significant subsurface extent of Neogene strata together with adjacent federal waters, an area approximately 275 miles long and 10-35 miles wide (Figure 1A).

Reservoirs

Throughout the assessment province, the major reservoir lithology is sandstone. In the Cuyama district, most oil is reservoired in sandstone of the Vaqueros Formation (Table 1) having porosity in the range 25-30% and permeabilities in the hundreds of millidarcies (NRG Associates, 1984). Even higher porosities (39-41%) are reported for the reservoirs of the San Ardo field in the Salinas district. Reservoirs in the La Honda district include a variety of sandstone horizons ranging from Eocene to Pliocene in age. According to Baldwin (1971), poor reservoir quality in this area is the major reason for its small cumulative production and overall resource potential.

Traps and seals

In the Cuyama district, traps are mostly structural. Two field areas account for most hydrocarbon resources: (1) the Main area of the South Cuyama field (the largest field in the district), where the trap is a faulted anticline (Figure 7A), and (2) the Main area of the Russell Ranch field, where the trap is a faulted homocline (Figure 7B). Traps in other smaller fields in the district are homoclines (Southeast area of the South Cuyama field and Cuyama Central field), faulted anticlinal noses (Southeast area of Russell Ranch field and Taylor Canyon field), and a faulted asymmetrical anticline (Morales Canyon field). Some traps (as in the Clayton area of the Morales Canyon field, Figure 7C) are in subthrust reservoirs. Throughout the area, the main seal is the fine-grained strata of the Monterey Formation.

In the Salinas district, the major trap (in the San Ardo field) is an anticlinal structure combined with intertonguing sandstones (reservoir) and shale (seal). Other smaller traps in the district include permeability barriers on anticlinal folds (Monroe Swell field), lenticular sands on a dome (Doud 3-1-32 area of the King City field), and sand overlap onto basement (Mc Cool Ranch field).

In the La Honda district, traps are mainly structural and include an anticlinal-homoclinal trap (Half Moon Bay field), nose (La Honda field), faulted nose (Oil Creek field), and a fold on the flank of a steeply inclined monocline (Moody Gulch field).

Oil Characteristics

Oil in the assessment province differs markedly between districts. In the Cuyama district, oil is generally light with API gravities in the range 26-46^0. In the Salinas district, oil is generally heavy with API gravities in the range 10-19^0; though included in the assessment as conventional oil resource, these heavy oils would by usual definition be classed as unconventional.

At the time of the assessment, no organic geochemical studies of the oils or oil-source correlation studies were published or otherwise available for the assessment province and the main source-rock was assumed to be the Monterey Formation throughout the area. Analogies with oil generation in the better-known Santa Maria, Ventura, and Los Angeles basins (Petersen and Hickey, 1984, 1987; Orr, 1986) suggested that the good-quality high-gravity oils of the Cuyama district were plausibly related to the clay-rich character of the Monterey Formation in that area (as speculated by Orr, 1986, for the Barham Ranch field in the Santa Maria basin). By similar analogy, the heavy oil characteristic of the Salinas basin was plausibly related either to biodegradation or to generation of primary heavy oil as in the Santa Maria basin (for a summary, see Isaacs and Petersen, 1987), but information was not available to distinguish between these possibilities.

Subsequent to the assessment, as mentioned above, studies suggested that oils in the Cuyama district derived from the Soda Lake Shale Member of the Vaqueros Formation (Kornacki, 1988; Lillis, 1988; Lundell and Gordon, 1988). The Soda Lake Shale Member is actually very similar lithologically to most strata included in the Monterey Formation in the Cuyama district, especially the Saltos Shale.

Depth of Occurrence

The depth to the top of oil reservoir horizons is moderate, being on average less than 6000 ft in all fields (as listed in the Nehring data base) with an average depth of about 3000 ft. Average reservoir thickness ranges from about 70 ft to about 600 ft, with an overall average of about 250 ft (by field; Table 1). Reservoirs in the Salinas basin are shallower (field averages 2000-2400 ft, Table 1; pool average 710-3200 ft, Table 3) than in the Cuyama basin, where the deepest average field depth (in the Cuyama Central field) is 7360 ft (Table 3).

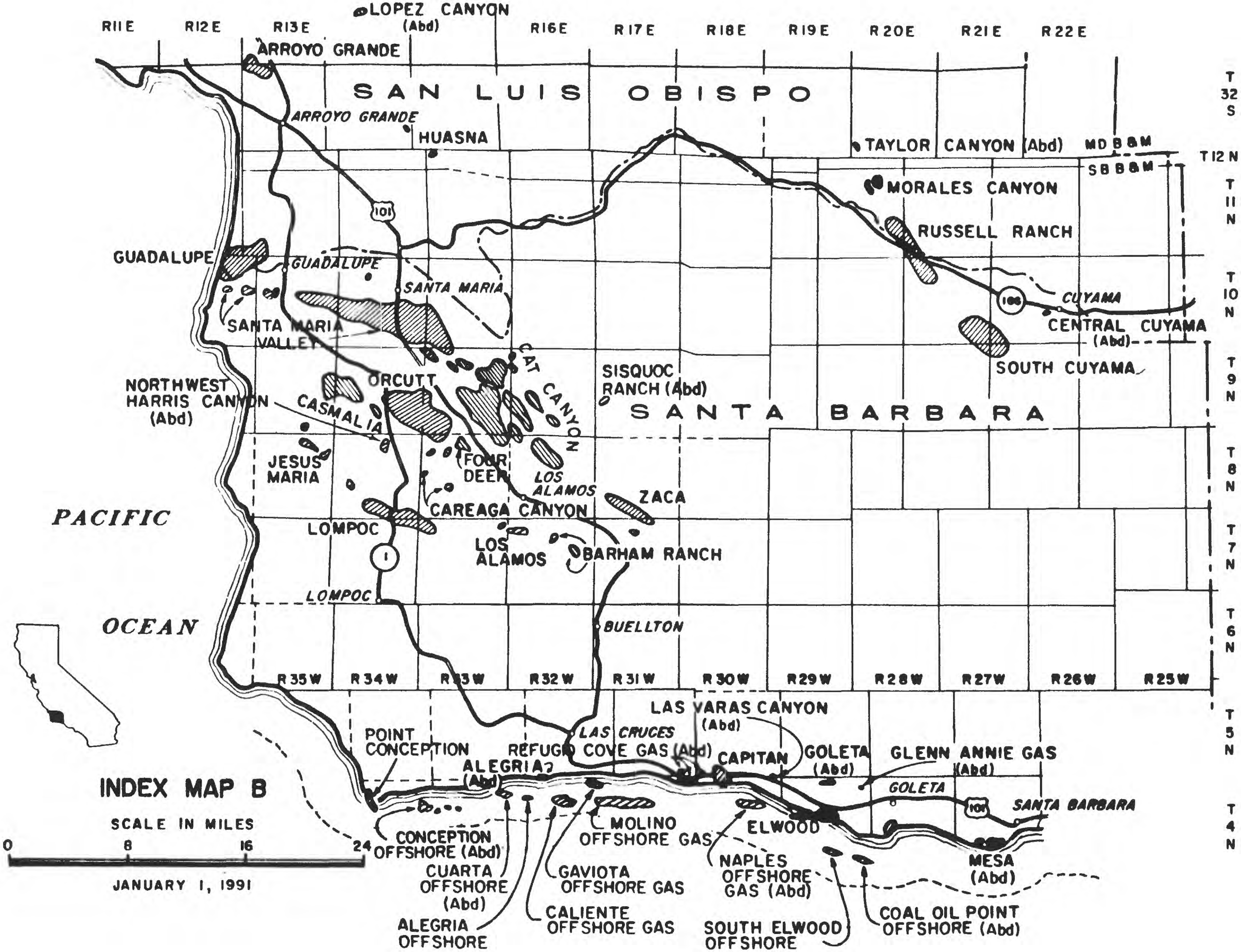


Figure 6A. Oil fields in the Cuyama district and adjacent areas. From California Division of Oil and Gas (1991).

