UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Summary of Geology and Petroleum Plays Used to Assess Undiscovered Recoverable Petroleum Resources,

San Joaquin Basin Province, California

By Larry A. Beyer[1] and J. Alan Bartow[2]

Open-File Report

87-450Z

[1]U.S. Geological Survey, 345 Middlefield Rd., MS 999, Menlo Park, CA 94025
[2]U.S. Geological Survey, 345 Middlefield Rd., MS 975, Menlo Park, CA 94025

1988

TABLE OF CONTENTS

ILLUSTRATIONS

INTRODUCTION

During 1987 the Geological Survey conducted an assessment, using a play analysis, of the undiscovered recoverable petroleum resources of the San Joaquin province, California, as part of a national assessment (Mast and others, 1988). This report describes the petroleum plays identified for that assessment, and briefly summarizes the geology and petroleum development of the San Joaquin province[1]. For purposes of this assessment, the San Joaquin province of central California includes the area west of the basement rocks of the Sierra Nevada, north of the basement rocks of the Tehachapi-San Emigdio Mountains, east of the San Andreas fault and outcrops of Franciscan rocks of the Diablo Range, and, arbitrarily, south of the Stanislaus-San Joaquin county line (fig. 1).[2] As defined above, the San Joaquin province covers about 37,000 km^2 (14,000 mi^2), and contains about 126,000 km^3 (30,000 mi^3) of sedimentary rock (Varnes and Dolton, 1982). It is about 360 km (225 mi) long, and averages 90 km (55 mi) wide.

The San Joaquin basin, essentially coincident with the San Joaquin province, is an asymmetrical structural trough, filled with up to 9,000 m (29,500 ft) of Upper Mesozoic and Cenozoic sediments, whose axis is parallel to and near its western margin (pl. 1). This trough is a hybrid feature, its northern portion developed as part of a Late Mesozoic forearc basin, and its southern portion developed during the Cenozoic, with some overlap toward the north and a transform rifted western margin.

GEOLOGICAL SUMMARY

Previous Work

The San Joaquin basin is one of the more thoroughly studied basins in the U.S., and many important studies of the basin and its tectonic setting have been published. Some of the more important studies of broad scope include Hoots and others (1954), Repenning (1960), Callaway (1964), Hoffman (1964), Hackel (1966), Bandy and Arnal (1969), Callaway (1971), Harding (1976), MacPherson (1978), Zieglar and Spotts (1978), Ingersoll (1979), Dickinson and Seely (1979), Webb (1981), Williams and Graham (1982), Blueford (1984), Graham (1985, 1987), Graham and Williams (1985), Bartow (1987a,b), Nilsen (1987), and Callaway and Rennie (1988). Many more areally or topically restricted studies are given in the reference section, including many not cited in this paper. Recent summary papers by Bartow (1987b) and Callaway and Rennie (1988) provide

---

[1]The geological summary through the Basin Evolution section is condensed from Bartow (1987b) with some supplemental information from other sources. The geological map (pl. 1), generalized structure sections (pl. 2), and paleogeographic maps and stratigraphic columns (pl. 3) also are from Bartow (1987b).

[2]The northern geological limit of the San Joaquin basin commonly is defined at the Stockton fault on the northern edge of the Stockton arch (fig. 1). However, gas acccumulations and resources north of the Stanislaus-San Joaquin county line and south of the Stockton fault are assigned to the Sacramento province in the recently completed petroleum assessment.

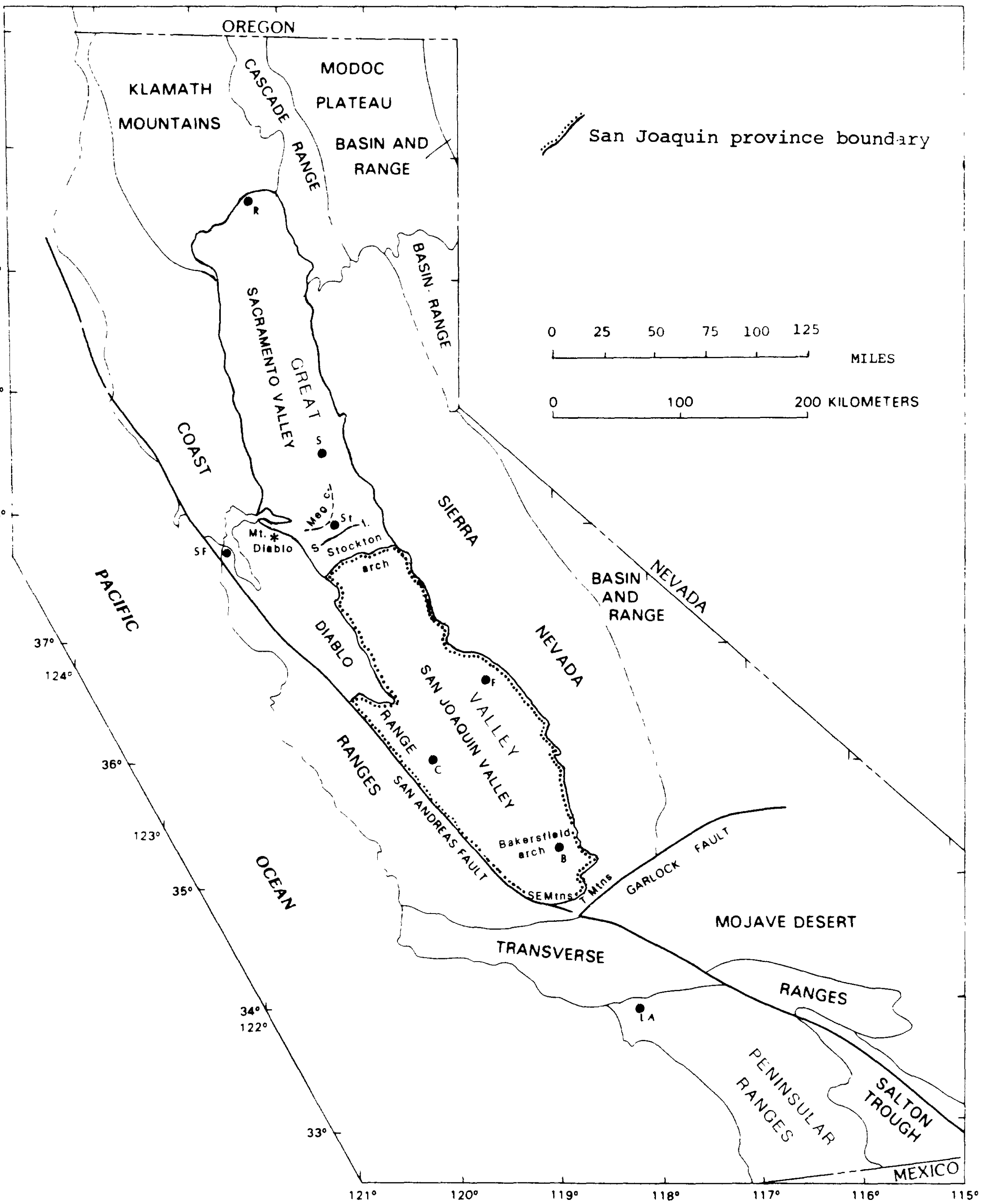

Figure 1. Location of San Joaquin province, principal California geomorphic provinces and cities, and other features mentioned in text. LA = Los Angeles, T Mtns = Tehachapi Mountains, SE Mtns = San Emigdio Mountains, B = Bakersfield, C = Coalinga, F = Fresno, Sf. = Stockton fault, St = Stockton, Meg C. = Meganos canyon, SF = San Francisco, S = Sacramento, and R = Redding.

excellent overviews. The following geological summary is taken substantially, though not exclusively, from Bartow (1987b).

Plate and Regional Tectonic History

Late Mesozoic

The San Joaquin basin occupies approximately the southern half of the Great Valley of California (fig. 1). During late Mesozoic and early Cenozoic time, the Great Valley was part of an extensive forearc basin developed in a convergent-margin setting by eastward subduction of oceanic crust beneath the western edge of North America (e.g., Dickinson and Seely, 1979). This forearc basin received sediment from the Sierra Nevada arc massif to the east and later also from an archipelago of uplifted subduction complex (Franciscan assemblage) to the west as it evolved from a terraced forearc basin in Late Jurassic to a shelved forearc basin by early Tertiary (Ingersoll, 1978, 1979; Dickinson and Seely, 1979).

Many thousands of meters of Upper Jurassic to lowest Tertiary marine sandstone, siltstone, and shale--the Great Valley sequence--were deposited in this forearc basin. These rocks underlie the northern three-quarters of the San Joaquin basin, and may be as thick as 5,100 m (16,700 ft) near Coalinga. The Great Valley sequence apparently is absent in the subsurface south of the Bakersfield arch (fig. 1), and is not found in outcrop around the southern margins of the province. These rocks, if originally present in this part of the province, were removed by erosion in pre-middle Eocene time.

Paleogene

The Paleogene history of the San Joaquin basin was dominated by a tectonic regime resulting from the continued presence of a subduction zone lying along the continental margin to the west. Oblique subduction with a northerly to northeasterly convergence direction during Late Cretaceous and early Tertiary (Engebretson and others, 1985) apparently produced a north-south compressive stress and a right-lateral shear couple in the western part of the continent in the early Paleogene (Page and Engebretson, 1984). Consequences of this early Paleogene stress regime were:

(1) Right-lateral slip on faults southwest of the basin that dismembered the southwest part of the Late Mesozoic forearc basin, moved the exotic Salinia terrane northwestward into position opposite the south end of the basin, and produced a continental borderland of small wrench-fault basins there (Nilsen and Clarke, 1975; Graham, 1978; Dickinson and others, 1979).

(2) Uplift of the Stockton arch, thought by Bartow (1987b) to be a simple, south-side-up, tilted fault block that formed during the early Paleogene in response to north-south compressive stress.

(3) Possibly, the development of the large Vallecitos syncline, Joaquin Ridge anticline, and White Creek syncline, apparently of the right age and orientation to have originated as an en echelon fold set associated with right slip (Harding, 1976). Early Paleogene fold growth might also be considered an indication of thrusting associated with early eastward movement of a Franciscan wedge at depth (Bartow, 1987b).

(4) Possibly, the oroclinal bending or rotation of the southern Sierra Nevada suggested by Kanter and McWilliams (1982) and McWilliams and Li (1985), at least part of which may have taken place during the Paleocene. This orocline might also be considered a tectonic effect of the accretion of the Tujunga terrane (part of the Salinia composite terrane) to the North American craton in the Mojave region near the end of the Paleocene (Howell and others, 1987; Nilsen, 1987).

Right-lateral strike-slip movement is generally believed to have ceased by about the end of the Paleocene (Nilsen and Clarke, 1975; Dickinson and others, 1979). Inasmuch as oblique subduction at the central California margin continued until nearly the end of the Eocene, strike-slip movement could conceivably have continued well into the Eocene, although the evidence is equivocal. Near the end of Eocene time, uplifts represent the beginning of tectonic activity that continued into the Oligocene and probably reflected the approach of the Pacific-Farallon spreading ridge and the transition from oblique to normal subduction (Engebretson and others, 1985).

The Oligocene marked the onset of tectonic change throughout the western United States. Following the change in convergence direction near the end of the Eocene, the angle of subduction steepened during the Oligocene (Page and Engebretson, 1984). This led to changes in the patterns of volcanism (Snyder and others, 1976) and to the initiation of extension in the Basin and Range Province (Zoback and others, 1981), which may have produced compression in the region between the Basin and Range and the trench. Continued uplift of the Stockton arch in the northern part of the basin, with concurrent movement on the Stockton reverse fault, was presumably subduction related.

The approach of the ancestral East Pacific rise to North America and subduction of young buoyant lithosphere somewhat in advance of the actual arrival of the spreading center at the subduction zone in mid-Oligocene time (Nilsen, 1984; Crowell, 1987) seems to have been responsible for the uplift and faulting of the southern end of the basin, particularly the San Emigdio Mountains and southernmost Sierra Nevada (Davis, 1983, 1986). At the southern end of the basin, at least for the later Oligocene, the tectonism was part of a major uplift extending throughout much of southern California in response to the ridge-trench encounter (Nilsen, 1984).

When the East Pacific rise encountered the subduction zone in mid-Oligocene, paired triple junctions formed and moved away from one another along a northwest-southeast transform (Atwater and Molner, 1973; Engebretson and others, 1985). The northwestward-moving junction, called the Mendocino triple junction, passed by the San Joaquin basin on the west approximately during the Miocene epoch (Snyder and others, 1976; Johnson and O'Neil, 1984), trailing a system of right-lateral subparallel faults that together constituted the boundary between the North American and Pacific plates (Garfunkel, 1973; Dickinson and Snyder, 1979; Graham, 1978).

Neogene and Quaternary

Neogene tectonism and evolution of the San Joaquin basin were controlled at first by the tectonic effects of the northwestward migration of the Mendocino triple junction along the California continental margin and later by wrench tectonism associated with the San Andreas fault system (Dickinson and Snyder, 1979; Page and Engebretson, 1984). Extension in the Basin and Range Province east of the Sierra Nevada was an important contributing factor to crustal shortening and consequent east-west compressional tectonism along the west side of the basin.

The effects of Mendocino triple junction passage were first recorded at about 23-24 Ma at the south end of the basin with east-west-oriented normal faulting and subsidence, probably beginning in the latest Oligocene, and volcanism in the early Miocene, both indicative of north-south extension (Davis, 1986; Hirst, 1986). The unstable configuration of the migrating triple junction (trench and transform not colinear) induced a wave of extensional tectonism and local volcanism in nearby regions (Dickinson and Snyder, 1979; Ingersoll, 1982; Johnson and O'Neil, 1984; Fox and others, 1985). At 15-17 Ma regional uplift in the southern part of the basin also seems to have been associated with passage of the triple junction, and may have been related, in some way, to the presence under the basin of the subducted Mendocino fracture zone (Loomis and Glazner, 1986). Continued subsidence after the uplift may have been augmented by thermal decay of the subducted plate.

Evidence from the provenance and distribution of Miocene sandstone in the Temblor Range (Graham and others, 1986) and of en echelon folding that appears on the west side of the basin at about the end of Saucesian time (about 16-18 Ma) (Harding, 1976) suggests that strike slip may have begun by 17-18 Ma on the central California portion of the San Andreas fault. This is consistent with the fault offset history of Huffman (1972). En echelon folding on the west side of the basin, beginning near the end of the early Miocene and continuing into the Pliocene, was a manifestation of a newly established northwest-southeast oriented shear couple centered on the San Andreas fault system (Harding, 1976).

Acceleration in the slip rate on the San Andreas fault in latest Miocene (10-12 Ma) and Pliocene time (Huffman, 1972; Graham, 1978) seems to correspond to increased folding eastward from the fault zone (Harding, 1976). Progressive basinward expansion of the fold belt, together with cessation of folding near the San Andreas while folding continued farther east, suggested to Harding (1976) that the folds and the San Andreas fault were independent responses to a diffuse coupling in the deep crust, and that the folds propagated outward in an expanding deformational front. The fact that younger folds, like the Kettleman Hills and Lost Hills anticlines, are approximately parallel to the San Andreas and not en echelon to it is an indication that they are not purely a response to shear in the San Andreas system. The explanation for the basinward expansion of the Kettleman Hills-Lost Hills part of the fold belt now seems to be that it has formed in response to an eastward-advancing thrust front at depth associated with the emplacement of a wedge of Franciscan at the base of the Great Valley sequence (Wentworth and others, 1983) (pl. 2A,B).

Extension in the Basin and Range Province again had an effect on the San Joaquin basin in Miocene time. Basin and Range faulting began in the late Miocene, probably about 10 Ma (Zoback and others, 1981), and left-lateral movement on the Garlock fault is assumed to have begun at about the same time. This resulted in the westward movement of the Sierra Nevada block, carrying the San Joaquin basin with it, and the consequent formation of the bend in the San Andreas fault (Davis and Burchfiel, 1973; Hill, 1982; Bohannon and Howell, 1982). The space problem arising from this westward movement is probably the cause of compression at the west side of the Sierran block (Wentworth and Zoback, 1986).

The last major uplift of the Sierra Nevada is also believed to have begun after 10 Ma (Christensen, 1966; Huber, 1981), but the uplift and the westward movement of the Sierra block, due to Basin and Range Province extension, are probably not directly related. It has been suggested that the late Cenozoic uplift of the Sierra Nevada was caused by thermal thinning of the lithosphere after northward passage of the Mendocino triple junction (Crough and Thompson, 1977; Mavko and Thompson, 1983). Uplift of the Sierra Nevada was accompanied by north-south-oriented normal faulting that, where observed in the east-central San Joaquin basin, indicates minor east-west extension. The Diablo uplift and the eruption of volcanic rocks in the Diablo Range during late Miocene are closely associated with the passage of the Mendocino triple junction (Johnson and O'Neil, 1984). These events seem to indicate compression, presumably oriented northeast-southwest, followed immediately by minor local extension in a developing northwest-southeast shear regime.

At 5 Ma near the Miocene-Pliocene boundary the motion of the Pacific plate changed to a more northerly direction, resulting in a component of compression normal to the San Andreas transform (Minster and Jordan, 1984; Page and Engebretson, 1984; Cox and Engebretson, 1985). This change in plate motions, together with the westward movement of the Sierran block as a result of extension in the Basin and Range Province (Eaton, 1979), caused northeast-southwest compressive stress along the west side of the Sierran block that is largely responsible for increased late Neogene deformation, including deep-seated thrust faults along the western part of the San Joaquin basin (Wentworth and Zoback, 1986). Strong north-south compression at the south end of the basin, probably due in part to transpression across the San Andreas fault in Pliocene and Pleistocene time, together with compression related to the developing bend in the fault, were probably the principal factors leading to northward-directed thrusting in the San Emigdio Mountains at the south end of the basin. The increased loading of the south end of the basin by thrust plates might be, in turn, responsible for the accelerated subsidence of the Maricopa-Tejon subbasin in the latest Pliocene.