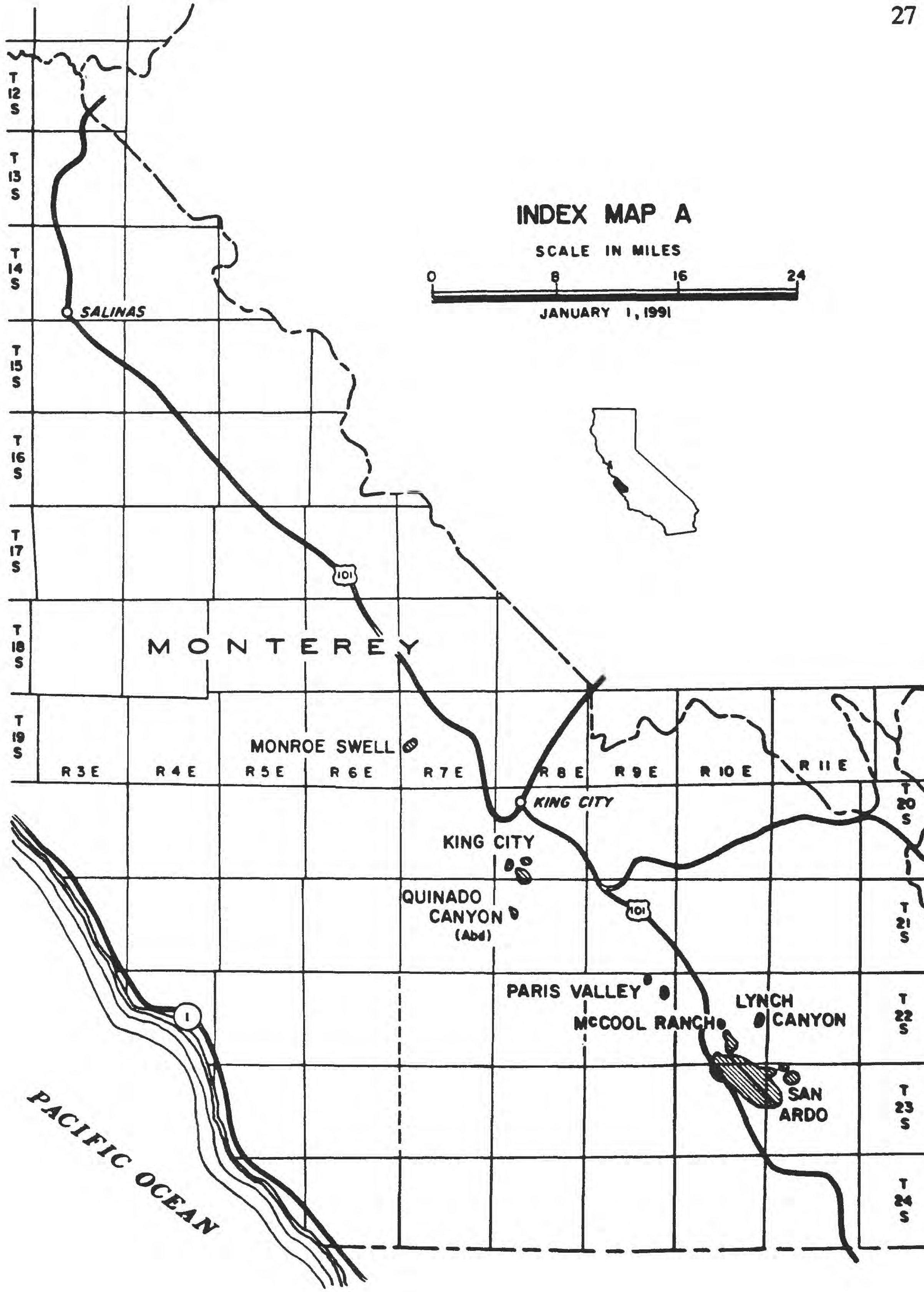


Figure 6B. Oil fields in the Salinas district. From California Division of Oil and Gas (1991).

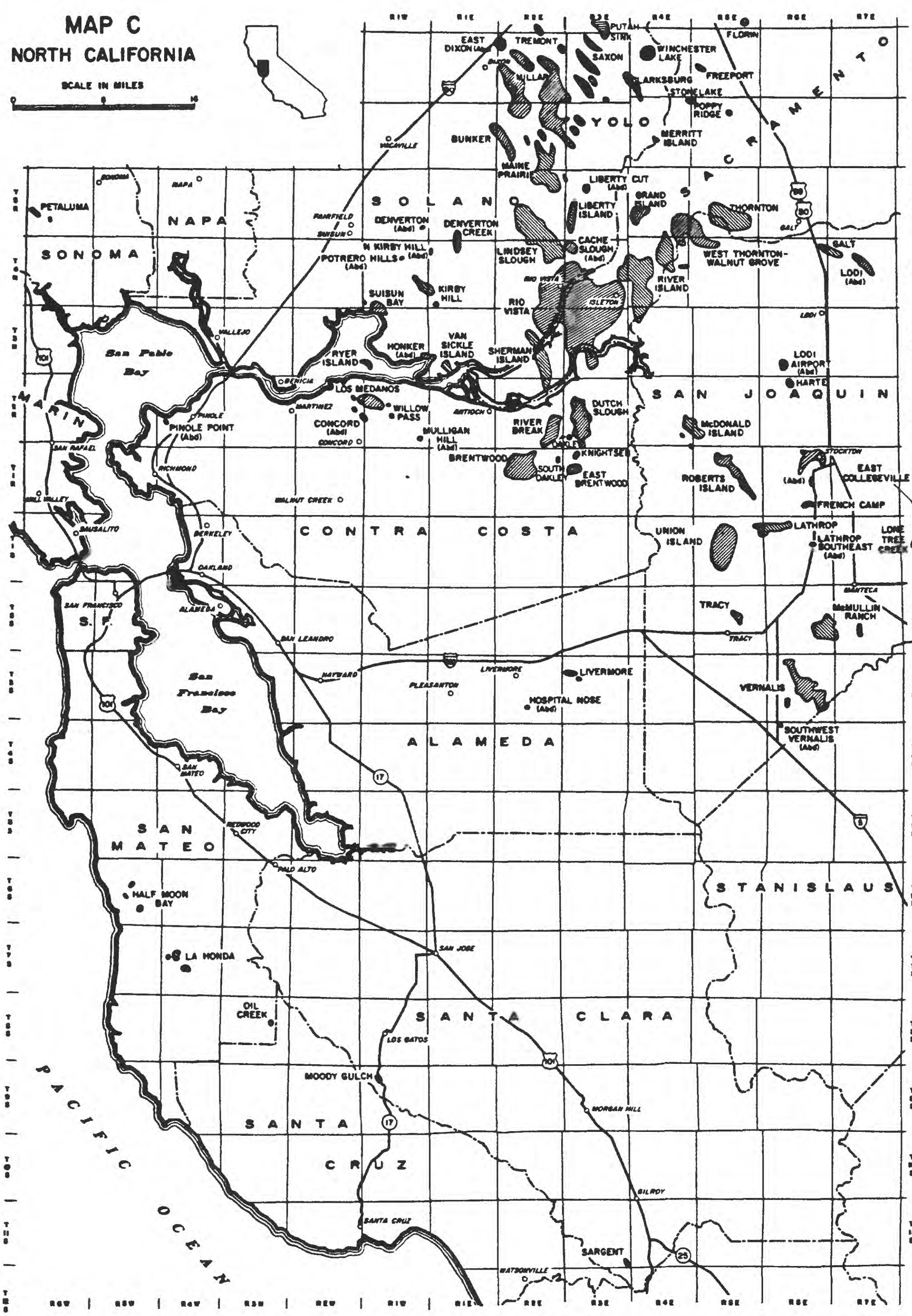


Figure 6C. Oil fields in the La Honda district and adjacent areas. From California Division of Oil and Gas (1982).

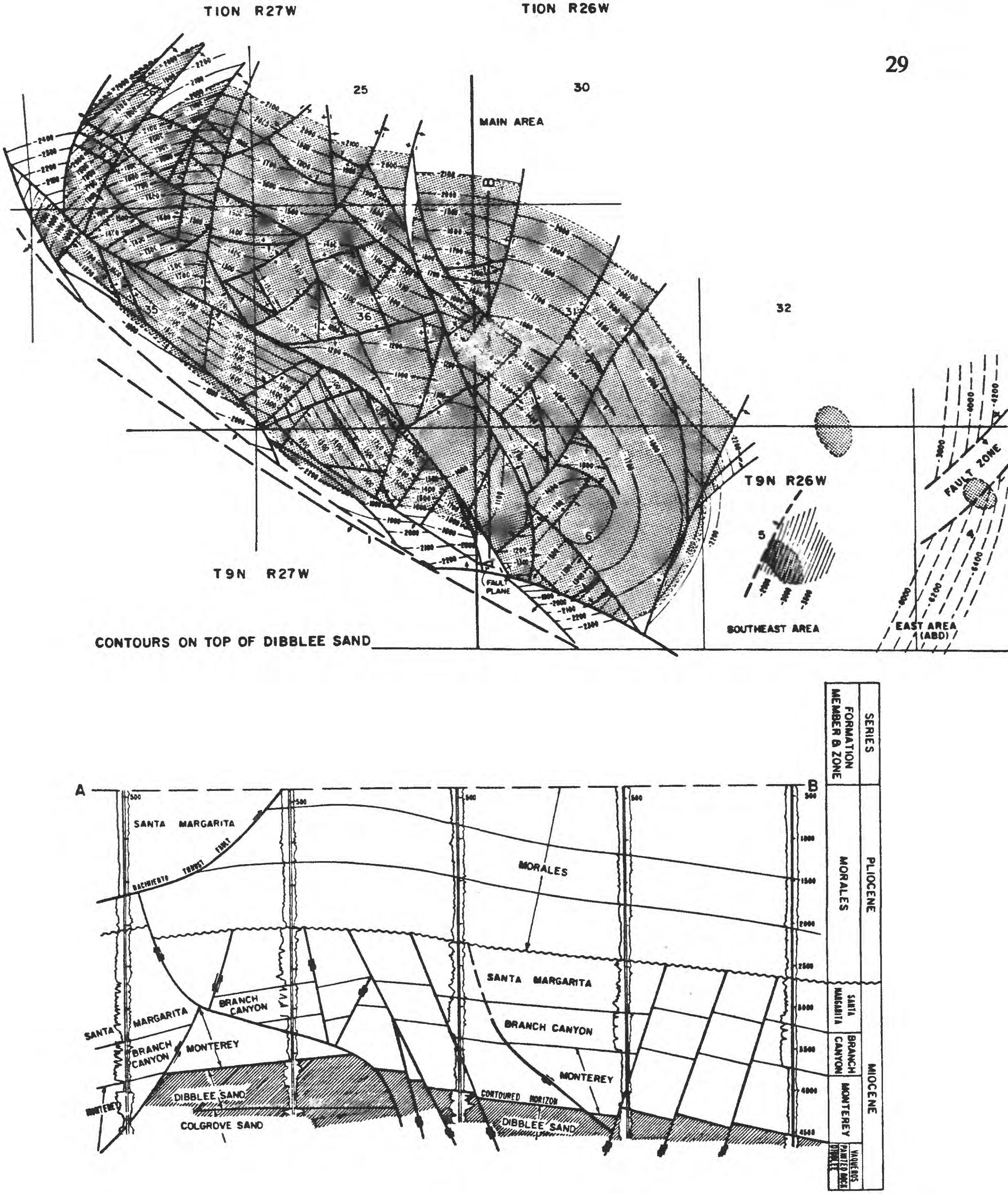


Figure 7A. Cross section and contour map of the Main area of the South Cuyama oil field (Cuyama district), showing the faulted anticlinal trap. From California Division of Oil and Gas (1991).