The most unambiguous evidence of continuing Holocene tectonism is seismicity, most notably the 1952 M_L 7.2 Arvin-Tehachapi and the 1983 M_L 6.5 Coalinga earthquakes. The 1952 Arvin-Tehachapi earthquake was centered on the White Wolf fault (Oakeshott, 1955; Stein and Thatcher, 1981), and the oblique slip during that event, reverse slip plus a left-lateral component, is evidence of an existing north-south to northeast-southwest compressive stress at the south end of the valley. The 1983 Coalinga earthquake occurred on a northeast-verging thrust fault under the Coalinga anticline (Eaton, 1985b), and may be related to folding and thrusting along the entire western margin of the Central Valley (Wentworth and Zoback, 1986). Coseismic uplift of up to 45 cm (18 in) associated with the Coalinga earthquake (Stein, 1985) demonstrates the continuing growth of young anticlines at the west side of the valley. Lower-level seismicity that has been recorded from several areas in the San Joaquin Valley collectively indicates north-south to northeast-southwest compression (La Forge and Lee, 1982; Eaton, 1985a, Wong and Ely, 1983; Wong and Savage, 1983; Zoback and others, 1987).

Structural Setting and Stratigraphy

The San Joaquin province can be subdivided somewhat arbitrarily into five regions on the basis of generally different structural style. They are the northern Sierran block, the southern Sierran block, the northern Diablo homocline, the west-side fold belt, and the combined Maricopa-Tejon subbasin and south-margin deformed belt (fig. 1). Considerable stratigraphic variation exists within the sedimentary basin, particularly in the Neogene, when a thick section of marine sediment accumulated in the south, while a relatively thin and entirely nonmarine section was deposited in the north.

Northern Part of Sierran Block

The northern part of the Sierran block, the stable east limb of the trough between the Stockton fault and the San Joaquin River, is the least deformed region of the province. Deformation consists mostly of a southwest tilt, probably beginning in late Miocene or Pliocene, and continuing through the Quaternary at an accelerating rate, with only minor late Cenozoic normal faulting.

Few faults have been recognized in the subsurface of the northern part of the San Joaquin Valley; the largest, the east-trending Stockton fault, bounds the Stockton arch on the north just outside the province (pl. 1). The Stockton fault is a south-dipping reverse fault that trends transversely to the regional structure. The fault appears to have had a complex history, but has a total down-to-the-north dip slip of up to 1,100 m (3,610 ft), most of which occurred during the Oligocene (Hoffman, 1964; Teitsworth, 1964; Bartow, 1985). A possible west-northwest-trending fault in the Merced-Chowchilla area is based mostly on the apparent offset of the post-Eocene unconformity (Bartow, 1985).

The Stockton arch is evident principally as an area where Paleogene and uppermost Cretaceous Great Valley strata have been truncated beneath Neogene strata (Hoots and others, 1954). There is little evidence of arching in overlying Tertiary units (Bartow, 1985), and no evidence of basement arching (Bartow, 1983) (pl. 2D). This structure probably formed initially in the latest Cretaceous or Paleocene, perhaps by local thickening of the Cretaceous section, with a major period of uplift in the Oligocene. The structure existed as a low-relief positive feature through most of the Paleogene.

The stratigraphy of the Modesto-Merced area (pl. 3, col. 3) is typical of the northeast side of the valley; farther west, the stratigraphy resembles that of the Orestimba Creek area on the west side of the valley (pl. 3, col. 1). Over the Stockton arch (pl. 1), Paleogene strata are absent, and nonmarine later Tertiary strata rest directly on the Mesozoic Great Valley sequence (Church and Krammes, 1958; Bartow, 1985). The Cenozoic deposits in this part of the valley are relatively thin (about 1,100 m) (3,600 ft), whereas the underlying Great Valley sequence may be over 3,000 m (9,840 ft) thick (Hoffman, 1964) (pl. 2A).

Southern Part of Sierran Block

The southern Sierran block, the stable east limb of the trough between the San Joaquin River and the south side of the Bakersfield arch, is similar in style to the northern part of the block, but with a higher degree of deformation. Miocene or older normal faults, that apparently are mostly in the Bakersfield arch, trend mostly north to northwest, and have a net down-to-the-west displacement with individual offsets of as much as 600 m (1,970 ft).

The southwest to west tilt of the Sierran block increases southward so that dips on outcropping Tertiary units in the Bakersfield area average 4-6° in contrast to the 1-2° dips in the north (pl. 2). Truncation of Cretaceous and various Cenozoic strata indicates a tilt event prior to the middle Eocene in the southern, as well as the northern, Sierran block, some tilting near the end of the Oligocene, and accelerating uplift and tilt of the Sierran block beginning in the late Miocene.

Normal faults along the east side of the valley are concentrated in the area of the Bakersfield arch, a broad southwest-plunging ridge of basement rocks. These faults generally trend northwest to north, although a secondary west to west-northwest trend is apparent (pl. 1). The net displacement is down to the southwest, although down-to-the-northeast faults are present (Bartow, 1984). One of the principal faults of this group is the Kern Gorge fault, along which basement rocks to the southwest have been downdropped more than 600 m (1,970 ft). Faulting appears to die out northwestward along the east edge of the valley, due in part to the fact that Quaternary deposits overlap the Tertiary strata onto the basement rocks about 65 km (40 mi) north of Bakersfield.

Many subsurface faults have been inferred by various workers in the area west of the Tertiary outcrop belt. Most of these seem to be small faults with a predominant northwest trend, and have been recognized only where oil-well density is sufficient for delineation of faults. The Pond fault and Greeley fault system are, however, major structures. The Pond fault, actually a zone of subparallel southwest-dipping normal faults up to 2 km wide (1.2 mi) with down-to-the-southwest offsets that decrease upward from a maximum of over 500 m on the basement surface, apparently joins the Poso Creek fault to the southeast (Los Angeles Department of Water and Power, 1975).

The buried Greeley fault system consists of an en echelon set of northwest-trending normal faults with the basement surface downdropped on the northeast as much as 615 m (2,017 ft). Offsets decrease markedly upward so that there is no apparent offset of strata younger than late Miocene (Los Angeles Department of Water and Power, 1975). The Greeley fault system is paralleled on the southwest by a series of short low-amplitude folds that have their strongest expression in early Miocene and older strata. In addition to the normal faults involving basement rocks, a number of syndepositional growth faults formed during late Miocene sedimentation in the area west of Bakersfield (MacPherson, 1978).

In contrast with the northern part of the block where the normal faulting was mostly late Cenozoic in age, normal faulting appears to have been mostly Miocene or older in the southern block. Faults with a general north-south trend (NW-SE to NNE-SSW), and those, such as the Poso Creek fault, with a general east-west trend (E-W to ESE-WNW), seem to be similar in that offset decreases upward. In general, north-south-trending faults were active in the early Tertiary, and again beginning in the late Miocene. East-west-trending faults may have had their origin in the latest Oligocene and early Miocene like those at the south end of the basin, as will be shown in a later section, and were probably active until about the late Miocene. There are few faults on the north side of the Bakersfield arch that offset Quaternary deposits.

From the northern Sierra block along cross section DD', Mesozoic deposits thin southeastward and pinch out or are truncated against the north flank of the Bakersfield arch, whereas Cenozoic strata reach a thickness of more than 4500 m at the Bakersfield arch (pl. 2). Aggregate thickness of Mesozoic and Cenozoic sedimentary deposits is more than 5,000 m (16,400 ft) in the area south of Tulare Lake. The stratigraphy of the Bakersfield arch area (pl. 3, col. 9) is typical of the southern part of this area. The Cenozoic stratigraphy in the subsurface of the Hanford-Tulare area (pl. 3, col. 6) probably has elements of both the Bakersfield arch area to the south and the Kettleman hills area to the west.

Northern Diablo Homocline

The northern Diablo homocline, the western limb of the trough between the Stockton arch and Panoche Creek, consists of a locally faulted homocline with northeast dips. Deformation was mostly late Cenozoic, complex in its history, and has included up-to-the-southwest reverse faulting (pl. 1).

The present Diablo Range is principally a product of Neogene tectonism, although there is some evidence that the northern Diablo Range existed as a positive area as far back as the Paleogene (Clarke and others, 1975; Nilsen and Clarke, 1975; Bartow and others, 1985). The relations between the Paleogene Diablo uplift and Stockton arch are unclear, but Neogene structures in the northern Diablo Range appear to have been superimposed on the older positive areas.

Late Mesozoic and Cenozoic rocks of the northern Diablo Range form a northeast-dipping homocline in which the dips of the Tertiary strata generally range from 30° to 50° (pl. 2). Subordinate structures are principally faults, but folds associated with the Vernalis and Black Butte faults occur near Tracy at the west end of the Stockton arch, and a small anticline near Patterson produces a local reversal of dip in the homocline. Near Gustine, the dips of Tertiary strata flatten abruptly to 10° or less to the northeast of a northwest-southeast-trending fault.

The principal Cenozoic faults or fault zones of the northern Diablo homocline are (1) the Black Butte fault, a northwest-southeast-trending reverse fault west of Tracy that has been active as recently as Pleistocene (Raymond, 1969); (2) the Vernalis fault, a subsurface reverse fault that parallels the Black Butte fault, trends at right angles to the Stockton fault near its west end, and has been active during or since Miocene (Bartow, 1985); (3) the San Joaquin fault zone, which lies along the west edge of the valley, has offset Quaternary depositional surfaces, and probably is a series of reverse faults (Bartow, 1985); and (4) the Tesla-Ortigalita fault zone, the western boundary of the Diablo homocline and the present boundary between the Franciscan Complex and the Great Valley sequence. The Tesla-Ortigalita fault is a zone of high-angle faults with a down-to-the-east displacement of many thousands of meters, is locally a southwest-dipping reverse or thrust fault (Briggs, 1953), and has influenced Cenozoic regional tectonics since, perhaps, early Paleogene (Page, 1981).

The stratigraphy of the Orestimba Creek area and the Los Banos-Oro Loma area (pl. 3, cols. 1 and 2) are representative of the Diablo homocline.

Approximately 1,400 m (4,600 ft) of Cenozoic deposits in that area thin northwestward toward the Stockton arch, mostly through truncation of the marine older Tertiary units (Hoffman, 1964; Hackel, 1966; Bartow and others, 1985).

West-Side Fold Belt

The west-side fold belt, the southwest part of the valley trough between Panoche Creek and Elk Hills and including the Temblor and southeastern Diablo Ranges, is characterized by a series of folds and faults trending slightly oblique to the San Andreas fault (pl. 1). Paleogene folds occur in the northern part of the belt; however, most folding was in Neogene time with the intensity of deformation increasing southeastward along the belt and southwestward toward the San Andreas fault.

The northernmost fold in the west-side fold belt is the Vallecitos syncline, located just south of Panoche Creek. The southeastern boundary of the fold belt is arbitrarily placed east and south of Elk Hills where the fold trends change from northwest-southeast to east-west. The east boundary deviates from the valley trough axis near Cantua Creek and south of Kettleman Hills to include the subdued Turk, Buttonwillow, Bowerbank, and Semitropic anticlines that lie east of the valley axis, but which are structurally more akin to the west-side fold belt than to the relatively less deformed southern Sierran block.

The intensity of deformation increases southeastward along the fold belt, as well as southwestward across the belt toward the San Andreas fault (pl. 1). The increased intensity is evidenced by tighter folds and an increased number of reverse and thrust faults (Vedder, 1970; Dibblee, 1973a). Thrust faults seem to be predominantly west dipping, although the faulting in the interior of the Temblor Range is complex.

Deflection of the shaleout line of the subsurface, lower Eocene Gatchell sand (of local usage) around the down-plunge end of the Joaquin Ridge and Coalinga anticlines in the northern part of the fold belt provides evidence of a structure that probably formed in the Paleocene or early Eocene (Harding, 1976). Paleogene deformation is difficult to identify in the south, however, because of the deep burial of Paleogene rocks and the strong overprint of Neogene deformation. Harding (1976) outlined the Neogene development of the fold belt in relation to the history of strike slip on the San Andreas fault. The first en echelon folds in the Temblor Range or southern part of the fold belt date from the late early Miocene, whereas the easternmost anticlines in the fold belt (Buttonwillow, Bowerbank, and Semitropic) are entirely Pleistocene in age (pl. 1). The age of faulting in the fold belt is not well controlled, but eastward-verging thrust faults seem to have formed relatively late in the deformation history in the more tightly folded area near the San Andreas fault (Harding, 1976), and are still active at the western margin of the valley. Recent thrust-fault-generated earthquakes at Coalinga anticline (May 1983) (Eaton, 1985b) and Kettleman Hills (August 1985) (Wentworth, 1985) are evidence of thrusting beneath major west-side folds, and are an indication of the style of Holocene deformation along the fold belt (Wentworth and others, 1983; Wentworth and others, 1984; Namson and Davis, 1984; Medwedeff and Suppe, 1986).

The structures of the west-side fold belt cumulatively record north-south to northeast-southwest compression through the Cenozoic. For the early Paleogene and most of the Neogene, this compression was apparently manifested as a northwest-southeast shear couple. A tendency for Pliocene and Pleistocene structures to be oriented more parallel to the San Andreas fault indicates an increasing component of compression normal to the fault in the latest Cenozoic (Zoback and others, 1987).

Stratigraphic columns for four separate areas--the Vallecitos syncline, Kettleman Hills north dome, Lost Hills-Devils Den area, and Elk Hills area (pl. 3, cols. 4,5,7,8)--provide some indication of the variation within the west-side fold belt. Total thickness for the combined Mesozoic and Cenozoic section may be over 9,500 m (31,200 ft) near the San Joaquin Valley trough axis. As with the southern Sierra block part of the valley, there is a northward-thinning trend for the Cenozoic (pl. 2) and, particularly for the Neogene, a northward trend toward shallower marine and nonmarine facies. Middle Tertiary deposits representing some of the deepest water depths in the San Joaquin basin are found in the southern Temblor Range. Older rocks are not as well known in the southern part of the area because of the absence of outcrops and the sparsity of drillholes that reached Paleogene strata.

Maricopa-Tejon Subbasin and South Margin Deformed Belt

The Maricopa-Tejon subbasin and the south margin deformed belt are structurally distinct, but genetically related, regions bounded by the Bakersfield arch on the north, the San Emigdio Mountains on the south, the Tehachapi Mountains on the east, and the southeast end of the west-side fold belt on the west (pl. 1). This region has experienced several kilometers of crustal shortening in the late Cenozoic (Davis, 1983) through north-directed thrust faulting at the south margin, as well as extreme Neogene basin subsidence north of this thrust belt.

Structural trends are variable in this part of the San Joaquin basin, but there is a general east-west trend along the south margin of the basin. The trends of the west-side fold belt change to west-northwest--east-southeast where that region merges with the deformed belt at the south end of the valley. The folds and faults of the San Emigdio Mountains form a northward-directed salient with an average east-west fold trend.

Most of the deformation of the San Emigdio Mountains, including uplift and folding, is a late Cenozoic event, and is directly related to thrust faults of the Pleito fault system (Davis, 1986). These thrusts date only from the Pliocene, and, based on the first appearance of coarse detritus in the basin to the north, most of the uplift was late Pliocene and Pleistocene (Davis, 1986). Although the basin continued to subside through the Miocene, subsidence accelerated in the Pliocene (Davis, 1986; Hirst, 1986).

Normal faults with an average east-west trend, but ranging from northwest-southeast to northeast-southwest, occur mainly in the subsurface at the south margin of the basin (Hirst, 1986; Davis, 1986). These faults were active during the latest Oligocene and early Miocene concurrent with volcanism and basin subsidence (Turner, 1970; Hirst, 1986; Davis, 1986). The mostly east-west-trending Edison normal fault with down-to-the-north offset of over 1,500 m (4,900 ft), as well as other normal faults of general east-west trend in this region of the basin, were also active at this time (Dibblee and Chesterman, 1953; Bartow, 1984).

The White Wolf fault, which was the locus of the M_L 7.2 Arvin-Tehachapi earthquake of July, 1952, is a southeast-dipping oblique-slip reverse fault (Oakeshott, 1955; Stein and Thatcher, 1981). Total vertical separation on the basement surface has been at least 3,600 m (11,800 ft) (Stein and Thatcher, 1981) or possibly more than 4,600 m (15,100 ft) (Davis, 1983). Although the early history of the White Wolf fault is uncertain, subsurface stratigraphic evidence suggests it originated during the late Oligocene-early Miocene period as a down-to-the-northwest normal fault and in Pliocene reversed its motion (Davis, 1986).

The western part of the Maricopa-Tejon subbasin contains the thickest Cenozoic deposits in the San Joaquin basin. Neogene and Quaternary strata are more than 6,100 m (20,000 ft) thick at the Paloma oil field and more than 6,900 m (22,600 ft) thick in the Tenneco Oil Company "Tenneco-Superior-Sand hills" 64X well located about 7 km (5 mi) north-northeast of Mettler where Davis and Namson (1987) believe the entire sedimentary section may be 9,000 m (29,500 ft) thick. Eocene strata rest on basement rocks in the San Emigdio Mountains and at South Coles Levee oil field at the west end of the Bakersfield arch (Church and Krammes, 1957), but no wells have reached basement in the intervening area. The thickness of Paleogene strata in the central part of the deep is not known, but more than 1,750 m (5,700 ft) of Paleogene is present in the outcrops in the near San Emgidio Mountains on the south side of the basin (pl. 3, col. 10), and a greater thickness might be present downdip to the north. There are no known Cretaceous or Paleocene deposits south of the Bakersfield arch.

Paleobathymetries recorded in the middle Tertiary deposits of the Maricopa-Tejon subbasin are the deepest found in the San Joaquin basin. Abyssal depths (>1,800 m) (>5,905 ft) were reached during Oligocene time, and continued through middle Miocene (Bandy and Arnal, 1969). Paleogene nonmarine deposits occur on the east and southeast, and the basin gradually shallowed through the late Neogene, and became entirely nonmarine in latest Pliocene time.

Basin Evolution

The evolution of the San Joaquin basin is traced through a series of paleogeographic maps that show the thickness of Cretaceous sediments at the beginning of the Tertiary, subsequent gradual restriction of the marine basin through uplift and emergence of the northern part in the late Paleogene, closing off of the western outlets in the Neogene, and final sedimentary infilling in the latest Neogene and Quaternary (pl. 3). The nine Cenozoic paleogeographic maps were constructed for relatively narrow time slices of the Tertiary, shown as stippled bands on the correlated stratigraphic sections (pl. 3). The paleogeography was compiled from published maps and modified to agree with more recent stratigraphic and sedimentologic data. In many cases where data are sparse or even nonexistent, the maps represent the interpretations and biases of the author (Bartow). See Bartow (1987b) for more details.