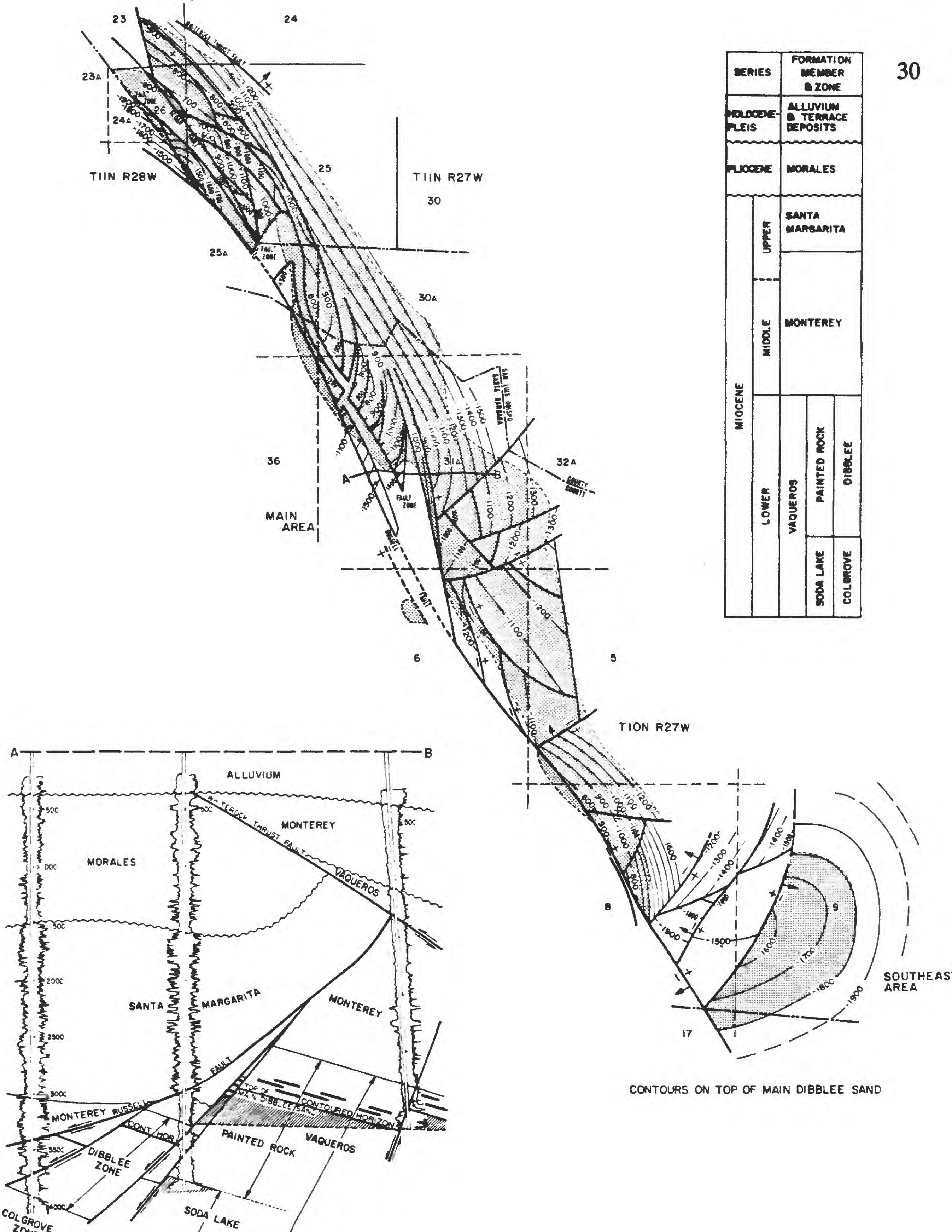


Figure 7B. Cross section and contour map of the Main area of the Russell Ranch oil field (Cuyama district), showing the faulted homoclinal trap. From California Division of Oil and Gas (1991).

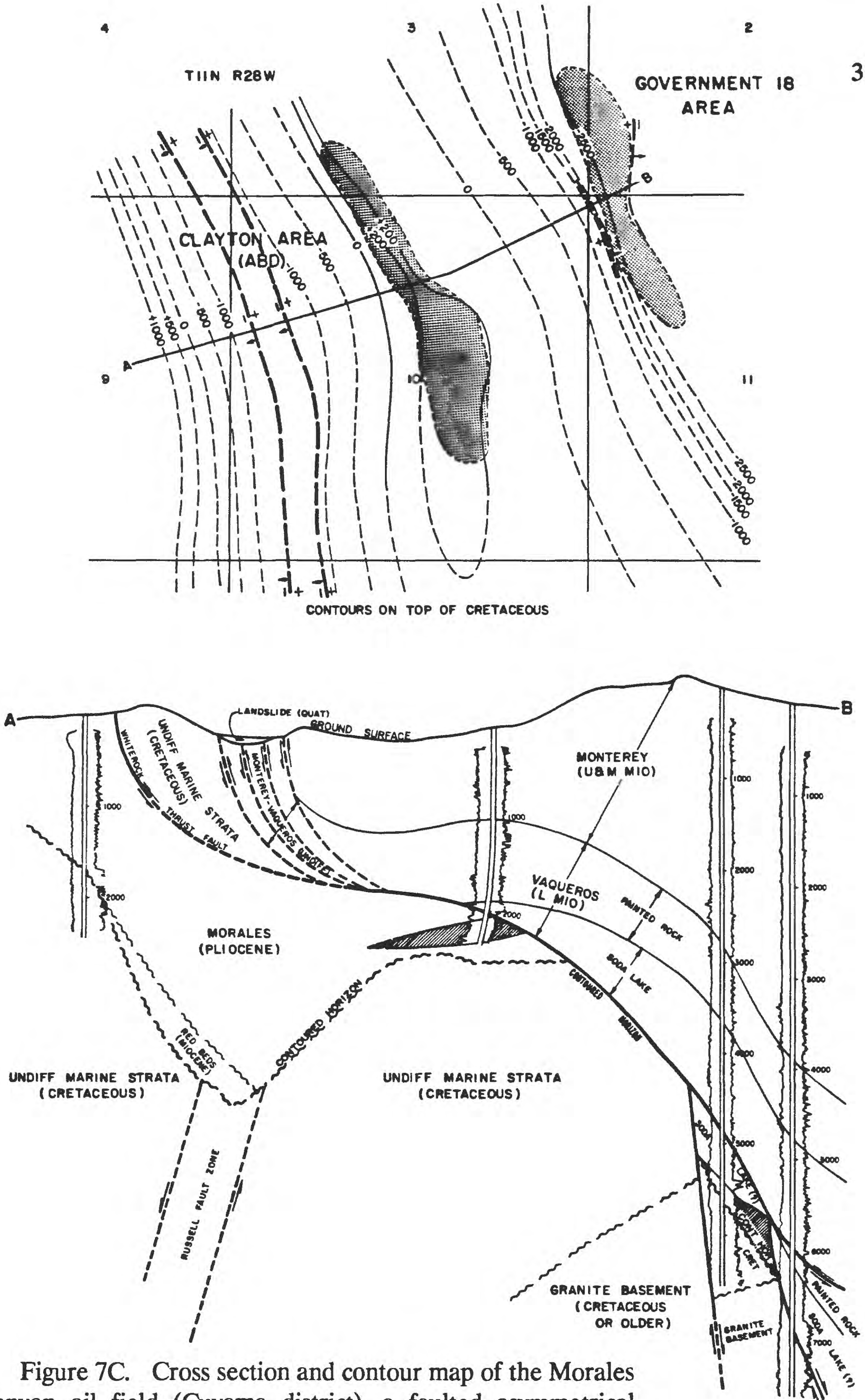


Figure 7C. Cross section and contour map of the Morales Canyon oil field (Cuyama district), a faulted asymmetrical anticline. Note the reservoirs in deep subthrust positions. From California Division of Oil and Gas (1991).

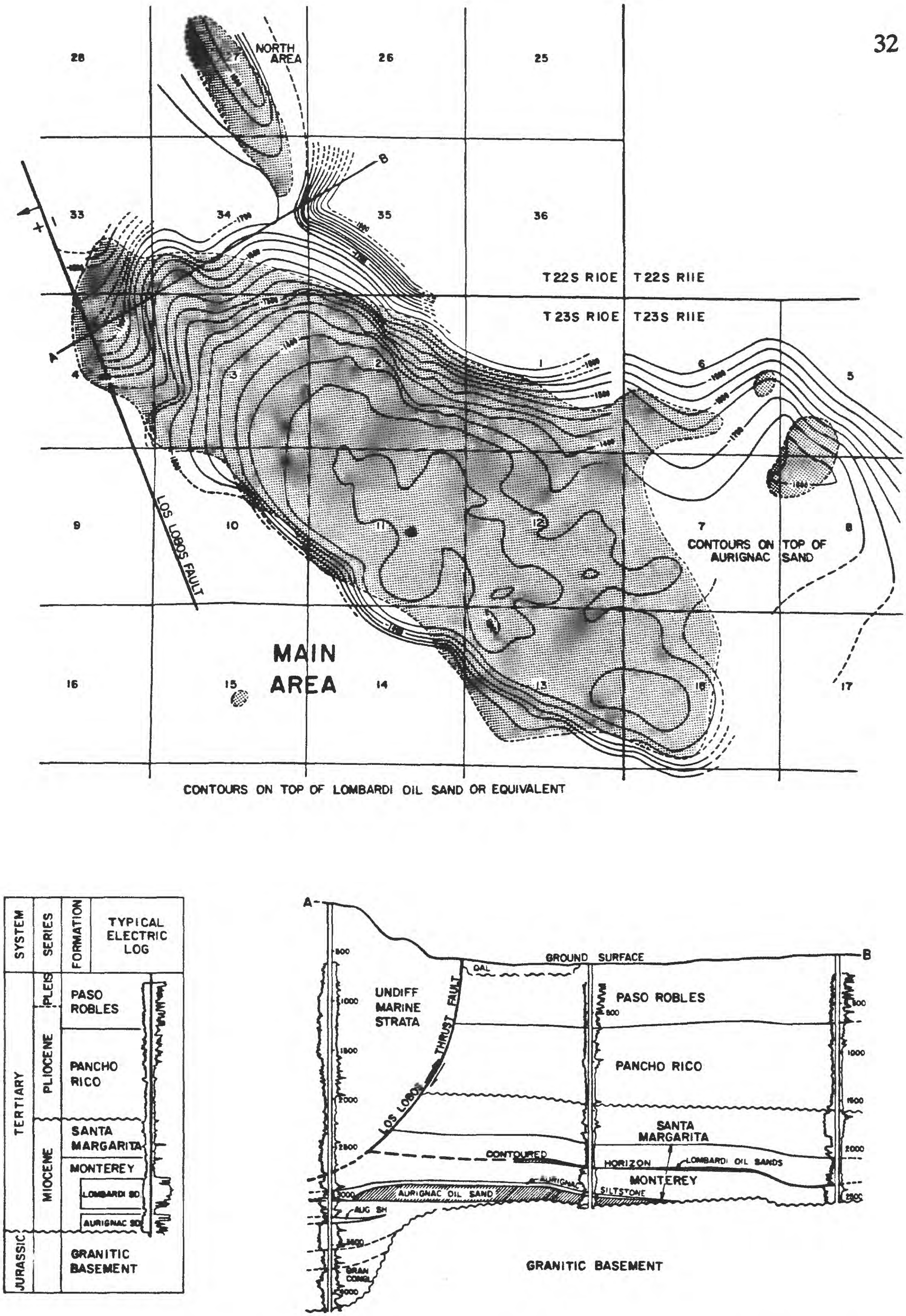


Figure 7D. Cross section and contour map of the Main area of the San Ardo oil field (Salinas district), showing the anticlinal trap with stratigraphic variations. From California Division of Oil and Gas (1991).

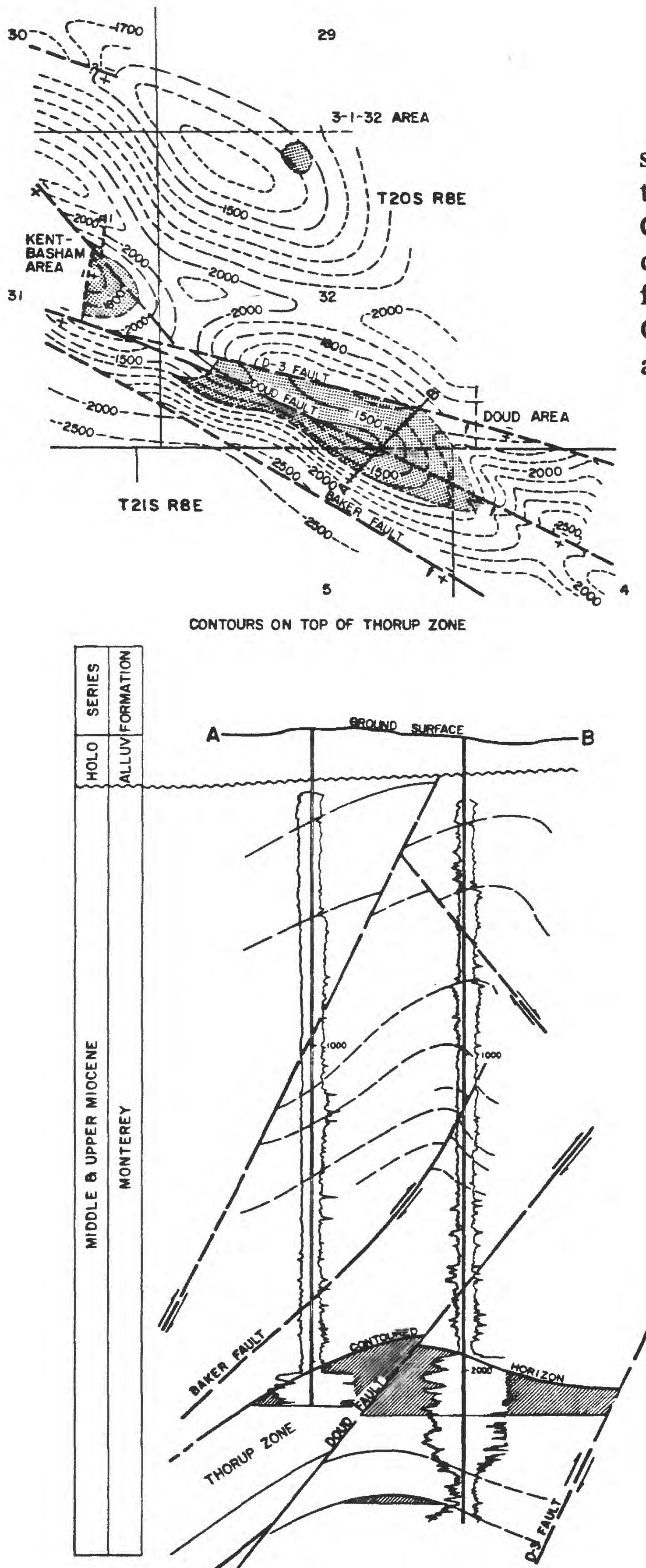


Figure 7E. Cross section and contour map of the Doud area of the King City oil field (Salinas district), showing the faulted dome trap. From California Division of Oil and Gas (1991).