The late Paleocene paleogeographic map (pl. 3) shows the transgressive phase of the upper Paleocene and lower Eocene depositional sequence. The northern and eastern parts of the basin were occupied by a marine shelf; deeper marine slope and basinal facies were restricted to the southwest. An upland, probably of low relief, lay to the northeast, and the shelf and slope were largely open to the ocean on the west. Uplift of the Stockton arch produced a broad west-trending peninsula between the San Joaquin and Sacramento basins. It is not known how much of the arch was exposed at this time because later erosion has removed Paleocene strata, but it is assumed that some shallow or nearshore marine deposition took place over the west end of the arch. Stratigraphic relations in the Mt. Diablo area suggest an emergent area south of the Meganos canyon (fig. 1). At the south end of the basin, the first stages of the oroclinal bending of the southern Sierra Nevada had produced a westward deviation of the southeast-trending shoreline, and left the future Bakersfield arch and the Maricopa-Tejon subbasin area emergent.

A major regression, separating two basinwide depositional sequences, affected the basin at the end of lower Eocene. The combined effects of tectonism and eustatic sea-level change resulted in broad fluctuations in the shoreline, and produced major changes in paleogeography. Tectonic activity included uplifts in the Diablo Range area in late early and late Eocene, and possibly in the San Emigdio Range area near the end of the Eocene. The early to middle Eocene paleogeographic map shows the effect of the major regression that occurred at the end of the upper Paleocene-lower Eocene depositional sequence, largely as a result of eustatic lowering of sea level that left the marine basin greatly restricted (pl. 3). Based on recent interpretations of facies patterns, large deltas are inferred to have prograded westward across the basin from the central Sierra Nevada, which was the principal source of Eocene sediment (Slagle, 1979).

The middle Eocene paleogeographic map shows the effect of the maximum transgression for the entire Tertiary which was reached at middle Eocene time (pl. 3). Widespread pelagic sediments indicate that most of the present San Joaquin Valley was covered by deep marine waters, and the basin was largely open to the west, as it had been in the Paleocene. A large deep-sea fan was constructed in the southwestern part of the basin, which had its source and proximal part on the Salinia terrane west of the present San Andreas fault (Clarke, 1973; Clarke and Nilsen, 1973). The east side of the basin was fringed by a relatively extensive belt of fluvial and deltaic deposits. The regressive phase of the Eocene depositional sequence near the end of the Eocene is recorded in the northern part of the basin and at the south end, while deep-water deposition continued in the central part.

The Oligocene paleogeographic map shows the situation at the time of maximum regression in the middle Oligocene (pl. 3). The entire northern half of the basin was emergent through the Oligocene, while deep-water sedimentation continued from the Eocene into the Oligocene in the southwest. The Stockton fault was active, the Stockton arch was being eroded, and alluvium was deposited to the north and to the south of the arch. The Diablo Range, and probably the northern Temblor Range areas, were emergent, and deep-marine deposition was restricted to the southwest part of the formerly extensive basin. A narrow fringe of nonmarine deposits lay along the east side of the marine embayment, while coarser alluvial fan deposits, derived from uplifts to the south, accumulated along the south and southeast margin of the basin.

Paleogeographic changes took place at a faster pace during the Miocene, particularly adjacent to the developing San Andreas fault system. Marine deposition was restricted to the southern part of the basin and extensive nonmarine deposition began in the north. The early Miocene paleogeographic map shows a marine embayment similar to the Oligocene embayment (pl. 3). The northern Temblor Range area that was briefly exposed at mid-Oligocene time was inundated in the early Miocene, as it had been in the late Oligocene, and the early Miocene strand line advanced even farther eastward onto the southern Sierran block. Nonmarine deposition expanded northwestward as tuffaceous alluvial plain deposits covered the northern basin and Stockton arch areas. The last stages of the previously extensive coarse alluvial fan deposition occurred at the south end of the basin.

The paleogeographic map near the early Miocene-middle Miocene boundary shows uplift of the southern part of the basin that produced a regression there as alluvial fan and fan delta deposits prograded basinward (pl. 3). Farther north, however, there was a transgression as the strand line advanced northwestward onto the Diablo uplift in the Coalinga area and in the Vallecitos syncline. The initiation of wrench tectonism on the southwest side of the basin resulted in uplifts in the adjacent Salinia terrane and nonmarine deposition in the southern Diablo Range area.

Following the early to middle Miocene regression, the marine embayment expanded to its Neogene maximum extent, coincident with a middle Miocene high stand of sea level. Marine deposits of late Middle Miocene age reach as far north as Chowchilla (70 km (44 mi) northwest of Fresno). The basin axis at that time seems to have been considerably farther east than the present axis, probably because uplift of the southern Diablo Range and consequent sediment influx from the west forced the northern basin axis to the east. In the deep southern part of the basin, extensive deep-sea fan deposits were derived from sources to the east, the south, and the southwest.

As shown on the paleogeographic map of late Miocene (pl. 3), the northward movement of the Salinia terrane, composed of isolated highs surrounded by shallow seas (Graham, 1978) west of the San Andreas fault, was beginning to close off the San Joaquin basin along its west margin. A new seaway had opened through the Priest Valley area west and northwest of Coalinga, but there was no longer a deep marine outlet to the Pacific Ocean. The deep-marine embayment was becoming more restricted as shallow-marine shelf deposits and nonmarine deposits prograded basinward along the east side of the basin. The late Miocene regression culminated in the southern part of the basin with a widespread unconformity (pl. 3). Coarse alluvial fan sedimentation along the southeastern margin of the basin in the latest Miocene marks the beginning of the accelerated late Neogene uplift of the Sierra Nevada.

Neogene tectonic activity around the San Joaquin basin increased in intensity in the Pliocene, leading to the elimination of the marine embayment by the close of the Pliocene. The San Andreas fault had become the principal element of the transform system by the beginning of the Pliocene (Graham, 1978), and the consequent increase in slip rates resulted in the Salinia terrane being moved rapidly northward to cut off the southwestern marine connection with the Pacific Ocean, as well as in increasing wrench tectonism along the fault zone.

The paleogeographic map for the Pliocene (pl. 3) differs significantly from the late Miocene map. The embayment is much smaller, and the basin, mostly brackish by this time, is enclosed on the south and southwest. Nonmarine deposits prograded into the shallowing embayment from all sides, and the now-emergent Salinia terrane was transported northwestward to completely close the marine outlet by about the end of the Pliocene. A developing uplift lay to the south of the basin, while the Maricopa subbasin immediately to the north was subsiding rapidly. A shallow seaway west of Coalinga connected the rapidly shallowing embayment with the Pacific Ocean.

By the beginning of the Pleistocene, the San Joaquin basin was entirely emergent. Uplift and westward tilting of the Sierra Nevada continued through the Pleistocene, while major deformation and uplift of the Coast Ranges, begun during the late Pliocene, also continued, including the southern part of the west-side fold belt being uplifted as the Temblor Range.

Heat Flow, Subsurface Temperatures and Pore-Fluid Pressures

Heat flow in the Coast Ranges to the west of the San Joaquin basin is higher than in the Sierra Nevada to the east, a fact that Lachenbruch and Sass (1980) attribute to the rapid eastward steepening of the subduction zone across central California where heat flux from basement rocks presumably decreases eastward beneath the San Joaquin basin. Heat flow within the basin generally is higher along the west side than in the central and eastern basin areas but everywhere is lower than in the Coast Ranges (Sass and others, 1971).

Generally, higher subsurface temperatures and temperature gradients occur along the western margin of the San Joaquin basin than in the central and eastern portions of the basin (French, 1939; Benfield, 1947; Hood and Castano, 1974; Wang and Munroe, 1982; Graham and others, 1982). Present-day temperature gradients are reported to range from about 22° C/km to about 36° C/km (1.21° F/100 ft to about 1.98° F/100 ft) (Ziegler and Spotts, 1978) and in water wells mostly from 20° C/km to 40° C/km (1.10° F/100 ft to 2.10° F/100 ft) (Wang and Munroe, 1982). The two published thermal gradient maps of the San Joaquin basin are disparate, suggesting further work is needed (American Association of Petroleum Geologists, 1975; Wang and Munroe, 1982).

The thermal history of the San Joaquin basin probably is complex because the basin evolved as part of the active margin of the North American plate. Present-day temperatures in the basin may not everywhere be historical maximum values due, for example, to changes in heat flux from below, uplift and removal of overburden or changes in fluid transport through the sedimentary section. Lachenbruch and Sass (1980) suggest that the broad positive heat flow anomaly extending southward from Cape Mendocino in northern California is a trailing effect of the northward migration of the Mendocino triple junction, which is believed to have passed by the San Joaquin basin during the Miocene. Miocene volcanism and its association with triple junction migration (Johnson and O'Neil, 1984) also suggest transient thermal events may have affected San Joaquin basin sediments. Actual evidence of a transient heating event in the vicinity of the North Tejon oil field in the Maricopa-Tejon subbasin comes from studies of laumontite crystallization, fission tracks in detrital apatites, and $^{40}Ar/^{39}Ar$ age spectrum of detrital microclines in core samples (McCulloh and Stewart, 1980; Naeser and others, 1988; Harrison and Be, 1983).

Similar data from other parts of the San Joaquin basin either do not exist or are not published.

High pore-fluid pressures, markedly greater than hydrostatic, have long been recognized in different parts of the San Joaquin basin by drillers and petroleum engineers. Berry (1973, 1980) systematically studied pore-fluid pressures in the Great Valley, derived mostly from extrapolation of shut-in pressure curves, and concluded that high pore-fluid potentials occur in a regional band along the western side of the valley. These high fluid pressures generally increase westward and with increasing depth, and approach the surface where overlying low-transmissibility rocks do, such as at the Lost Hills oil field (Berry, 1973, 1980).

Berry (1973) believed the high pore-fluid potentials were derived from the combined effects of gravitational compaction and local and regional compression of the very thick Great Valley sequence which expelled pore-waters, to the extent that transmissibility permitted, into the overlying Tertiary section. Pore fluids from the lower Tertiary section in the west-central part of the basin have been interpreted as membrane-effluent waters derived principally by compaction from underlying Cretaceous rocks (Berry, 1973; Kharaka and Berry, 1974). Berry (1980) attributes high pore-fluid pressures in the central syncline, generally east of the South Belridge oil field, and in the Maricopa-Tejon subbasin to thermal catagenesis of kerogen and aquathermal pressuring (Barker, 1972), the latter effect being enhanced by rapid subsidence and sedimentation during late Tertiary.

Yerkes and others (1985) assessed mud weights and pressure data from about 300 wells in the southwest part of the basin and concluded that abnormally high pore-fluid pressures exist generally below 3 km (1.9 mi) and probably are caused, in the southernmost San Joaquin basin where pre-Tertiary rocks are absent, by diagenetic/metamorphic reactions supplemented by compaction. Local pore-fluid pressure distributions undoubtedly are more complex, and generalizations can lead to overbalanced drill mud systems that may be detrimental to formation evaluation (e.g., Estill, 1980).

Petroleum Source Rocks

The Monterey and Kreyenhagen Formations are thought to be the principal source rocks for most oil and associated gas in the San Joaquin basin (Ziegler and Spotts, 1978; Graham and others, 1982; Clark and Clark, 1982; Kruge, 1983; Williams, 1984; Graham and Williams, 1985; Milam, 1985; Lampley, 1986; Graham, 1987). The Marca Shale Member of the upper Cretaceous Moreno Formation has been proposed as another possibly significant source rock in the northern part of the basin (McGuire, 1986; Lampley, 1986; Graham, 1987; McGuire, 1988). Fine-grained facies of the Oligo-Miocene Temblor and its eastern equivalents, although not abundant, may also be source rocks in some areas (Graham, 1985; Kuespert, 1985; Gillespie, 1986). Mesozoic rocks in the central and northern parts of the basin, and in the southern Sacramento basin, generally are less organic-rich, but, by virtue of their great thickness and type III kerogen, probably generated the dry gas reservoired in northern fields of the basin (Ziegler and Spotts, 1978; Larue and Underwood, 1986; Graham, 1987).

Today the abundance and type of kerogen in the Monterey Formation are known, partly by analogy with modern depositional systems (e.g., Ingle, 1981;

Williams and Reimers, 1983), to be controlled by depositional environment, proportion of terrestrially-derived organic and inorganic debris brought to the site of deposition and the biological productivity of the paleo-ocean (e.g., Graham and Williams, 1985; Williams, 1984). Low oxygen conditions, limited influx of terrestrial debris, and high marine planktonic and bacterial productivity have resulted in unusually rich, oil-prone upper Miocene source rocks generally distributed along the southwest, south-central, and south part of the basin (Graham and others, 1982; Graham and Williams, 1985; Williams, 1984; Kruge, 1983). To the east and north, stratigraphically equivalent source rocks are less organic-rich and more gas-prone because of a higher proportion of clastic debris and a preponderance of kerogen derived from terrestrial sources (Graham and Williams, 1985). Presumably, similar systematic variations occur in the source rocks of the Kreyenhagen, Moreno, and other formations, but published studies are lacking.

The richness and oil-versus-gas generative potential of San Joaquin basin source rocks is evident from measurements (made with immature to marginally mature samples) of total organic carbon and the abundance of hydrogen in the kerogen. Modified Van Krevelen diagrams show that (1) Monterey and Kreyenhagen source rocks are relatively hydrogen-rich, oil-prone, mostly Type II kerogen derived from marine plankton and bacteria; (2) Temblor source rocks possibly contain more terrestrially derived kerogen; and (3) Jurassic through Campanian source rocks are relatively hydrogen- and oxygen-depleted, mostly gas-prone Type III kerogen (Graham and Williams, 1985; Milam, 1985; Kuespert, 1985; Graham, 1987) (fig. 2). Total organic carbon and kerogen type are summarized for these source rocks and those of the Moreno Formation in Table 1. Additional data are needed to more fully characterize the source-rock potential of the Temblor, Kreyenhagen, Moreno, and pre-Moreno formations.

In a rudimentary way, hydrocarbon generation depends on the reconstruction of a time-temperature history of the source rocks and the concept of temperature windows within which oil or gas is generated (e.g., Waples, 1980). This approach was used by Zieglar and Spotts (1978) to construct burial history/hydrocarbon maturation diagrams (so-called Lopatin diagrams) for the eastern part of the Maricopa-Tejon subbasin, the central syncline east of the South Belridge oil field, and the delta area of the Sacramento basin that is located approximately 50 km (31 mi) northwest of the north boundary of the San Joaquin basin (fig. 3). These Lopatin diagrams were constructed by using present-day sedimentary rock thicknesses (Graham, 1987), a geothermal gradient of 2.72^{o} C/100 m (1.49^{o} F/100 ft), assumed constant over time, and sedimentation rates assumed to be fairly uniform over time within each age unit (Zieglar and Spotts, 1978). Based on these assumptions, oil generation began about 15 Ma in Eocene-Oligocene rocks in the eastern Maricopa-Tejon subbasin and about 5 to 6 Ma in lower Tertiary and Miocene rocks in the central syncline, generally east of the South Belridge field, and in Miocene rocks in the eastern Maricopa-Tejon subbasin (Zieglar and Spotts, 1978). Gas generation from Cretaceous source rocks in the delta area of the Sacramento basin (which may have sourced some of the northernmost gas fields of the San Joaquin basin) commenced about 70 to 80 Ma and in the central syncline of the San Joaquin basin about 55 Ma according to Zieglar and Spotts (1978).

Graham and Williams (1985) believe the assumed geothermal gradient used by Ziegler and Spotts (1978) is too high for the Mesozoic forearc basin and report that, based on analysis of outcrop samples, much of the Mesozoic

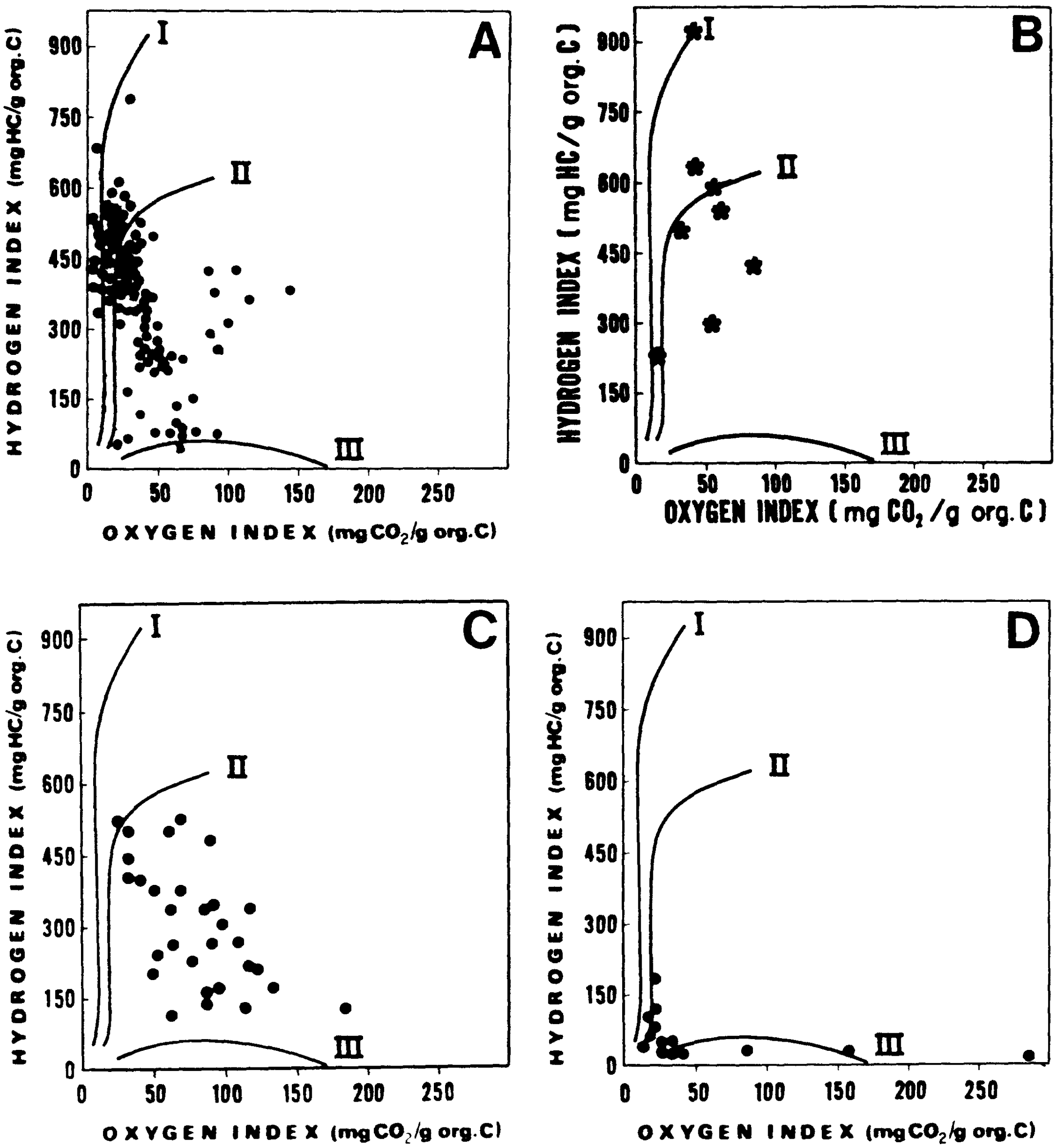

Figure 2.--Modified Van Krevelen diagrams that give the hydrogen versus oxygen richness of source rocks from the (A) middle Miocene through early Pliocene Monterey Formation (Graham, 1987; Graham and Williams, 1985), (B) Oligocene through middle Miocene Temblor Formation in the Kettleman North Dome oil field (Kuespert, 1985), (C) middle through late Eocene Kreyenhagen Formation (Milam, 1985; Graham, 1987), and (D) Jurassic through Campanian exposures west of Sacramento (Graham, 1987).