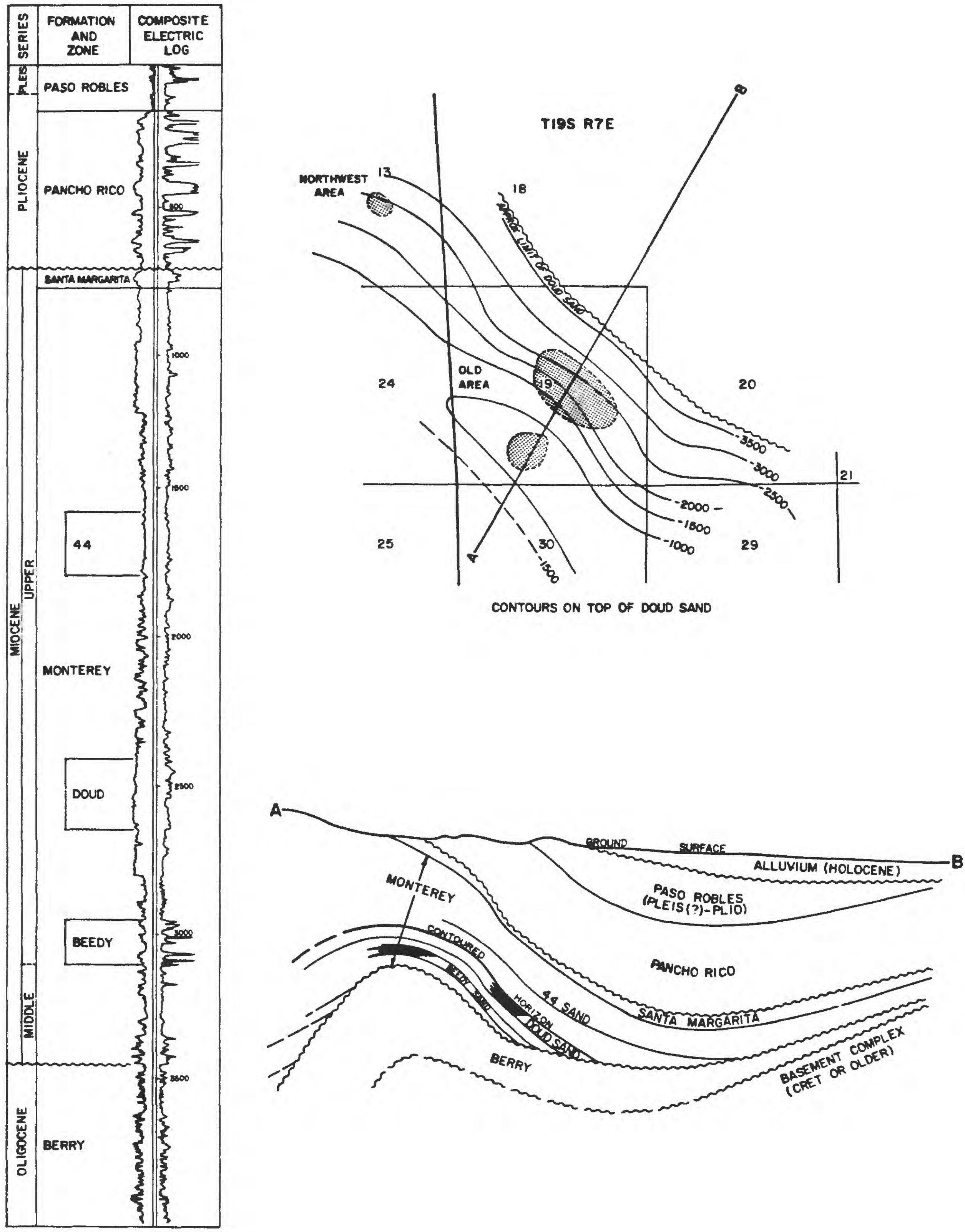


Figure 7F. Cross section and contour map of the Monroe Swell oil field (Salinas district). The trap in this field is due to permeability barriers on the anticlinal fold. From California Division of Oil and Gas (1991).

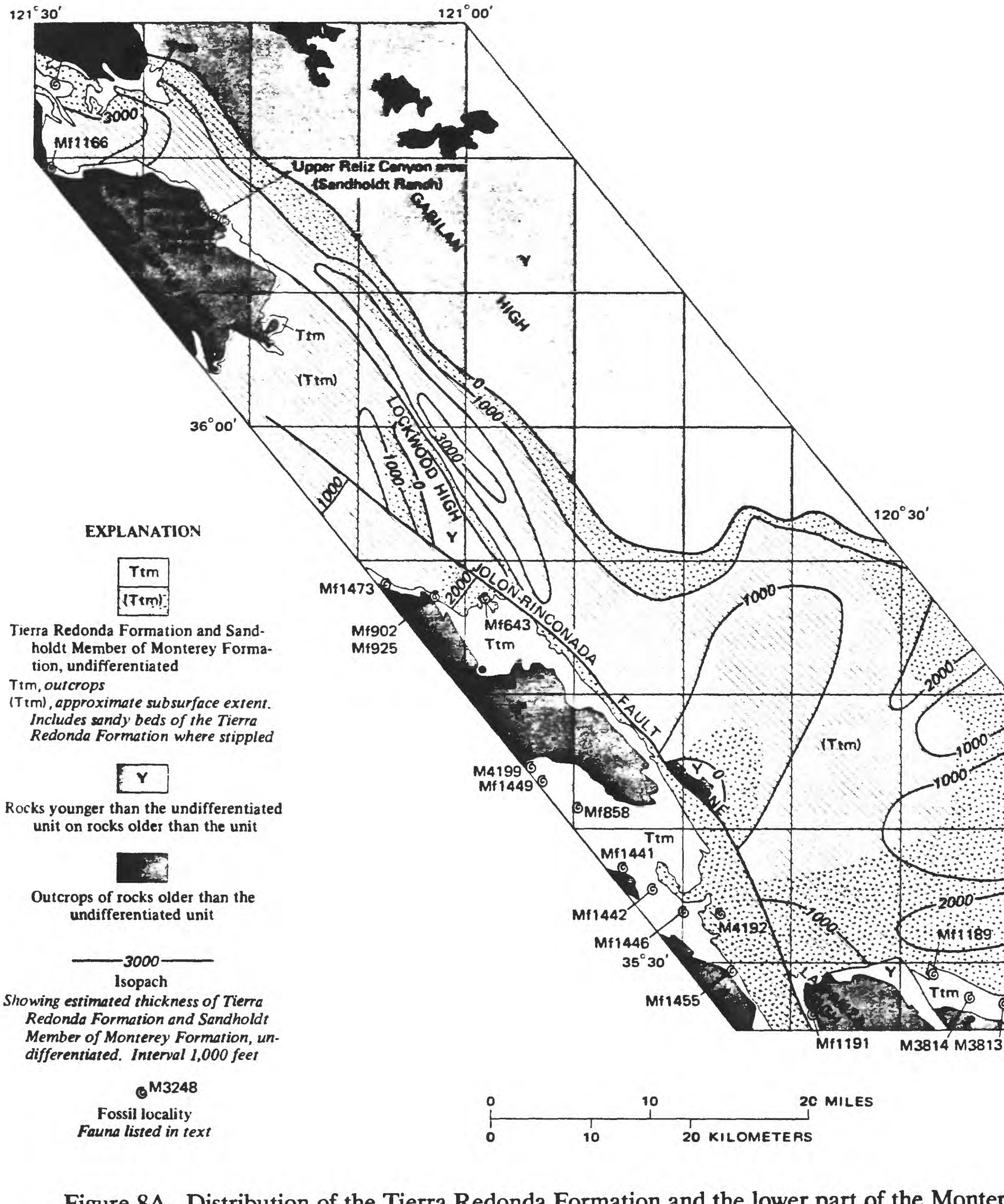


Figure 8A. Distribution of the Tierra Redonda Formation and the lower part of the Monterey Formation (Sandholdt Member) undifferentiated. Stippled areas indicate sandy beds in the Tierra Redonda Formation. From Durham (1974).

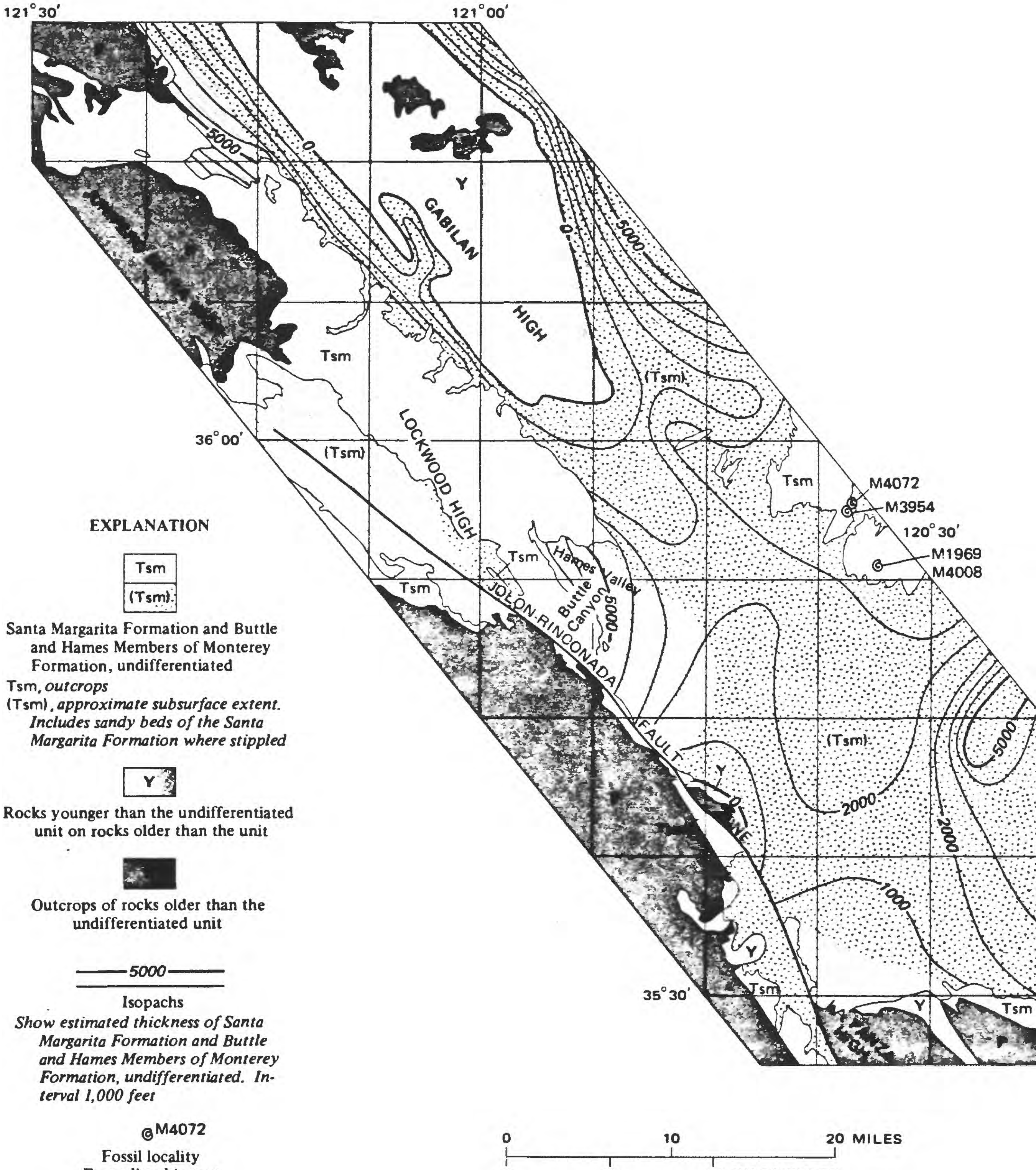


Figure 8B. Distribution of the Santa Margarita Formation and the upper part of the Monterey Formation (Hames and Buttle Members) undifferentiated in the southern Salinas Valley. Stippled areas indicate sandy beds in the Santa Margarita Formation. From Durham (1974).

Exploration status

History

Earliest discoveries in the assessment province were in the La Honda district, where oil was discovered in the small Half Moon Bay field (with cumulative oil production through 1983 of 0.05 Mbbl) in about 1890 and in the Moody Gulch field (0.1 Mbbl) in 1898.

Further discoveries were not made until the late 1940s and early 1950s. In the Salinas district, these were (with cumulative oil production through 1983) the small North area (0.3 MMbbl) of the San Ardo field, 1947; the Main area of the San Ardo field (376.0 MMbbl), 1948; the Biaggi area (<0.0005 MMbbl) of the Paris Valley field, 1948; and the Monroe Swell Field (0.2 MMbbl), 1949. In the Cuyama district, discoveries began with the Main area of Russell Ranch field (66.8 MMbbl) in 1948. All subsequent area and field discoveries in this district were made within 3 years: Main area of South Cuyama field (215.1 MMbbl), 1949; Clayton area of Morales Canyon field (1.0 MMbbl), 1950; Government 18 area of Morales Canyon field (1.4 MMbbl), 1950; Taylor Canyon field (0.5 MMbbl), 1950; Cuyama Central field (0.03 MMbbl), 1951; and Southeast area of South Cuyama field (0.1 MMbbl), 1951.

During the mid-late 1950s, minor discoveries were made in the La Honda district: Oil Creek field (0.2 MMbbl), 1955; Main area (0.8 MMbbl) of La Honda field, 1956; and South area (0.5 MMbbl) of La Honda field, 1959. Exploration in the Salinas district during the 1950's and 1960's also resulted in some small discoveries: Main area (0.1 MMbbl) of Paris Valley field, 1958; Doud area (1.8 MMbbl) of King City field, 1959; Kent-Basham area (0.1 MMbbl) of King City field, 1961; Lynch Canyon field (0.1 MMbbl), 1962; Quinado Canyon field (0.01 MMbbl), 1963; Doud 3-1-32 area of King City field (0.002 MMbbl), 1963; and McCool Ranch field (0.1 MMbbl), 1964.

During the 1970's and early 1980's, discoveries made in the Cuyama district were the East area of the South Cuyama field (1975) and a new gas pool in the Southeast area of South Cuyama field (1981). In the Salinas district was discovered the E sand pool in the McCool Ranch field (1981).

Future potential

Future resource potential in the assessment province seems likely to be fair to good, mainly in the less well-explored parts of the Salinas and Cuyama districts, with discovery of another giant field in the Salinas district the most promising possibility. Baldwin (1971) placed remaining potential new reserves at 2.5 Bbbl for the assessment province as a whole, 2 Bbbl for the Salinas district.

In terms of future potential, important features of the Salinas district include proven oil generation in significant quantities, a wide areal extent of thick subsurface sequences of Neogene sedimentary rocks likely to represent oil sources, and trap types (stratigraphic variations on slight structural highs) that are difficult to identify. However, future reserves would probably be difficult to find due to the difficulty of interpreting the complexities of stratigraphy and structure concealing potential traps (Baldwin, 1971). Suggested exploration targets have included sandstone traps in the Vaqueros Formation on Miocene-Pliocene structures westward of the Neogene basin center (Baldwin, 1971) and the underexplored margins of basement highs where Miocene sandstones are present (Durham, 1974; Figures 8A, 8B). Fractured reservoirs or diagenetic traps within the Monterey Formation may also have future potential. A number of prospect wells were drilled during the 1980s, notably in the deep Hames Valley area with fractured-reservoir and diagenetic-trap potential, but results had not been announced at the time of the assessment.

In the Cuyama district, potential prospects seem most likely to be similar to existing fields but in deeper locations that have been difficult to identify, for example deep traps in concealed subthrust sandstone reservoirs. However, reservoir quality (sandstone permeability) may be a limiting factor in more deeply buried strata. Baldwin (1971) also suggested that uplifted areas northeast and southwest of the central overthrust graben were underexplored.

Future potential in the La Honda district seems generally poor and further drilling unlikely to produce significant new reserves, based on the long history of exploration resulting in only minor discoveries. Offshore prospects in the assessment province are likewise not highly promising, based on the paucity of discovered resources in adjacent onshore areas.