Table 1. Kerogen type and range of total organic carbon of studied source rocks of San Joaquin basin listed by formation

Formation	Age	Predominant Kerogen Types	TOC(wt.%)	Reference
Monterey	middle Miocene to early Pliocene	I,II	0.4 to 10.2	Kruge (1983); Graham and Williams (1985)
Temblor	Oligocene to middle Miocene	I,II	.8 to 4.1[a]	Kuespert (1985)
Kreyenhagen	middle to late Eocene	I,II	2 to 5[b]	Milam (1985); Graham (1987)
Moreno	late Maestrichtian to early Paleocene	II,III	as much as 7.25[c]	McGuire (1986, 1988)
Pre-Moreno	pre-late Maestrichtian	III	generally <1[d]	Zieglar and Spotts (1978); Graham (1987)

[a]Based on analysis of conventional core samples from Kettleman North Dome oil field. Gillespie (1986) also reports "organic-rich, silty shales" from outcrops of Temblor Formation near Capitola Park oil field in southernmost Temblor Range. There are no other studies published to support or deny the significance of fine-grain facies of the Temblor Formation as source rocks.

[b]Based on analysis of samples from three wells, one located 10 km south of Coalinga, one located 30 km northeast of Coalinga, and one located 10 km north of the South Belridge oil field (Graham, 1987).

[c]Based on analysis of samples from wells located from Coalinga northward.

[d]Based on analysis of Jurassic through Campanian samples taken from outcrops located west of Sacramento (Graham, 1987).

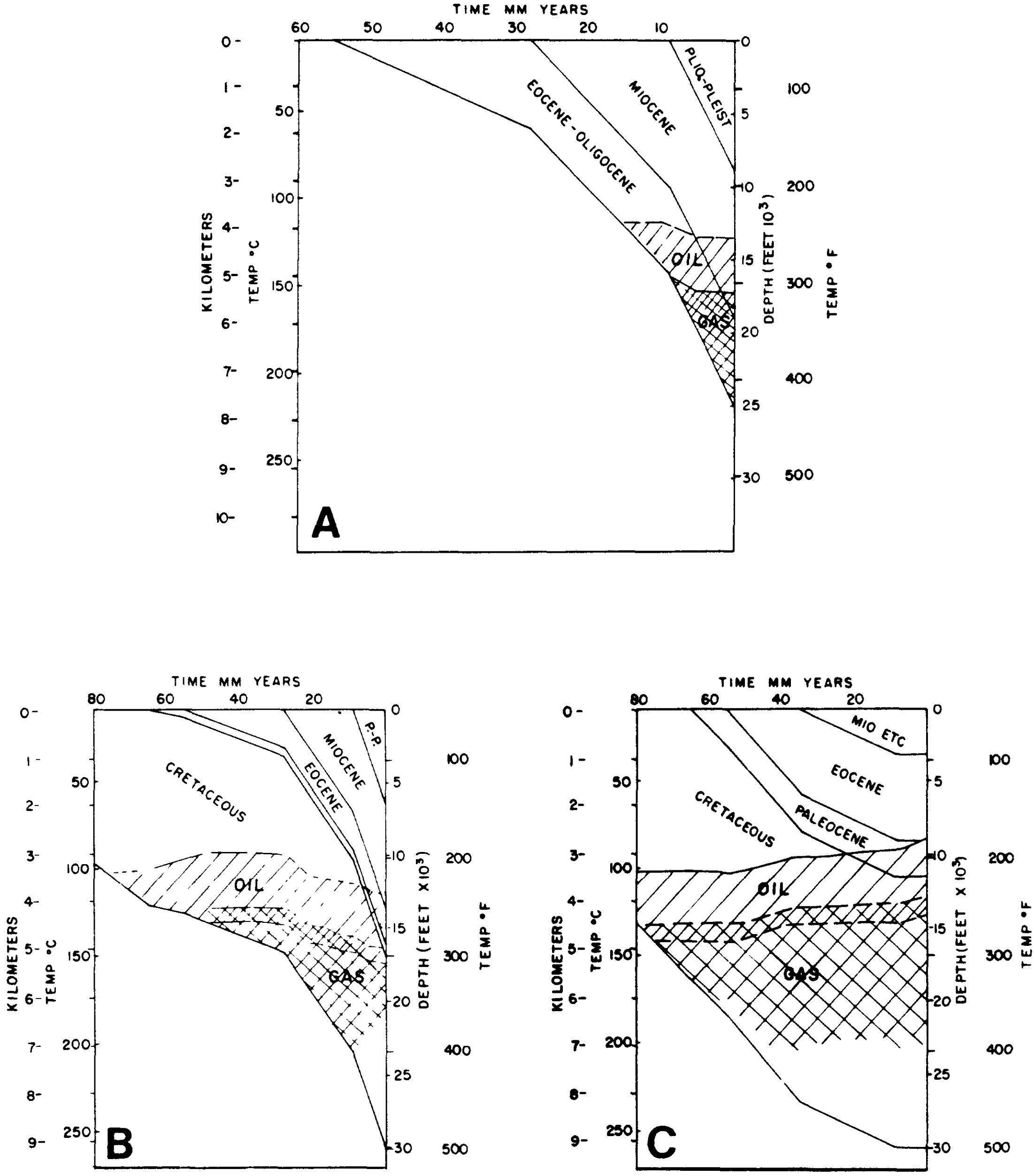

Figure 3.--Burial-history/petroleum maturation diagrams (Lopatin diagrams) for (A) eastern part of the Maricopa-Tejon subbasin, (B) central syncline east of the South Belridge oil field, and (C) delta area of the Sacramento basin (Zieglar and Spotts, 1978).

section resides in the "oil window" or is even immature; they conclude that gas origin is not necessarily thermogenic in the conventional sense, but must be related to gas-proneness of the kerogen. Graham and Williams (1985) also question the importance to hydrocarbon maturation of transiently high heat flow in the basin (due to triple junction migration) because of the possibility that high Miocene through Pleistocene sedimentation rates acted in opposition by depressing isotherms. Graham and Williams (1985, fig. 14) show the approximate distribution of source rocks of the upper Monterey Formation in the central syncline that are now oil-generative based on present depth of burial, present subsurface temperatures estimated from uncorrected bottom-hole log temperatures (Graham and others, 1982), and an oil-generating threshold temperature of 43° C (109° F).

Graham and Williams (1985) believe rocks of the Monterey Formation sourced the major oil accumulations in the central San Joaquin basin while the Kreyenhagen was the source of accumulations in the northern oil fields, such as the Coalinga, Helm, and Riverdale fields. Berry (1980) speculates that oil present in the Lost Hills anticlinal trend, especially in the Temblor Formation, was displaced northwestward to the present-day Kettleman North Dome and Coalinga Nose oil fields by extreme hydrodynamic conditions related to abnormally high fluid pressures. Within the Maricopa-Tejon subbasin, Eocene through Micoene source rocks, especially the Monterey Formation, provided the petroleum reservoired there according to Zieglar and Spotts (1978).

Diagenesis of Petroleum Reservoir Rocks

Sandstones of the San Joaquin basin generally are mineralogically immature and may contain significant amounts of feldspar, mica, volcanic rock fragments, and(or) argillaceous matrix, making them more susceptible to diagenetic alteration than, for example, the more mineralogically mature sandstones of the Gulf Coast. Sandstone diagenesis in the San Joaquin basin has received increased attention in recent years because exploration for subtle and deeper reservoirs and improved recovery efficiency from existing reservoirs requires better understanding and prediction of reservoir porosity, permeability, and timing of hydrocarbon migration. The long-standing tradition of cutting and archiving conventional cores has been invaluable to these more recent investigations.

Merino (1975) appears to have been the first to publish a comprehensive description of the multiple cycles of authigenic mineral formation in sandstones of the Temblor Formation at Kettleman North Dome oil field. He also estimated the mass balance of the diagenetic reactions, noted pervasive fracturing of quartz and plagioclase grains due to either compaction or regional tectonic deformation and, in a companion paper (Merino, 1975), examined chemistry of pore-fluids and diagenetic mineralogy.

Several recent studies have focused on the diagenesis of sandstones in selected oil fields in the southern part of the basin. Boles (1984) and Boles and Ramseyer (1987) present a diagenetic history of the east-sourced Stevens sandstones in the North Coles Levee oil field that sequentially includes carbonate cementation, plagioclase dissolution and kaolinite precipitation, calcite dissolution, and hydrocarbon emplacement (fig. 4). Menzie and Horton (1987) describe the diagenetic history of arkosic sandstones from the Coalinga oil field that in some respects follows the cementation-dissolution-

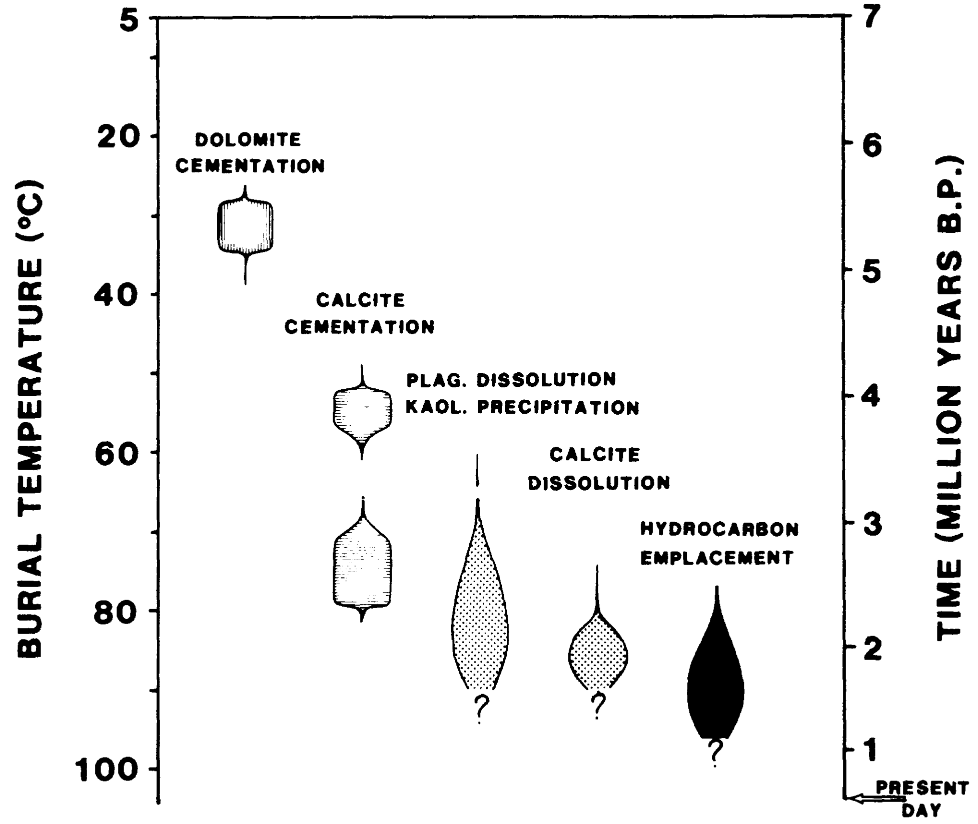

Figure 4.--Timing of diagenetic reactions at North Coles Levee oil field (after Boles and Ramseyer, 1987). Note that time scale along right vertical axis is non-linear and presumably highly speculative because the author provides no age documentation.

precipitation-hydrocarbon emplacement sequence of Boles and Ramseyer (1987). Eslinger and Ranganathan (1983) describe a similar multi-stage diagenetic history of east-sourced upper Miocene Stevens sandstones in the Paloma oil field.

Tieh and others (1986) studied upper Miocene arkosic sandstones from the Yowlumne oil field and found that the dominant composition of detrital feldspar correlates with the nature and sequence of authigenic mineral assemblages. In K-feldspar-dominated sandstones, feldspar diagenesis produced clay minerals dominated by kaolinite, while plagioclase-dominated sandstones produced clay minerals dominated by montmorillonite. While feldspar diagenesis results in a net loss of porosity, arkoses dominated by K-feldspars and authigenic kaolinite have higher porosity and permeability than arkoses dominated by plagioclase and montmorillonite.

Krystinik (1980) studied samples of conventional cores from Elk Hills Naval Petroleum Reserve #1 to show that the abundance of authigenic silica, clay, and carbonate minerals in sandstones decreases with increasing distance from adjacent shale beds. Based on this observation, Krystinik concluded that thin sandstone units, typical of outer fan and overbank deposits, probably are less favorable petroleum reservoirs.

McCulloh and Stewart (1979, 1980) described the distribution of the first occurrence with depth in the southern part of the basin of the permeability- and porosity-reducing calcium zeolite mineral laumontite. They concluded that laumontite can form at any depth, and is favored by (1) presence of suitable Ca-aluminosilicate mineral, such as detrital plagioclase; (2) pore waters of low total salinity (30,000 ppm) and exceptionally low pCO_2; (3) high initial sandstone permeability for high pore-water flow rates; and (4) generally normal to abnormally low pressure gradients, although high thermal gradients can compensate for greater than normal hydrostatic pore-pressures. They believe laumontite-bearing sandstones are poor prospects for petroleum production. Crossey and others (1984) propose from theoretical and experimental studies that decarboxylation reactions might destabilize previously formed laumontite to create secondary porosity. MacGowan and Surdam (1987) analyzed formation waters and aqueous extracts of crude oils, partly from the San Joaquin basin, and found 1 to 3 weight percent carboxylic acid anions, which they believe may be useful in modeling clastic reservoir diagenesis.

Residence time at temperature, not simply maximum burial temperature, appears to be an important influence on the observed illite/smectite ratio in equivalent-aged rocks of different burial histories in the southern San Joaquin basin (Ramseyer and Boles, 1986). The dependence of clay dewatering on a time-temperature index, perhaps analogous to the time-temperature effect on kerogen decomposition, has important implications because of the potential of the dewatering process to catalyze and flush hydrocarbons from shale, produce abnormally high pore-fluid pressures, and provide cementation agents to sandstones (Ramseyer and Boles, 1986).

Diagenesis of fine-grained siliceous rocks of the Monterey Formation is well documented by Isaacs (1980, 1981, 1982) and is described in the Midway-Sunset (Isaacs, 1985), Lost Hills (Stosur and David, 1976; Kruge and Williams, 1982; McGuire and others, 1983), McKittrick (Mulhern and others, 1983), and South Belridge (Schwartz and others, 1981; Beyer, 1987) oil fields. These siliceous rocks, either as opal-A, opal-CT, or quartz-dominated silica phases, are widespread in the southwest part of the basin where, in places, they are oil productive. The silica-phase transformations from opal-A to opal-CT to quartz are accompanied by pronounced reductions of porosity and increased fracture toughness, compressive strength, and tensile strength; all are important considerations in the natural or artificial fracturing of these very low permeability rocks.

Porosity of Petroleum Reservoir Rocks

Porosity and permeability of sandstones are governed by diagenetic processes. These processes are controlled by such factors as the original detrital mineralogy, texture and organic content of the sandstone, its depositional environment and rate of burial, and post-burial histories of temperature, pore-fluid chemistry, pore-fluid pressure, and confining stresses (McCulloh, 1967).

Little definitive information has been published on the systematics of sandstone porosity and permeability in the San Joaquin basin, but several observations are possible. The rate of decrease of porosity with increasing depth, the porosity-depth gradient, is greater for sandstones of the San Joaquin basin than for similar-aged, more mineralogically mature sandstones, such as those of the Gulf Coast (Zieglar and Spotts, 1978; Berg, 1986, fig. 9-30). The porosity-depth gradient generally is greater where the present or past geothermal gradient is or has been greater (McCulloh and others, 1978; Dixon and Kirkland, 1985). The porosity-depth gradient is higher for sandstones whose original detrital mineralogy possessed greater chemical lability (Berg, 1986, fig. 9-30).

Zieglar and Spotts (1978) present evidence that the porosity-depth gradient is higher for west-side reservoir sandstones than for east-side reservoir sandstones in the San Joaquin basin. They state "the more abrupt loss of porosity with depth for reservoirs of the west-side structures is mainly indicative of postburial uplift". This is, of course, not possible unless there are erosional unconformities within the west-side section that cause steplike discontinuities in the porosity-depth profile. Because the overall porosity-depth gradient decreases with increasing depth of burial, movement of a segment of this porosity-depth curve to a shallower depth, as a result of uplift and removal of overburden by erosion, results in a lower-than-normal observed porosity-depth gradient. The observed higher porosity-depth gradient for west-side reservoir sandstones must be due to (1) unconformities within the section juxtaposing rocks with different burial histories, (2) higher temperature gradients on the west-side, (3) possibly more chemically labile sandstone mineralogies on the west side, (4) possibly more reactive pore-fluids on the west side, and(or) (5) more tectonic compression of west-side rocks.

The nature and causes of porosity and permeability variations, particularly on the local scale of individual reservoirs or prospects, undoubtedly is much more complex and less predictable than the above generalizations suggest. A summary of porosity versus depth data from Zieglar and Spotts (1978), together with sandstone porosities from the Paloma oil field, are shown in figure 5. They provide some idea of expectable sandstone porosities at greater depth in the central part of the Maricopa-Tejon subbasin. Limited permeability data is available in Zieglar and Spotts (1978).

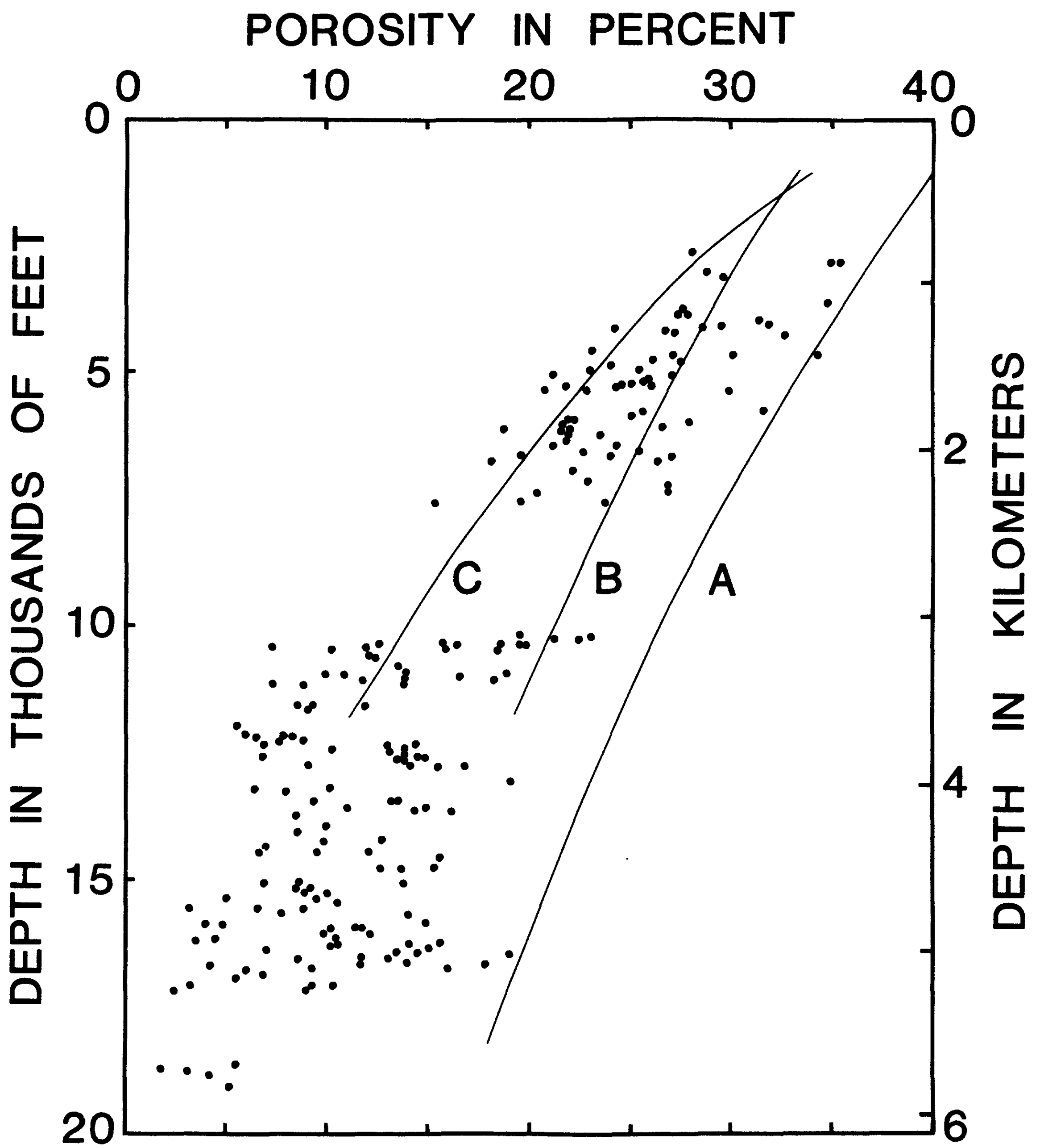

Figure 5.--Porosities of middle Miocene through Pliocene sandstones from Paloma oil field and vicinity determined from laboratory measurements of conventional core samples (Beyer, 1972, unpublished data). Measurements are uncorrected for <u>in situ</u> stress and temperature conditions. Curves A, B, and C are "best reservoir limit", "eyeball best fit" of sandstone reservoirs from Sacramento Valley and eastside of the San Joaquin Valley, and "eyeball best fit" of sandstone reservoirs on west side of San Joaquin Valley, respectively, from Zieglar and Spotts (1978).

PETROLEUM PLAYS

The play concept in the analysis of petroleum resources is defined as a group of hydrocarbon prospects and/or discovered accumulations that have common geological characteristics such as source rock, trapping mechanism, structural history or depositional pattern (Procter and others, 1982). Within a basin, play definition is a subjective process and different workers may define different numbers of plays based on different criteria. For the 1987 petroleum assessment of the San Joaquin province, seven plays were defined on the basis of depositional system (including sequence, facies, source direction and distribution), structural setting, age, and, in one case, lithology. Because the USGS resource assessment by play analysis utilized statistical data of discovered accumulations within the play, the need to logically group the large number of discovered oil and gas reservoirs in the basin also influenced play definition. The seven plays are described below by proceeding, more or less, from youngest to oldest rock units.

PLAY I: Uppermost Miocene to Pleistocene Marine and Nonmarine Sandstones, South-Central and Southwest Area

Sands and sandstones that are part of the last sequence of Neogene marine transgressive-regressive cycles and Quaternary nonmarine deposition occur in the south-central and southwest area of the province within the Etchegoin, San Joaquin, and Tulare Formations (pl. 4). These rocks share a simple burial history, and generally are less deformed than upper Miocene rocks which they unconformably overlie. This play consists of two elements, one characterized by nonassociated gas, and the other by oil reservoirs[3].

Mostly thin (less than 10 m (30 ft)), generally transgressive marine sands of Pliocene age, grading upward into Pleistocene deltaic and nonmarine sands in the south-central and southwest area, produce nonassociated gas, mostly from gently folded anticlines (Dudley Ridge, Harvester, Trico, Semitropic, Buttonwillow, Rio Bravo, Bowerbank, Canal, Ten Section, North and South Coles Levee, Paloma, Elk Hills and Buena Vista fields) (pl. 4). Seals are fine grained, low-permeability claystone and tightly cemented sandstone. Reservoir depth ranges from less than 300 m (1,000 ft) to about 1,500 m (4,900 ft) in the deeper central part of the basin. Gas presumably migrated upward after thermal generation in Cretaceous, Eocene and(or) Miocene source rocks, although some of the shallow gas may be biogenic in origin.

Mostly thin (3 to 20 m) (10 to 65 ft), generally transgressive marine sands of Pliocene age, grading upward into Pleistocene deltaic and nonmarine sands in the southwest area, produce large quantities of mostly low-gravity oil. Larger fields include Midway-Sunset, Buena Vista, Elk Hills, McKittrick, Asphalto, Cymric, South and North Belridge, and Lost Hills (pl. 4). Seals are

---

[3]Age, formation, average depth, average net thickness, and porosity of individual reservoirs are from California Division of Oil and Gas (1985) and various publications of the California Division of Oil and Gas referenced herein.

fine grained, low-permeability claystone, tightly cemented sandstone and tar zones. Traps include anticlines, faults, pinchouts, truncations, and permeability barriers. Reservoir porosities range from 20 to 35 percent, are found at depths of about 100 m (330 ft) in the west to more than 2,400 m (7,900 ft) at the Yowlumne field, and may be expected to slightly greater depths in the deepest basinal areas. Oil has migrated generally from the underlying upper Miocene Monterey Formation. In the case of some Pleistocene reservoir accumulations, the history of ground-water movement has controlled the final accumulation (Chamberlain and Madrid, 1986).

PLAY II: Upper Miocene West- and Southwest-Sourced Channel and Turbidite Sands, Southwest Area

Thick (up to 150 m (500 ft)), discontinuous and sinuous upper Miocene sandstone units along the southwest area are enclosed in off-shelf fine-grained siliceous rocks. These sands, mostly contained in the Monterey Formation and Reef Ridge Shale, have been interpreted as submarine canyon deposits and proximal to distal turbidite deposits that came from a steep nearby trans-San Andreas plutonic source terrane. Some of these sands have been traced as channels for many kilometers; others are thick bodies with little areal extent. Undoubtedly, many of these sand bodies were lost to erosion during the uplift of Temblor Range in the Pleistocene. Most reservoir sands have porosities in the 25- to 35-percent range, have good permeabilities, and have been found at depths above 2,400 m (7,900 ft). Reservoirs include, for example, Spellacy, Lakeview, Sub-Lakeview, Monarch, Asphalto, 555, Republic, Williams, Leutholtz, Reef Ridge, 26R, and 24A sands of local usage in fields that range southeastward from the Cymric field through Midway-Sunset to White Wolf, including parts of the Buena Vista and Elk Hills oil fields (pl. 4).

More distal turbidite facies have proven productive at depths of 3,650 m (12,000 ft) with porosities in the 10- to 20-percent range and variable permeabilities. Fields with such reservoirs include San Emidio Nose, Yowlumne, Cal Canal, Rio Viejo, and Landslide.

For all reservoirs, upper Miocene organic-rich shales, which in some places encase the sands, are believed to be the source rocks. Traps include pinchouts, tilted lenses, folded or domed channel and lobe sands, differential compaction of shales over sand lobes, faults, and diagenetic permeability barriers.

PLAY III: Middle and Upper Miocene Fractured Shales and Diatomaceous Rocks

Deposition of fine-grained biogenous (siliceous) sediments in a largely anoxic basin during middle and upper Miocene, with dilution and dominance by fine-grained terrigenous sediments in part of middle Miocene, resulted in thick sequences (450 to 3,000 m) (1,500 to 9,800 ft) of fine-grained siliceous deposits composed of biogenous material (mostly diatom frustules), clay and silt with sand lenses and partings in some locations. These rocks make up the fine-grained lithofacies of the (1) Reef Ridge Shale (including Belridge diatomite of local usage), (2) the McLure (Antelope or McDonald of local usage), Devilwater, and Gould Shale Members of the Monterey Formation that are widely distributed in the southwest part of the province, and (3) parts of the Fruitvale Shale in the southeast part of the province (pl. 4).

Where not buried deeply (South Belridge, Buena Vista, Lost Hills, and portions of Midway-Sunset and McKittrick fields), these rocks are diatomaceous with porosities as high as 60 percent (Beyer, 1987), but with low permeabilities. Although some oil production has been obtained from these rocks for many years, greatly improved production resulted from extensive fracture stimulation begun in 1980 (Strubhar and others, 1984). Also, successful pilot studies at the McKittrick oil field to extract oil from quarried surface deposits of diatomaceous mudstone (estimated 832 million barrels in-place resource) probably only await economic incentive and environmental solutions (Mulhern and others, 1983).

With greater burial depths, diagenetically altered equivalents are porcelaneous shales (opal-CT) and hard, quartz-rich rocks with relatively low intergranular porosity. The opal-CT and, especially, quartz-rich rocks may be naturally fractured, but the distribution of these fractured regions has not been adequately explored or explained. Intriguingly, limited amounts of oil production have been obtained from naturally fractured upper Miocene shales in a number of widely dispersed fields (e.g., Jerry Slough, Wasco, North Belridge, South Belridge, Elk Hills, west of Midway-Sunset, White Wolf, and McDonald Anticline). Significant oil has been produced from these types of rocks in the Lost Hills field (Hardoin, 1963; McGuire and others, 1983). Substantial production may be present in the Elk Hills field (Maher and others, 1975) and elsewhere, as predicted by Graham and Williams (1985).

The diatomaceous rocks probably have been sourced by more deeply buried, relatively organic carbon-rich Miocene shales, while more deeply buried fractured quartz-rich shales may themselves be the source rock. These fine-grain rocks represent a substantial volume of the Neogene basin in its southwest quadrant. Reservoirs and traps may result from tectonic, stratigraphic, and(or) diagenetic effects, and probably will need stimulation to achieve adequate production rates.

PLAY IV: Upper Eocene to Recent Marine and Nonmarine Sandstones, Southeast Margin and Tejon Platform

Deposition in the southeast margin of the San Joaquin basin has been controlled since latest Eocene by basin subsidence, eustatic sea level changes, and successive uplift of the basin margin and sediment source areas to the east and southeast. As a consequence, deltaic, fluvial and terrestrial wedges, shelf, channel, and slope (ramp?) deposits, and, more basinward, turbidite sequences characterize this part of the basin. The mostly upper slope, shelf, and nonmarine facies that extend from the vicinity of the Jasmin field southward to the Comanche Point field and westward across the Tejon platform to include the Wheeler Ridge field are grouped in this play (pl. 4). Fractured basement reservoirs, to date found only in the Edison and Mountain View fields, also are grouped in this play for want of a better location. To the west of Bakersfield and north of the White Wolf fault, the generally lower slope and turbidite deposits of Eocene(?), Oligocene, and Miocene age, including the important Stevens sands, are considered in Play V.

North of the White Wolf fault, Oligocene to Pleistocene (and minor older) productive sandstone reservoirs occur in practically every formation, but are most prolific in the Kern River, Chanac and Santa Margarita (local usage) formations, and in the Jewett Sand, Freeman Silt, and Vedder Sand. Reservoirs tend to wedge out or to be overlapped to the east, and to pass into deep-water facies to the west. Dips and folds are mostly gentle, and normal faults are common. Some gently folded anticlines are intensely faulted, but throws are relatively small. Common trap types include faults, tar seals, or other permeability barriers, pinchouts, and truncations. Source rocks probably are the organic carbon-rich Miocene shales in deeper basinal areas to the west and southwest, although Eocene shales might have sourced some of the oldest, most basinward sands in the northern area. Most oil comes from depths of about 50 m (165 ft) (Kern River field) to 600 m (2,000 ft) (Fruitvale field), although oil is produced from reservoirs as deep as 1,800 m (5,900 ft) in the Edison field, 3,000 m (9,800 ft) in the Mountain View field, and equivalent sandstones are as deep as 5,000 m (16,400 ft) southward at the White Wolf fault (Bartow, 1984). Porosities generally range from 25 to 38 percent, except in the deepest reservoirs (Mountain View field), where they may be less than 20 percent.

South of the White Wolf fault and westward across the Tejon platform to the northeast-facing trace of the Pleito fault, southeast-sourced Miocene shelf, ramp(?), and turbidite sands are productive in the Comanche Point, Tejon Hills, Tejon, North Tejon, and Wheeler Ridge fields at depths ranging from about 140 to 2,200 m (460 to 7,200 ft). Upper Eocene and lower Oligocene marine sandstones (Tejon and San Emigdio Formations) are productive in the Tejon Hills, Tejon, Tejon Flats, North Tejon, and Wheeler Ridge fields at depths of about 640 to 3,350 m (2,100 to 11,000 ft). None of the above units have been reached by drill to the north across the White Wolf fault, except to the east, south of Arvin (Bartow, 1984).

Hydrocarbon traps on the Tejon platform include truncations, pinchouts, permeability barriers, and normal faults on gently dipping anticlines and a generally north-dipping homocline permeability barriers, and, at Wheeler Ridge, north-directed thrust faulting on a prominent anticline. Reservoir porosities vary from as low as 5 to 15 percent for deeply buried upper Eocene sandstones to as high as 35 percent for shallow buried Miocene shelf sands.

Arguably, the Tejon platform is distinct structurally and depositionally from the eastern margin north and south of Bakersfield, but trap types (except in the turbidite sequences) are similar, and the mild deformation (except for the Wheeler Ridge field) is similar to the Bakersfield margin. The marine shelf seems to have been narrower on the Tejon platform during late Oligocene and all except latest Miocene deposition so that more deeper water sands were deposited on parts of the platform than along the Bakersfield margin.

The south margin of the San Joaquin Basin is especially complex due to its complicated structural history (Davis, 1986), the convergence of westside and eastside stratigraphic nomenclature (Lagoe, 1987), and in outcrop, the general westward-directed (rather than basinward-directed) proximal to distal facies changes of upper Eocene through lower Miocene sediments (Nilsen, 1987; DeCelles, 1986; Gillespie, 1986). For all of the above reasons, the west boundary of relatively stable south margin is taken as the northeast-facing trace of the Pleito fault (pl. 1) and the Tejon platform is grouped with the Bakersfield margin in this play.

PLAY V: Upper Cretaceous(?) through Miocene East- and Southeast-Sourced Basinal Sandstones, South-Central and Southeast Area

Mostly Oligocene and Miocene slope and turbidite sandstones from east and southeast sources occur in the south-central and southeast parts of the San Joaquin basin (pl. 4). These are the westward and northward stratigraphic equivalents of the marine and nonmarine rocks described in Play IV. The prolific Bakersfield arch has many fields that produce from the upper Miocene Stevens sands, a sequence of up to 1,200 m (3,900 ft) of turbidite sands with interbedded siltstone and shale derived from source areas at the eastern end of the Bakersfield arch (e.g., MacPherson, 1978; Webb, 1981). These sands form oil reservoirs as far-reaching as the Paloma, Elk Hills (eastern portion), and Bowerbank fields, and have been a major exploration target for decades. Stevens reservoirs have porosities ranging from about 14-33 percent, and have been found at depths ranging from about 1,700 to more than 3,600 m (5,600 to 11,800 ft). They may be present east of the Paloma field and north of the White Wolf fault at depths not yet reached by the drill in the Tejon depocenter.