ACKNOWLEDGMENTS

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Table 1. Oil field data for the Central Coastal Basins assessment province, based on Nehring data base through 1983 (NRG Associates, 1984).

BASIN / Field	Trap type	Formation	Average Depth to top (ft)	Average Thickness (ft)	Average API Gravity	Disc'y Year	Cumulative prod'n + reserves Oil (MMbbl)	NGL (MMbbl)	Gas (Bcf)
CUYAMA BASIN									
South Cuyama – Main area	Structural	Vaqueros	3600	520	33	1949	220.0	9.9	215.6
Morales Canyon – Clayton area	Structural	Morales	1900	100	31	1950	1.0	–	0.5
Morales Canyon – Govnt 18 area	Combination	Vaqueros	5800	400	38	1950	1.4	–	1.3
Russell Ranch – Main area	Structural	Vaqueros	2800	600	37	1948	67.3	2.0	46.8
Russell Ranch – Southeast area	Structural	Vaqueros	3600	70	39	1952	0.7	0.1	3.1
SALINAS BASIN									
San Ardo	Combination	Lombardy	2000	150	11	1947	525.0	–	71.4
		Monterey	2400	120	13				
King City – Doud area	Structural	Monterey	2000	100	16	1959	2.0	–	0.1
AVERAGE			3013	258	27	1951	117	2	48
TOTAL							817	12	339

Table 2. Cumulative production + reserves in small fields not included in the Nehring data base (NRG Associates, 1984). Based on California Division of Oil and Gas (1984, 1986), see also Table 3.

BASIN Field	Cumulative production + reserves Oil (MMbbl)	 Gas (Bcf)
CUYAMA BASIN		
Taylor Canyon	0.49	0.14
South Cuyama – Southeast area	0.11	0.93
South Cuyama – East area (abd)	0.04	0.03
Cuyama – Central area (abd)	0.03	0.01
SALINAS BASIN		
McCool Ranch	0.35	<0.001
San Ardo – North area	0.31	–
Monroe Swell	0.27	0.003
Parris Valley	0.14 *	<0.001
Lynch Canyon	0.12	<0.001
King City – Kent–Basham area	0.11	<0.001
Quinado Canyon	0.01	0.003
King City – Doud 3–1–32 area	0.002	–
LA HONDA BASIN		
La Honda – Main area	0.80	0.11
La Honda – South area	0.52	0.04
Oil Creek	0.19	0.08
Moody Gulch (abd)	0.10	0.04
Half Moon Bay	0.05	0.02
TOTAL	3.639	1.406

* Reserves not included.

Table 3. Oil field data for Central Coastal Basins assessment province (from California Division of Oil and Gas, 1974, 1984).

BASIN / FIELD / AREA / Pool	Pool Disc'y Date	Cumulative production Oil (MMbbl)	Cumulative production Gas (Bcf)	Trap Type	Average Reservoir Depth (ft)	Average Reservoir Thickness (ft)	Pool API gravity
CUYAMA BASIN							
SOUTH CUYAMA							
MAIN AREA		215.1	221.2	Faulted anticline	1830	35	26
52-1 Gas (Santa Margar	1953				3600	400	33
Dibblee (Vaqueros)	1949				4300	120	33
Colgrove (Vaqueros)	1950						
SOUTHEAST AREA		0.1	0.03	Faulted homocline			
Colgrove (Vaqueros)	1951				5840	50	37
RUSSELL RANCH		66.8	46.9				
MAIN AREA		66.1	43.8	Faulted homocline			
Santa Margarita	1948				2500	200	25
Dibblee (Vaqueros)	1948				2800	350	34
Griggs-Dibblee (Vaquer	1949				4300	150	38
Colgrove (Vaqueros)	1949				3500	100	35-40
SOUTHEAST AREA		0.6	3.1	Faulted anticlinal nose			
Dibblee (Vaqueros)	1952				3600	70	39
MORALES CANYON		2.4	1.8	Faulted asymmetrical anticline			
CLAYTON AREA (abd)		1.0	0.5				
Clayton (Morales)	1950				1900	100	31
GOVERNMENT 18 AREA		1.4	1.3				
Government 18 (Vaquer	1950				5800	400	38
TAYLOR CANYON		0.5	0.1	Faulted nose			
Quail Canyon sand (Vaq	1950				5620	200	38
CUYAMA CENTRAL		0.03	0.01	Faulted homocline			
Branch Canyon	1951				7360	20	46

BASIN / FIELD / AREA / Pool	Pool Disc'y Date	Cumulative production Oil (MMbbl)	Cumulative production Gas (Bcf)	Trap Type	Average Reservoir Depth (ft)	Average Reservoir Thickness (ft)	Pool API gravity
SALINAS BASIN							
SAN ARDO		376.0	71.4				
MAIN AREA		375.7	71.4	Anticline			
Lombardi (Monterey)	1948				2000	150	11
Aurignac (Monterey)	1948				2400	120	13
NORTH AREA							
Lombardi (Monterey)	1947	0.31			2100	40	10
KING CITY		1.9	0.06				
DOUD AREA		1.8	0.06	Faulted dome			
Thorup (Monterey)	1959				2000	100	16
DOUD 3-1-32 AREA		0.002	<0.001	Sand lens on a dome			
Thorup (Monterey)	1963				1860	30	13
KENT-BASHAM AREA		0.11	<0.001	Faulted nose			
Thorup (Monterey)	1961				2450	65	17
McCOOL RANCH		0.13	<0.001	Sands overlap onto basement			
Lombardi (Monterey)	1964				2150	30	12
MONROE SWELL		0.24	0.003	Permeability barriers on			
44 (Monterey)	1960			anticlinal fold	2000	200	19
Doud (Monterey)	1959				2900	200	19
Beedy (Monterey)	1949				3200	150	17
PARIS VALLEY		0.13					
BIAGGI AREA		<0.0005		Anticline			
Basal Ansberry (Montere	1948				1090	70	13
MAIN AREA		0.13	<0.001	Faulted anticline			
Basal Ansberry (Montere	1958				710	80	12
LYNCH CANYON		0.13	<0.001	Dome on basement high			
Lanigan (Monterey)	1962				1800	55	10
QUINADO CANYON		0.01	0.003	Faulted nose			
Gamboa-Kelly (Montere	1963				2035	60	19

BASIN / FIELD / AREA / Pool	Pool Disc'y Date	Cumulative production Oil (MMbbl)	Cumulative production Gas (Bcf)	Trap Type	Average Reservoir Depth (ft)	Average Reservoir Thickness (ft)	Pool API gravity
LA HONDA BASIN							
LA HONDA		1.3	0.15				
MAIN AREA	1956	0.79	0.11	Anticline			
Upper Costa (Butano)					1660	45	40
Lower Costa (Butano)					1800	30	40
SOUTH AREA		0.50	0.04	Nose (?)			
Burns	1959				1400	60–180	17
OIL CREEK	1955	0.18	0.08	Faulted nose			
Tony (Butano)					1860	55	41
Costa (Butano)					2090	120	41
MOODY GULCH (abd)		0.10	0.04	Fold on flank of steeply inclined			
San Lorenzo	1898			monocline	800	40	45
HALF MOON BAY (abd)		0.05	0.02	Anticline and homocline, accumulation			
Purisima	ca 1890			in updip lenses.	800		45

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