More distal facies of the Oligo-Miocene Vedder sand, in part resembling slope or "ramp" deposits (Bloch, 1986), have produced oil in the Greeley, Rio Bravo, Strand, Shafter, and Wasco fields from depths of about 3,400 to 4,000 m (11,000 to 13,000 ft). Porosities of reservoirs range from about 15 to 24 percent. Other sands, productive locally, include the lower Miocene Rio Bravo and Olcese sands of local usage (Rio Bravo and Greeley fields).

Intriguingly, small amounts of oil were reportedly produced from the Vedder sand at a depth of 5,370 m (17,600 ft) in the Semitropic field, and from "Eocene sands" at a depth of 4,570 m (15,000 ft) in the Wasco field. The latter sands may be part of the Eocene Famosa sand (Edwards, 1943) of local usage that presumably is derived from the Sierran block, produce minor amounts of oil in the West Jasmin field, and may be coeval with the west side middle Eocene Domengine and Avenal Sandstones (Bartow, 1984) or grade westward into the middle and upper Eocene Kreyenhagen Formation (Nilsen, 1987). Also, the upper Eocene through Miocene marine sands productive on the Tejon platform and described in Play IV may have deeply buried, more distal equivalents across the White Wolf fault to the north, but these have not yet been reached by drill. Oligo-Miocene sands from the east and from the Bakersfield area to the northeast may extend into the eastern Maricopa-Tejon subbasin which remains largely undrilled at greater depths. Lastly, undifferentiated Upper Cretaceous marine and(or) nonmarine rocks underlie Eocene rocks in some areas north of the Bakersfield arch (Bartow and McDougall, 1984, p. J7; Kiser, 1987).

Hydrocarbon traps in this play include anticlines, faulted anticlines, faulted homoclines, stratigraphic traps with and without structural elements, and permeability barriers. Miocene shales are the principal source rock in this play, but, north of the Bakersfield arch, Eocene and older shales also may have been important source rocks, especially for upper Eocene, Oligocene and lower Miocene sands.

Play VI: Upper Cretaceous through Middle Miocene Marine Sandstones, Southwest Basinal Area and Areas Westward to San Andreas Fault, including Vallecitos Syncline

This play includes rocks of the southwest part of the late Mesozoic forearc basin and the western part of the Tertiary basin up through the Middle Miocene sandstones of the Temblor Formation, locally as young as Luisian. This area is the most structurally complex part of the San Joaquin basin and most important formations of this play are time-transgressive and possess complex lithofacies that reflect active tectonic control of sedimentation (e.g., Harding, 1976; Nilsen, 1979; Warren, 1983; Isaacson and Blueford, 1984; Graham, 1985). Generally, deformation and complexity of lithofacies increase from the eastern basinal area of this play to its west and south margins.

The eastern boundary of the play is the approximate eastern edge of Neogene compressional deformation (Harding, 1976, figs. 3 and 8; Callaway, 1971, fig. 6) (pl. 4). The northern part of this eastern boundary also corresponds approximately to the average position of the Sierra block marine shelf edge during Miocene, as defined by the 300-ft (90-m) paleoisobaths of Bandy and Arnal (1969). The very north end of the eastern play boundary is curved westward to include the Vallecitos syncline within this play (pl. 4).

The mid-section of the eastern play boundary is located near the average position of the bathymetric basin axis during Miocene (Bandy and Arnal, 1969). Further south between the North Coles Levee and Wheeler Ridge oil fields, the boundary is drawn arbitrarily as a straight line to, more or less, define an eastern limit for the west-, southwest-, and south-sourced sands of this play that are distinct from the east- or southeast-sourced sands of Play V. There is little available information with which to place the play boundary between North Coles Levee and Wheeler Ridge oil fields. Possible clockwise rotation of the Tehachapi Mountains (and presumably the terrain of the present San Emigdio Mountains) 22 Ma or earlier (Plescia and Calderone, 1986; Golombek and Brown, 1988) confounds this problem. From the west end of the Wheeler Ridge field, the play boundary follows the trace of the Pleito Fault southeastward to basement rocks in the eastern San Emigdio Mountains.

This play encompasses a depositionally diverse sequence of sedimentary rocks distributed over a wide geographic area along the west and southwest portion of the basin. Several separate plays easily could be defined from this rather large, all-encompassing play. Description of the play is divided by age into Upper Cretaceous through lower Paleocene, upper Paleocene through lower Eocene, middle Eocene through upper Eocene or lowest Oligocene, and Oligocene through middle Miocene rocks. Within each age category, the description proceeds from north to south along the west side of the basin.

Upper Cretaceous through lower Paleocene

The oldest sedimentary rocks of this play belong to Upper Cretaceous Panoche Formation of Goudkoff (1945) (Campanian through lower Maestrichtian), the much thinner and southward overlapped Moreno Formation of Payne (1960) (upper Maestrichtian through lower Paleocene), and other undifferentiated Cretaceous rocks (primarily in the subsurface). These sediments were deposited largely as turbidite sequences in the final regressive phase of the Late Mesozoic forearc basin. About 7,000 m (23,000 ft) of marine sandstone and shale are exposed on Joaquin Ridge just north of Coalinga (Dibblee, 1979b). Southward near Orchard Peak at least 4,900 m (16,000 ft), and possibly as much as 6,000 m (19,700 ft), of Upper Cretaceous forearc basin sediments are reported (Marsh, 1960). The southernmost outcrops along the western side are near the Temblor Ranch oil field in T. 29 S., R. 20 E. (Dibblee, 1973a).

In the subsurface, east and southeast of Coalinga, these forearc sediments are believed to be 4,500 to 6,100 m (14,800 to 20,000 ft) thick beneath as much as 5,100 m (16,700 ft) of overlying Cenozoic deposits (Hackel, 1966; Zieglar and Spotts, 1978; Wentworth and others, 1984). However, undifferentiated Cretaceous rocks are reported in the subsurfaace only as far south as T. 25 S., R. 24 E., just south of the Trico gas field (Church and Krammes, 1958), and may be present at great depth beneath the western part of the Elk Hills Naval Petroleum Reserve No. 1 (pl. 4). There have been no reports of these rocks in the subsurface south of these locations.

Little is known about these Upper Cretaceous through lower Paleocene forearc basin rocks in the structurally deepest parts of this play except that they have not produced oil or gas where sparsely penetrated by drilling. To the west where they are less deeply buried, and eventually exposed in outcrop, turbidite sands that are (1) most prevalent in the upper part of the Panoche Formation (principally, the Joaquin Ridge and Brown Mountain Sandstone Members near Coalinga and their equivalents) and (2) occur locally within the Moreno Formation (e.g., Cima sand of local usage in northern area) offer the best reservoir potential. However, only minor oil (Vallecitos oil field and Oil City area of Coalinga oil field) and scant nonassociated gas (west area of Pyramid Hills oil field) have been produced from these rocks.

The great burial depth and consequent poor reservoir rock quality, and probable lack of migration routes from younger, overlying rich, oil-prone source rocks in most areas discourage feelings that much undiscovered recoverable oil exists in this sequence. Nevertheless, nonassociated gas reservoirs in tectonically fractured rocks may exist, perhaps aided by abnormal fluid pressures (Berry, 1973) and the possibility of east-verging thrust faults at great depth along the west margin of the basin (Wentworth and others, 1984; Namson and Davis, 1988).

Upper Paleocene through lower Eocene

Upper Paleocene through lower Eocene rocks of this play consist of bathyal to neritic marine shale and turbidite sandstone facies of the Lodo Formation, generally restricted to the northern play area and including the informally named subsurface Gatchell sandstone. Also included are overlying shallow marine sands of the Yokut and Domengine Sandstones in the north and Avenal Sandstone in the south that were deposited during the major regressive-transgressive cycle at the end of lower Eocene (Dibblee, 1973b; Mallory, 1959; Slagle, 1979; Nilsen, 1979; Kappeler and others, 1984; Bartow, 1987a). The upper Paleocene-lower Eocene section is thickest to the southeast, east, and north of Coalinga, and in the Vallecitos syncline. These rocks thin and apparently are overlapped by younger rocks west of the Bakersfield arch (Hackel, 1966).

Northwest of Coalinga, an unnamed basal sandstone member of the Lodo Formation (Nilsen, 1979) apparently is restricted to the region of the Vallecitos syncline where, as a minor oil reservoir, it is informally called the San Carlos sand. The Cantua Sandstone Member of the Lodo Formation, also restricted to the area north of Coalinga, is more widespread, extending from outcrops in the Vallecitos syncline region southeastward to the Turk anticline and possibly northeastward to the Cheney Ranch gas field (Nilsen and others, 1974; Graham and Berry, 1979) (pls. 1 and 4). The Cantua Sandstone Member is a submarine fan deposit, with west-northwest to east-northeast current directions in outcrop, apparently derived from a submarine canyon or channel in the Sierra shelf to the east (Graham and Berry, 1979; Nilsen, 1987). The Cantua Sandstone Member has produced small amounts of oil from the Cantua Creek and Vallecitos oil fields.

The Gatchell sandstone of local usage is a generally shallow marine sandstone (Ryall, 1974) of the Lodo Formation whose source was from the east and probably was partly coeval with the Cantua (Graham and Berry, 1979). The Gatchell sandstone has been correlated in the subsurface from about Kettleman Middle Dome to East Coalinga Extension oil fields on the west, to Westhaven and Tulare Lake oil fields on the east (Schneeflock, 1978). Thin, generally low permeability oil-bearing sands that underlie the Gatchell sand in parts of the Coalinga and Pleasant Valley oil fields may be early distal facies of the overall shallow marine sand sequence so well developed at the East Coalinga Extension oil field (MacPherson, 1978, fig. 17). The Gatchell sand is a primary oil reservoir in the Coalinga East Extension, Guijarrel Hills, Kettleman North Dome (lower McAdams sand of local usage), and Pleasant Valley oil fields where it ranges in depth from 2,250 to 3,570 m (7,400 to 11,700 ft) and in thickness from 0 to 190 m (0 to 620 ft). Porosities range from 9 to 22 percent. Gatchell reservoir traps are caused by stratigraphic, structural and(or) diagenetic effects (Schneeflock, 1978).

The generally thin, fluvial to shallow marine Yokut and Domengine Sandstones, undivided in the Vallecitos syncline area, occur in outcrops northwest of Coalinga (White, 1940; Nilsen, 1979). The Domengine Sandstone, also discussed in Play VII, extends northward of the play area, and is recognized in the subsurface at least as far southeast as the Westhaven (abandoned) and Kettleman North Dome oil fields (pl. 4). These sands have produced relatively small amounts of oil in the Vallecitos and Kettleman North Dome (upper McAdams sand of local usage) oil fields.

South of Coalinga along the westside outcrop belt, the generally thin, fluvial to shallow marine Avenal Sandstone (Dibblee, 1973b; Kappeler and others, 1984) is exposed intermittently with its probable equivalents, the Acebedo Sandstone west of McLure Valley and the Mabury Sandstone of the Devils Den area. These sands are recognized, but unproductive in the Jacalitos and Kreyenhagen oil fields, presumably are correlative with the upper McAdams sand of local usage at the Kettleman North and Middle Dome fields, have produced minor amounts of oil in the Pyramid Hills (Norris area), Shale Point (Mabury sand) and Shale Flat (Mabury sand) fields, and are not recognized or reached by drill in other fields further to the south and east (pl. 4). The Avenal Sandstone and its equivalents south of Coalinga probably are correlative with the Domengine Sandstone to the north, and mark the beginning of the major transgressive cycle in middle Eocene that led to the deposition of the middle Eocene Kreyenhagen Formation (Dibblee, 1973b; Kappeler and others, 1984).

Middle Eocene through upper Eocene or lowest Oligocene

The middle and upper Eocene rocks of this play belong to the Kreyenhagen Formation, with its major deep-sea fan, the Point of Rocks Sandstone, and the overlying Tumey Formation (north of Pyramid Hills oil field) and Wagonwheel Formation (south of Pyramid Hills oil field) (Dibblee, 1973b; Clarke, 1973; Nilsen, 1979; Isaacson and Blueford, 1984). In the southern part of this play, extending northward from the San Emidgio Mountains, the middle Eocene Tejon Formation and upper Eocene San Emigdio Formation are coeval with the Kreyenhagen and Tumey/Wagonwheel Formations, and are part of this play (Nilsen, 1987). Taken together, these formations represent the most widespread and long-lasting marine transgressive cycle of the Tertiary in the San Joaquin basin. Proven and potential oil reservoirs are mostly in the turbidite sand sequences of the Point of Rocks Sandstone, and the shallow-marine Oceanic sand of local usage in the Wagonwheel Formation and the Metralla Sandstone Member of the Tejon Formation.

North of Coalinga the Kreyenhagen Formation consists mostly of deep marine shale with just a few sandstone lenses (Nilsen, 1979), one of which (the Ashurst sand of local usage) has produced minor amounts of oil in the Vallecitos field. Exposures of the overlying Tumey Formation about 20 km (12 mi) of the Vallecitos field include a sandstone member 245 m (800 ft) thick that lenses out both to the north and south (Nilsen, 1979). However, no other productive sands of either the Kreyenhagen or Tumey Formations have been found north of the Pyramid Hills oil field south of Coalinga.

Fractured shale has produced some oil from the (1) Kreyenhagen in the Kettleman North Dome, Kettleman Middle Dome, and possibly the Kettleman City oil fields, and (2) Wagonwheel (Tumey) formation in the Welcome Valley field, and must be considered as a potential oil reservoir.

The Kreyenhagen Formation has a lower, fine-grained unit, the Gredal Shale Member (Dibblee, 1973b), that underlies the Point of Rocks Sandstone in outcrops south of Reef Ridge. In the subsurface the Gredal Member is frequently called the Canoas in reference to Canoas Siltstone Member of the Kreyenhagen described on Reef Ridge by Marsh (1960), but this term probably is inappropriate south of the Pyramid Hills oil field (Dibblee, 1973b). The Gredal Member has generally thin sandstone units that have produced small amounts of nonassociated gas in the Antelope Plains, Shale Flats, and Shale Point fields, and small amounts of oil in the Devils Den and Pyramid Hills fields (pl. 4). These sands apparently are not widespread, appear to be turbidite deposits, and probably came from generally westerly sources or are related to the depositional system of the overlying Point of Rocks Sandstone.

The principal proven oil reservoir in the middle and upper Eocene sequence of this play is the Point of Rocks Sandstone, a very large south- to southwest-sourced, deep-sea fan complex that is exposed intermittently from Avenal and Reef Ridges southward to the central Temblor Range, and is mapped in the subsurface from the Pyramid Hills oil field southeastward to at least the northern part of the Midway-Sunset oil field (Clarke, 1973) and possibly eastward to the North Coles Levee oil field (Dunwoody, 1986) (pl. 4). The southern and southeastern limit of the Point of Rocks Sandstone in the western part of the Maricopa-Tejon subbasin is uncertain as no wells have been drilled deep enough to penetrate Eocene rocks there, although no Point of Rocks

Sandstone was found at the Gonyer Anticline field (abandoned) west of the Midway-Sunset field (Clarke, 1973).

The Point of Rocks wedges out in the subsurface toward the north and east within the Kreyenhagen Formation and thickens toward the west, reaching its maximum thickness of at least 1,500 m (4,900 ft) the Cymric and Belgian Anticline oil fields (Clarke, 1973). Further to the northwest, Point of Rocks Sandstone begins to thin before being truncated by the post-Eocene, pre-mid Oligocene unconformity. Apparently, the Point of Rocks turbidite sand sequence was derived from a source southwest of the central Temblor Range, west of the present-day San Andreas fault which has subsequently dismembered the southwest part of this deep sea-fan complex (Clarke and Nilsen, 1973).

The Point of Rocks Sandstone has produced oil in the Antelope Hills, Antelope Hills North, Belgian Anticline, Cymric, Devils Den, McDonald Anticline, McKittrick, Pyramid Hills, and Temblor Hills oil fields at depths ranging from about 180 to 2,770 m (600 to 9,100 ft) (p. 4). Reservoirs range in thickness from about 10 to 100 m (30 to 300 ft) or more, and porosities are about 10 to 35 percent. Traps are mostly structural and combination structural-stratigraphic, and include anticlines, faulted anticlines and homoclines, and truncated homoclines. The Point of Rocks Sandstone is widespread and has not been tested in many places, especially at greater depths to the east of oil fields in which it is presently productive.

The Oceanic sand of informal usage (Foss and Blaisdell, 1968) is an uppermost Eocene to lowermost Oligocene, shallow-marine sandstone, derived from west-side source areas, that has been correlated in the subsurface from the northern part of the Midway-Sunset oil field to near the Devils Den oil field (Seiden, 1964, fig. 4). According to Foss and Blaisdell (1968), the Oceanic sand, generally less than 60 m (200 ft) thick, has no outcrops to the west because it is truncated in the subsurface. However, Dibblee (1973b) reports outcrops of a basal sandstone of the Wagonwheel Formation in the Devils Den area. In the subsurface the Oceanic sand conformably and unconformably overlies the Kreyenhagen Formation and Point of Rocks Sandstone, and is overlain by, and grades laterally into, the fine-grained lithofacies of the Wagonwheel (Tumey) Formation.

The Oceanic sand has produced oil from areas of the Belgian Anticline, Cymric, McDonald Anticline, McKittrick and North Belridge (Y sand of local usage) oil fields at depths ranging from about 1,600 to 2,600 m (5,250 to 8,550 ft). Reservoirs are up to 45 m (150 ft) thick, and have porosities of about 13 to 27 percent. Traps are mostly structural and combination structural-stratigraphic like those of the Point of Rocks Sandstone.

Age-equivalent rocks of Kreyenhagen and Tumey/Wagonwheel Formations are exposed in the San Emigdio Mountains, and occur in the subsurface along the southern edge of the western Maricopa-Tejon subbasin as the Tejon and San Emigdio Formations (DeLise, 1967; Nilsen and others, 1973; Weber, 1973; DeCelles, 1986). The Tejon Formation consists of a basal transgressive unit, an overlying generally deep-marine sequence (Liveoak Shale Member), and an upper regressive sandstone (Metralla Sandstone Member) (Nilsen, 1987). The overlying San Emigdio Formation similarly consists of transgressive, deep-marine and regressive sequences (DeCelles, 1986). The Tejon and San Emigdio Formations both thin eastward and interfinger with the nonmarine Tecuya Formation (Nilsen and others, 1973).

Lithofacies indicate that the Eocene basin in which these rocks were deposited deepened both westward and northward so that more fine-grained rocks generally occur at the west end of the San Emigdio Mountains and presumably northward beneath the western part of the Maricopa-Tejon subbasin (Nilsen, 1987).

The Metralla Sandstone Member of the Tejon Formation is an oil reservoir in the Wheeler Ridge and North Tejon oil fields of Play IV, and possibly equivalent sands have produced minor amounts of oil to the southwest in the San Emigdio Creek and Eagle Rest fields of this play (pl. 4). Sandstone units in the San Emigdio Formation produce oil in fields on the Tejon platform (Play IV), including the North Tejon and Wheeler Ridge fields, but have not been found productive in the subsurface to the west in the area of this play. Nilsen (1987) does not rule out the possibility that deep-marine turbidite sand facies were deposited to the northwest in the western part of the Maricopa-Tejon subbasin where their present depth of burial probably exceeds 6,000 m (19,700 ft) (Davis and Namson, 1986), although available outcrop (Nilsen and others, 1973) and subsurface (Weber, 1973) evidence suggests fine-grained facies are more likely.

This part of the Eocene basin margin shows the record of many minor, as well as major, transgressive/regressive cycles (DeCelles, 1986) during which sand deposition may have been more widespread than present evidence predicts. Also, recently developed models of deformational style along the south margin of the Maricopa-Tejon subbasin pose intriguing questions about the distribution of possible reservoir rocks in the subsurface and their tectonic fracturing at great depth (Davis, 1986).

Oligocene through middle Miocene

The Oligocene to middle Miocene Temblor Formation contains the dominant oil-producing reservoirs of this play. The Temblor Formation embraces a variety of lithofacies that range from nonmarine to deep-marine deposits, bears the distinct impact of active tectonic control of sedimentation, and is exposed extensively along the southwest side of the San Joaquin basin from the region of the Vallecitos syncline southeastward through the southern Diablo and Temblor Ranges and eastward through the San Emigdio Mountains (Dibblee, 1973a, 1979a; Dibblee and Nilsen, 1973; Harding, 1976; Graham, 1985). The Temblor also has been extensively studied in the subsurface in areas basinward from the southern Diablo and the central and northern Temblor Ranges where it has produced oil from 36 fields (e.g., Foss and Blaisdell, 1968; Seiden, 1964).

Predictable difficulties with the stratigraphic nomenclature of the complex Temblor Formation are largely resolved today (Graham, 1985) except for the well-entrenched but outdated terminology applied to subsurface Oligocene age rocks in the Kettleman Hills region (e.g., Kuespert, 1985). These rocks are considered here to be lower Temblor because they are age equivalents of the lower Temblor sequence in the type and reference sections in the Temblor Range (Dibblee, 1973b; Bent, 1985; pl. 3, col. 5). Ultimately, the name Vaqueros should be dropped to avoid confusion with the formation of the same name on the west side of the San Andreas fault (Dibblee, 1973b). To the south in the San Emgidio Mountains, the Pleito Formation is coeval with the lower part of the Temblor as defined in the central Temblor Range (Tipton, 1971; Nilsen and others, 1973).

Toward the northeast, across the eastern boundary of the play, the Temblor thins and grades laterally into the nonmarine Zilch formation of local usage and the fluvial Valley Springs Formation (Bartow, 1987a). Toward the east and southeast, the Vedder Sand, Jewett Sand, Freeman Silt and Olcese Sand are applied to coeval deposits derived from east-side source areas (Dunwoody, 1986; Bartow, 1987a). Unfortunately, the eastern play boundary does not necessarily delineate the use of the east-side versus west-side stratigraphic nomenclature in the subsurface.

In outcrops along the west and south sides of the play area, the Temblor unconformably overlies rocks that range in age from Late Cretaceous to early Oligocene, generally with increasing discordance toward the San Andreas fault (Dibblee, 1973b, 1979b). Multiple unconformity-bounded depositional sequences, with environments that range from nonmarine to deep marine, have been determined from careful outcrop and subsurface studies of the Temblor (Graham, 1985). Sandstones and interbedded argillaceous units in the San Emigdio Mountains were derived from source areas to the south and southeast (Gillespie, 1986), those in the Temblor Range from westerly and northerly source areas (Carter, 1985; Pence, 1985), and those in the southern Diablo Range and Coalinga region from source areas to the west, north, and east (Bate, 1985; Bent, 1985; Kuespert, 1985). Localized emergent highs along the west side, some enduring and some ephemeral, furnished Temblor sediment, and, together with syndepositional deformation of the sea floor, controlled depositional patterns and environments (Graham, 1985). Because of its complexity, the Temblor Formation is discussed from north to south by geographic area.

Northwest of Coalinga in the Vallecitos syncline region, the Temblor Formation rests unconformably on the Kreyenhagen Formation and consists mostly of shallow-marine sandstone with lesser deep-marine argillaceous rocks, all arranged in three unconformity-bounded depositional sequences that reflect the contemporaneous deformation of the southern Diablo Range during early and middle Miocene (Rentschler, 1985). No oil or gas is produced from Temblor sandstones in the Vallecitos oil field. Rentschler (1985) believes the Temblor Formation in the Vallecitos syncline may not have shared an entirely common history with Temblor rocks exposed in basin-facing outcrops to the southeast on Coalinga anticline (Bate, 1985). About 42 km (26 mi) east of Vallecitos, minor amounts of oil have been produced from thin zones of Temblor sandstone in the Cantua Nueva and Turk Anticline oil fields where the Temblor occurs at an average depth of 2,200 m (7,200 ft) and has a gross thickness of 500 to 700 m (1,600 to 2,300 ft) (pl. 4). A short distance to the east beyond the play boundary in the Five Points oil field, the Temblor is replaced by the nonmarine rocks of the Zilch formation of local usage.

South-southeast of the Cantua Nueva and Turk Anticline oil fields, the Temblor produced minor amounts of oil from a thin sand at a depth of 3,347 m (10,980 ft) in the abandoned Westhaven field (pl. 4). Further to the southeast, oil and gas condensate is produced from lower Temblor sands at a depth of 3,860 to 4,060 m (12,650 to 13,320 ft) in the Kettleman City field (Estill, 1980). The nearby Tulare Lake oil field produces oil and gas from Temblor sands at a depth of about 4,050 m (13,290 ft). No other oil or gas accumulations have yet been discovered along this north-northwest to south-southeast trend, or to the south where, east of the Lost Hills oil field, the top of the Temblor lies below 4,200 m (13,800 ft) (Ziegler and others, 1987). Traps appear to be stratigraphic or combination structural-stratigraphic.

The Temblor Formation has been extensively studied, both in outcrop and in the subsurface, in the Coalinga-Kettleman Hills region where it is the primary petroleum reservoir in the Kreyenhagen, Jacalitos, Coalinga, Guijaaral Hills, Kettleman North Dome, and Kettleman Middle Dome oil fields (e.g., Arnold and Anderson, 1910; Goudkoff, 1934; Woodring and others, 1940; Anderson and Ellison, 1952; Adegoke, 1969; Rennie, 1972) (pl. 4). Studies of the Temblor Formation on Coalinga anticline (Bate, 1985), Reef Ridge (Cooley, 1985), and in the subsurface (Kuespert, 1985) reveal several transgressive-regressive cycles from Oligocene through early middle Miocene, depositional environments that range from nonmarine to deep-marine, and a general eastward thickening of the section. A large number of individual sandstone units, some of local extent and others of broader extent, have been drilled and mapped in the subsurface, possibly as far east as the Tulare Lake field (e.g., Webster and Ryall, 1972; Kuespert, 1985).

The Temblor Formation in the Coalinga-Kettleman Hills region has a number of informal subdivisions principally developed during the course of subsurface exploration and petroleum development of the area. Included here are the Leda sand, Vaqueros sand, Allison sand, Burbank sand, Felix silt, First through Fifth sands at Kettleman North Dome field, Smith sand, Sanger sand, upper and lower Variegated sands, and upper and lower Temblor sands of local usage. One or more of these sandstone units is the principal petroleum reservoir in every Coalinga-Kettleman Hills area field, except for the Pleasant Valley and Coalinga East Extension fields where the Eocene Gatchell sand is the reservoir. Temblor reservoirs occur at depths of 150 to 2,700 m (500 to 8,850 ft), are 6 to 460 m (20 to 1,500 ft) thick, and have porosities that range from about 13 to 35 percent. Temblor traps are combination structural-stratigraphic and stratigraphic, although the west-side area of the Coalinga field may involve a tar seal (Anderson and Ellison, 1952) or a type of hydrodynamic ("fluid level") trap (Foss, 1972a).

South of the Coalinga-Kettleman Hills region, sandstones of the Temblor Formation have produced oil in 19 active and abandoned fields from Pyramid Hills and Lost Hills oil fields on the north to Elk Hills and the Belgian Anticline oil fields on the south (pl. 4). The Temblor Formation in this area has been extensively studied in outcrop and in the subsurface (e.g., Foss and Blaisdell, 1968; Young, 1968; Dibblee, 1973a,b,; Graham, 1985). It is more than 2,133 m (7,000 ft) thick in the southeast part of the Temblor Range, generally less than 610 m (2,000 ft) thick in the southwest flank of the Diablo Range, and generally thin in the Pyramid Hills oil field to the north (Dibblee, 1973b; Webster and Ryall, 1972). On the northeast flank of the central Temblor Range, and in the nearby oil fields to the east, long-recognized subdivisions of the Temblor were formalized by Dibblee (1973b) who cautioned that they do not have regional significance and cannot be recognized in outcrop in other areas. These subdivisions from oldest to youngest are the Cymric Shale (Salt Creek shale of local usage), Wygal Sandstone, Santos Shale, Carneros Sandstone, Media Shale and Buttonbed Sandstone Members.

Generally, successively younger members of the Temblor Formation onlap toward the west and northwest (Dibblee, 1973b; Pence, 1985), but locally may be missing or partly removed by erosion. Careful study shows that four partial and complete unconformity-bounded cycles of deposition, representing repeated periods of uplift and subsidence, are present in the Temblor

Formation in this region (Carter, 1985). Depositional environments range from shallow-marine to deep marine (Carter, 1985; Pence, 1985), and syndepositional deformation of the sea floor partly controlled sandstone depositional patterns (Harding, 1976).

The Wygal Sandstone Member (Phacoides, 64, Y and Bloemer sands of local usage) is a shallow-marine sandstone that has produced oil from the Antelope Hills and Beer Nose fields on the north to the Belgian Anticline and Railroad Gap fields on the south (pl. 4). Net reservoir thickness ranges from 5 to 90 m (15 to 300 ft), reservoir depths range from 120 m (400 ft) on the west to 3,090 m (10,100 ft) (toward the east, and porosity ranges from about 15 to 32 percent.

The superjacent Santos Shale Member, in some places separated by the Agua Sandstone Member into an upper and lower sequence, is a lower to upper bathyal shale that contains some thin interbeds of siltstone and sandstone in its upper portions (Carter, 1985). The Santos Shale Member has produced oil in the Belgian Anticline field from naturally fractured zones (Wilson, 1979), and must be considered a potential oil reservoir elsewhere.

The shallow-marine Agua Sandstone Member of the Temblor Formation overlaps and truncates older strata in the northern Temblor Range (Pence, 1985; Carter, 1985) and is mapped in the subsurface northeastward from outcrops to the McDonald Anticline, Antelope Hills, North Antelope Hills, and North Belridge (R sand) oil fields (Carter, 1985) where it produces oil (pls. 1 and 4). Oil-producing sandstones correlated to the Agua are also reported in the Cymric, Belgian Anticline, Blackwells Corner, Elk Hills, and Temblor Hills fields. In its main productive area, the Agua Member has net reservoir thickness of about 20 to 50 m (65 to 165 ft), ranges in depth from 700 to 2,160 m (2,300 to 7,100 ft), and has porosities of about 16 to 33 percent.

The deep-marine Carneros Sandstone Member conformably overlies the upper part of the Santos Shale Member and consists of as many as four discrete sandstone units with interbedded shale (Foss and Blaisdell, 1968; Dibblee, 1973b; Carter, 1985). These turbidite sands locally thicken and pinch out over short distances where mapped in outcrop and the subsurface (Carter, 1985) and have produced oil in 10 oil fields that extend from the Devils Den and Lost Hills fields on the north to the Elk Hills, Asphalto, and Belgian Anticline fields on the south (pls. 1 and 4). Reservoirs occur at average depths of 410 to 2,830 m (1,350 to 9,280 ft) and have net thicknesses of 15 to 75 m (50 to 250 ft) with porosities of 11 to 34 percent.

Paleocurrent directions in outcrop and southeastward thickening of the Carneros Member in the subsurface indicate that the dominant flow direction was toward the east-southeast (Carter, 1985). Coeval shallow-marine facies of the Temblor are present in the Antelope Valley area to the northwest (Pence, 1985). Dibblee (1973b) gives a maximum thickness for the Carneros Sandstone Member in the east-central Temblor Range of about 150 m (500 ft). Foss and Blaisdell (1968) give maximum thicknesses, presumably of subsurface sections, of 728 m (2,390 ft) for the lower sand sequence in the Devils Den field that extends southward to the North Belridge field, 610 m (2,000 ft) for the middle sand sequence that extends from outcrops in the central Temblor Range eastward to the Elk Hills field, and 1,524 m (5,000 ft) for the upper sand sequence that extends from west of the Midway-Sunset oil field southeastward to the

Pioneer oil field, although it seems unlikely correlations can be made in the last case (Bent, 1985; Gillespie, 1986). The most basinward section drilled east of the central Temblor Range is at a depth of about 3,800 m (12,500 ft) in the North Coles Levee oil field. It is about 115 m (375 ft) thick and is not productive (Dunwoody, 1986).

The shallow-marine Buttonbed Sandstone Member of the Temblor Formation conformably overlies the Media Shale Member in the central Temblor Range and eastward in the subsurface (Foss and Blaisdell, 1968; Dibblee, 1973b; Carter, 1985). In the northernmost Temblor Range and Devils Den area, the Buttonbed is thin (about 10 m (30 ft)) and overlaps older rocks to the west and north (Pence, 1985). Outcrops in the central Temblor Range are lenticular (0 to 51 m (0 to 167 ft) thick) and represent a variety of marine shelf environments (Carter, 1985). The Buttonbed actually is the basal portion of the depositional cycle of the overlying Monterey Formation but, as the result of historical precedence, is grouped in the Temblor Formation where it is the only member of the fourth and youngest depositional cycle (Foss and Blaisdell, 1968; Carter, 1985).

Southeastward from Devils Den and eastward from the north-central Temblor Range, the Buttonbed Member thickens in the subsurface and can be traced at least as far as the Lost Hills, North Belridge, and the Cymric (Welport area) oil fields (pl. 4). Relatively small amounts of oil have been produced from the Buttonbed Member in the Antelope Hills, Antelope Hills North, Carneros Creek, and McDonald Anticline oil fields. Reservoirs occur at an average depth of about 650 m (2,130 ft), are 6 to 27 m (20 to 90 ft) thick, and have porosities of about 23 to 32 percent.

Sandstones that occur above the Buttonbed Member in the Gould and Devilwater Shale Members of the Monterey Formation, the Temblor (a misnomer), and Devilwater sands of local usage, have produced significant oil in the North Belridge field and minor amounts of oil or gas in the Antelope Hills, Blackwells Corner and McDonald Anticline fields (pl. 4). Reservoir depths range from about 200 to 1,500 m (650 to 4,900 ft) in these fields, but elsewhere in this part of the basin these sands have been found by drill at depths of at least 2,900 m (9,500 ft). Net reservoir thickness ranges from about 6 to 150 m (20 to 500 ft) and porosities from 25 to 30 percent. Presumably some of these sands represent the deepening marine deposits of the middle Miocene transgressive cycle of which the Buttonbed Member of the Temblor Formation was the initial proximal, shallow-marine sequence. The overall distribution and origin of these sands, especially younger ones within the Devilwater Member, remain unclear, but they must also be considered as potential oil reservoir rocks.

The members of the type Temblor Formation discussed above have not been mapped in the southern Temblor Range west and southwest of the Midway-Sunset oil field. However, unnamed sandstone units, generally not continuous over great distances, are mapped east of the Recruit Pass fault on the southwest flank of the Temblor Range as far south as the Gonyer Anticline oil field and again for about 5 km (3 mi) northwestward from state highway 33/166 southwest of the town of Maricopa (Dibblee, 1973a; Vedder, 1970; pls. 1 and 4). Some of these sandstone units have produced minor amounts of oil, after artificial fracturing, from a depth of about 530 m (1,740 ft) in the abandoned Gonyer Anticline oil field located west of the Midway-Sunset oil field (pl. 4).

Wells drilled as deep as 3,486 m (11,435 ft) in the vicinity of the Gonyer Anticline field remain in Oligocene(?) to middle Miocene Temblor rocks, but true thicknesses are obscured by complex structure (Payne, 1964).

The base of the Temblor Formation is not exposed in the southern Temblor Range where the formation is reported to be as much as 2,130 to 2,380 m (7,000 to 7,800 ft) thick (Dibblee, 1973b; Vedder, 1975). Only limited information is available about the biostratigraphy, depositional environments and provenance (and nothing about paleocurrent directions) of the Temblor in this area. According to Vedder (1975), microfaunal assemblages indicative of deep-marine environments suggest that early Miocene interbedded sandstone and shale units in and adjacent to the Temblor Range near Taft are probable correlatives of the Santos Shale and Agua Sandstone Members of the type Temblor Formation. Also, the microfauna of the upper part of the Temblor Formation in the southeastern Temblor Range indicates deposition at lower bathyal depths (Vedder, 1975; Gillespie, 1986). Petrofacies analysis of Temblor sandstones of the northern Temblor range and those of the San Emigdio Mountains to the southeast have been addressed by Bent (1985), but few Temblor sandstones from the southern Temblor Range were included, and the structural setting of rocks in this area is complicated by close proximity to the San Andreas fault.

Along the south margin of the western part of the Maricopa-Tejon subbasin in the San Emigdio Mountains, Oligocene through middle Miocene rocks are represented by the Pleito and overlying Temblor Formations (e.g., Nilsen and others, 1973). These formations are not divided into formal members in this area, but their biostratigraphy, lithofacies, and depositional environments have been studied where excellent exposures occur in the San Emigdio Mountains (Nilsen and others, 1973; DeCelles, 1986; Gillespie, 1986). Exposures extend from approximately south of the Wheeler Ridge oil field westward almost continuously to the southeast end of the Temblor Range (Dibblee, 1973a; Dibblee and Nilsen, 1973; pls. 1 and 4).

The Pleito and Temblor Formations thin eastward in the San Emigdio Mountains and partly intertongue into the nonmarine Tecuya Formation (Nilsen and others, 1973). Westward and northwestward in the San Emigdio Mountains these formations thicken and consist of progressively deeper marine sandstone, siltstone, and shale. Several transgressive-regressive cycles and periods of deformation are evident (Nilsen and others, 1973; DeCelles, 1986; Davis, 1986). As pointed out by DeCelles (1986), the east-west section exposed in the San Emigdio Mountains is approximately normal to the late Oligocene through middle Miocene paleoshoreline.

Pleito and Temblor sediment apparently were derived from south and southeast source areas and distributed across a narrow shelf and down a relatively steep slope, part of the time a stepped basin-margin and part of the time a ramped margin, to bathyal depths (DeCelles, 1986; Gillespie, 1986; Tipton, 1971). The thickness of Pleito and Temblor Formations is variable, probably because of unrecognized structural effects and(or) bathymetric relief during deposition, but generally exceeds 2,000 m (6,600 ft) in the western San Emigdio Mountains where the bottom of the Pleito is recognized (Nilsen and others, 1973; Gillespie, 1986). The Temblor presumably thickens northward into the western part of the Maricopa-Tejon subbasin and northwestward into the southern Temblor Range where its base has not been reached by drilling and is not exposed in outcrop.

Sandstones in the upper part of the Temblor Formation have produced small amounts of oil from the Capitola Park, Cienaga Canyon, and Pioneer oil fields located along the east-west trending Pioneer anticline just south of the southeast end of the Midway-Sunset oil field (Dibblee and Nilsen, 1973; pls. 1 and 4). Also, minor oil was obtained from upper Temblor rocks from the now abandoned San Emigdio field and from an abandoned well in the southeast end of the Midway-Sunset oil field. Discovered reservoirs are at average depths of 200 to 1,225 m (650 to 4,000 ft), are 15 to 300 m (50 to 1,000 ft) thick, and have estimated porosities of 20 to 30 percent.

The prospect for oil or gas reservoirs in the Temblor Formation basinward from the San Emigdio Mountains and southern Temblor Range is speculative. As shown by drilling, the Temblor Formation occurs from about 3,500 to 4,620 m (11,500 to 15,150 ft) in the North Coles Levee field just east of Elk Hills (Dunwoody, 1986), from about 5,600 m (18,375 ft) to more than 6,548 m (21,480 ft) in the Paloma oil field to the east (Emery, 1956), from about 4,500 m (14,760 ft) to more than 6,311 m (20,705 ft) the Yowlumne field just north of the San Emigdio Mountains (Land and Bright, 1978), and must occur at shallower depths between the Yowlumne field and the San Emigdio Mountains (Davis, 1986; pls. 1 and 4). Sandstones are present in the Temblor Formation (or its east-side equivalents) at these locations, but little is known about them, and they have not given up commercial quantities of oil or gas at these few sites. The recently developed thrust-fold belt models (Namson and Davis, 1988) suggest undiscovered structural traps and(or) fractured-rock reservoirs that involve Temblor-Pleito rocks may exist along the south and southwest margins of the Maricopa-Tejon subbasin.

All recognized source rocks for hydrocarbons in the San Joaquin basin, at one location or another, may have been important for the Upper Cretaceous through middle Miocene marine sandstones of this play because of the wide range of structural settings of these sandstones.

Play VII: Upper Cretaceous through Miocene Marine and Nonmarine Sandstone, Northern and Northeast Areas

This play encompasses the part of the late Mesozoic forearc basin that is located in the northern San Joaquin province, and the relatively stable northeast limb of the southerly Tertiary basin where Oligocene and younger rocks are mostly nonmarine (pl. 4). The southwest boundary of this play, corresponds approximately to the average position of the Sierra block marine shelf edge during Miocene, as defined by the 300-foot (90-m) paleoisobaths of Bandy and Arnal (1969). The northern part of this boundary corresponds approximately to the eastern limit of Neogene compressional deformation and the northeastward limit of the marine Oligo-Miocene Temblor Formation that is contained in Play VI.

The upper Cretaceous and lower Paleogene rocks of this play represent the final regressive phase of the late Mesozoic to early Paleogene forearc basin. Rocks consist principally of deep-sea fan deposits and associated lithofacies on the west side, and shallow marine to deltaic deposits on the east side (Ingersoll, 1979; Cherven, 1983). The uppermost or lower Paleogene part of the sequence consists mostly of westward and southwestward prograding slope, shelf, and deltaic facies (Hoffman, 1964; Bartow, 1987b).

The greatest thickness of these rocks is in the elongate trough just east of and parallel to the Diablo Range where, at the north end, it exceeds 5,100 m (16,700 ft) (Zoback and Wentworth, 1986) (pls. 1 and 2). The potential petroleum reservoirs are sandstone in submarine fans, slope channel deposits, prograding deltas, and shelf deposits, which came intermittently from east, north, and west sources during late Campanian through early Eocene time (Cherven, 1983; Callaway, 1964; Bartow, 1985). The distribution of these sands is complex, and stratigraphic nomenclature is only partly resolved, particularly in the pre-Upper Paleocene section (e.g., Cherven, 1983; Hoffman, 1964; Earl H. Brabb, personal communication, 1988).

Generally, the prospective sandstones are grouped in the upper part of the Panoche Formation (upper Campanian through lower Maestrichtian), Moreno Formation (upper Maestrichtian through lower Paleocene), and, north to south, the Tesla, Laguna Seca and Lodo Formations (upper Paleocene through lower Eocene). These formations include sandstones with such local usage names as Forbes, Lathrop, E, Tracy, Starkey, Blewett, Panoche (First through Fourth), Azevedo, Garza, Wheatville, Martinez, Cima, Jergins, and Weyant sands.

The upper Cretaceous through lower Eocene section described above contains a number of angular unconformities, disconformities, locally thick, condensed or missing units, transgressive-regressive cycles, and structural deformation that attest to (1) intermittent east-west compression, causing uplift and erosion, mainly on the west side, and the formation of the present-day asymmetrical basin shape, (2) lateral shifting over time of sediment entry points along the east and west sides, (3) eustatic sea-level fluctuations, and (4) beginning during Paleocene, the uplift of the Stockton arch (Callaway, 1964, 1971; Cherven, 1983; Hoffman, 1964; Bartow, 1987b).

There are also younger, mostly thin marine and nonmarine sandstones in this play. The middle Eocene Domengine Sandstone is a widespread, thin beach and shelf sand, as is the thin Nortonville sand of local usage in the upper Eocene Kreyenhagen Shale. The Canoas and Eocene sands of local usage in the Kreyenhagen Shale are locally well developed. Along the south and west boundary of the play area, north- and east-thinning wedges of Oligocene and Miocene marine formations (e.g., Temblor, Vedder, Olcese, Round Mountain, and Santa Margarita) extend into the play area, and contain shallow, marine sands. Lastly, the nonmarine section, especially the Oligocene and Miocene portion, which, in places, lies between Eocene and upper Miocene shales with source-rock potential, contains suitable reservoir sands (Zilch formation of local usage).

Despite the abundance of sandstones and relatively large area of this play, only nine small oil fields (including two abandoned ones) and five nonassociated gas fields have been discovered within the play boundaries (pl. 4). Oil has been found in sandstones of the Moreno and Lodo Formations, Domengine Sandstone, Kreyenhagen Shale, and Zilch and Santa Margarita formations of local usage. Nonassociated gas has been discovered in the Panoche, Moreno, and Lodo Formations, Domengine Sandstone, and basal sands of the Kreyenhagen Shale. Reservoirs with accumulations occur at depths of 800 to 2,800 m (2,600 to 9,200 ft), generally are 2 to 15 m (6 to 50 ft) thick, and have reported porosities of 23 to 35 percent.

Gentle anticlinal traps with stratigraphic variations and minor faulting account for most discovered fields. Simple truncated pinchouts in shelf facies (Camden field), and complex stratigraphic trapping (with structural or diagenetic control) in basinal and slope facies, such as basin-margin wedging of turbidite sands (MacPherson, 1978; Cherven, 1983), probably will predominate in future discoveries.

Petroleum source rocks and possibly long migration distances always have been a concern in this play area. Oil-prone Eocene and Miocene shales from the deeper Tertiary basin to the south and southwest presumably are the source rocks for the small quantities of oil discovered in the southern part of this play. However, McGuire (1986) reports that shales of the Moreno Formation near Coalinga are favorable oil-source rocks. Are similar Moreno shales at depth in or adjacent to the play area? Have they generated oil? Might oil be found farther north?

Cretaceous shales of the Great Valley generally are gas prone, and the gas fields just north of the province are believed to have derived their gas from the delta depocenter in the Sacramento basin (Zieglar and Spotts, 1978; Callaway and Rennie, 1988). Are the nonassociated gas fields in this play also sourced from the north? Or has there been adequate gas generation within the play boundaries? Callaway and Rennie (1988) speculate that the Cretaceous section between Fresno and Stockton is too sand rich, and the thermal gradient too low to have generated much gas. However, Wang and Munroe (1982) report relatively high geothermal gradients just east of the Diablo Range.

One area excluded from the play analysis is the "San Benito-Waltham Canyon trough" (Flynn, 1963). The portion of this so-called trough within the San Joaquin province extends northwestward from west of Coalinga and bounded on the west by the San Andreas fault zone (pl. 1) (Flynn, 1963). Although several oil seeps have been reported in this region and minor amounts of oil have been produced in the Bitterwater field (pl. 4), the potential for discovery of significant new petroleum resources is believed to be low.

PETROLEUM DEVELOPMENT

The history of commercial petroleum exploration and production in the San Joaquin basin dates back at least to the 1860's and has been summarized in numerous publications (e.g., Franks and Lambert, 1985). Discovery dates, descriptions of oil and gas reservoirs and production data are available from various sources, but especially from publications and annual reports of the California Division of Oil and Gas and the Conservation Committee of California Oil Producers. Only a brief summary of the petroleum development of the San Joaquin basin is presented here.

Cumulative production and estimated reserves of oil, condensate and natural gas totaled slightly more than 15 billion barrels at the end of 1986 after gas is converted to energy-equivalent barrels of oil (Table 2). About three-fourths of the estimated recoverable oil and condensate, and about four-fifths of the estimated recoverable natural gas had been produced at the end of 1986 (Table 2).

Table 2. Cumulative production and estimated reserves of discovered accumulations of oil and condensate, associated gas and nonassociated gas in the San Joaquin Basin at the end of 1986. Figures are rounded off from California Division of Oil and Gas (1987)

Oil and condensate (billions of barrels)		
cumulative production	9.49	74%
estimated reserves	3.39	26
total	12.88	100
Associated natural gas (trillions of ft^3)		
cumulative production	9.75	81%
estimated reserves	2.31	19
total	12.06	100
Nonassociated natural gas (trillions of ft^3)		
cumulative production	0.75	78%
estimated reserves	0.21	22
total	0.96	100
Total oil, condensate, natural gas (billions of barrels) (gas conversion: 6 Mcf = 1 BOE)		
cumulative production	11.24	75%
estimated reserves	3.81	25
total	15.05	100

The San Joaquin basin is characterized by many oil fields and reservoirs that are very structurally and(or) stratigraphically complex. Present-day understanding of these fields usually is based on a long history of exploration and development (Table 3). The complex character of many oil accumulations has resulted in a lack of uniformity of field definition. For example, oil fields like Midway-Sunset, Cymric, Round Mountain, and Mount Poso incorporate a number of separate pools and areas, while others like Bellevue and English Colony consist of single reservoirs of relatively small lateral extent. Consequently, the petroleum history of the basin is not properly described by field discovery rate and field-size distribution data because complex fields (e.g., Midway-Sunset) cannot be equated to simple fields (e.g., Bellevue) and because complex fields invariably have had discovery histories that span many decades. Individual reservoirs and areas of complex fields are better equated to simple fields.

To illustrate the above point, new field discovery rate is contrasted with the discovery rate of indivisible (simple) fields and new pools and new areas of divisible (complex) fields (Table 4). Differences are particularly significant between about 1940 and 1980 when reserve increases from discoveries of new areas and pools of existing fields exceeded those due to new field discoveries (Table 4). The large difference between the center and right-hand columns of Table 4 for recoverable oil discovered prior to 1920 is caused by the removal of pools and areas discovered after 1920 from pre-1920 complex fields. Revisions of recoverable oil of individual reservoirs over time, due to extensions and improved recovery techniques, are not apparent in Table 4 because estimates for all fields, pools, and areas are taken for a single time--the end of 1986.

During the ten-year period from 1977 through 1986, less than 50 million barrels of recoverable oil was discovered in new fields, new field areas, and new pools in the San Joaquin basin. However, during this same period, oil reserves (prior to subtraction of production) increased by 2.5 billion barrels (Department of Energy, 1978-1987) to 2.8 billion barrels (California Division of Oil and Gas, 1977-1987) due to upward revision of estimated reserves of large fields in response to reservoir extensions and production increases brought about mostly by improved and expanded recovery techniques. During this period 2.31 billion barrels of oil was produced, yet estimated reserves at the end of 1986 were 0.24 billion barrels (Department of Energy, 1978-1987) to 0.50 billion barrels (California Division of Oil and Gas, 1977-1987) higher than at the end of 1976. Further large increases in estimated reserves are expected if improved and expanded recovery techniques continue to be applied to the larger fields of the basin.

SUMMARY

This report supported the 1987 petroleum assessment of the San Joaquin basin by providing (1) a geological summary of the basin, (2) brief summaries of the thermal regime, source rocks, reservoir diagenesis and porosity, and petroleum development, and (3) definitions and descriptions of seven petroleum plays used in the assessment procedure. Many excellent papers are published that provide more detail of the subjects summarized here (see References).

Table 3. Chronological list of discovery wells of reservoirs in the Cymric oil field between 1909 and 1967 (Anderson and Land, 1969)

Completion date	Area	Pool	Present operator	Well number	M.D.B.& M.			Total depth (feet)	Initial production		
					Sec.	T.	R.		Oil (bbl/d)	Gravity (°API)	Gas (Mcf/d)
Nov. 1909	McKittrick Front	Tulare	Sun Oil Co. - DX Div.	"Old" 1	6	30	22	900	50	15	--
Apr. 1916	Welport	Tulare	Victory Oil Co.	20	26	29	21	1,405	106	13	--
Dec. 1917	McKittrick Front	Olig	Mobil Oil Corp.	"McKittrick Fee" 1	8	30	22	2,553	50	13.8	--
Nov. 1928	Sheep Springs	Etchegoin	Henry Quandt	"Kendon" 1	27	29	21	2,858	15	22	--
Feb. 1939	1-Y	Olig	Estate of F. R. Short	"Williams" 1	2	30	21	2,942	--	--	1,750
Jan. 1945	Sheep Springs	Carneros	C. C. Killingsworth	"Anderson" 2	20	29	21	3,054	200	25	300
July 1945	Welport	Carneros	Union Oil Co. of Calif.	"Anderson" 45-26	26	29	21	3,610	883	32.6	685
Oct. 1945	Welport	Oceanic	Tesoro Petroleum Corp.	"Oceanic" 1	22	29	21	4,700	956	36.9	500
Nov. 1945	Welport	Etchegoin	Union Oil Co. of Calif.	"Anderson" 56	26	29	21	3,830	40	31.7	--
Jan. 1946	Salt Creek Main	Etchegoin	Tesoro Petroleum Corp.	"Temblor" 1	17	29	21	2,920	23	11.6	--
Mar. 1946	Salt Creek Main	Carneros Unit	Tesoro Petroleum Corp. Opr.	"Temblor" 2	17	29	21	2,828	430	17	43
Mar. 1946	Welport	Point of Rocks	The Superior Oil Co.	"Woody" 77-22	22	29	21	5,340	60	50	4,000
Nov. 1946	Welport	Phacoides	Standard Oil Co. of Calif.	"Weston" 271	27	29	21	4,030	312	33.3	65
Mar. 1947	Salt Creek Main	Carneros	Standard Oil Co. of Calif.	"Anderson" 71	19	29	21	2,150	224	15.6	43
July 1947	Sheep Springs	Oceanic	E. A. Bender Opr.	"Sheep Springs" 8	17	29	21	4,903	250	43	1,000
June 1949	Salt Creek Main	Phacoides	Carneros Oil Co.	"Anderson Comm." 3	19	29	21	2,531	96	23.7	--
July 1951	Salt Creek West	Phacoides	Edco Oil Co.	"Anderson" 2	19	29	21	496	20	21.7	--
Aug. 1952	Sheep Springs	Phacoides	Tesoro Petroleum Corp.	"Cymric" M34	21	29	21	5,215	62	33.0	1,010
Jan. 1956	Welport	Agua	Standard Oil Co. of Calif.	"Weston" 382	27	29	21	3,750	290	30.3	60
Aug. 1965	McKittrick Front	Carneros	Standard Oil Co. of Calif.	536	6	30	22	8,741	907	33.3	1,194
Aug. 1965	McKittrick Front	Phacoides	Standard Oil Co. of Calif.	536	6	30	22	8,741	906	32.9	826
Aug. 1965	McKittrick Front	Oceanic	Standard Oil Co. of Calif.	536	6	30	22	8,741	890	33.5	542
Mar. 1966	Cymric Flank	Carneros	Standard Oil Co. of Calif.	512	9	30	22	11,847	1,188	38.7	1,697
Aug. 1967	Cymric Flank	Phacoides	Standard Oil Co. of Calif.	534	9	30	22	10,350	--	--	97

Table 4. Recoverable oil of San Joaquin Basin attributed to decade of discovery

Decade of Discovery	Recoverable oil of new fields expressed as percent of recoverable oil of basin[a]		Recoverable oil of new fields, areas and pools expressed as percent of recoverable oil of basin[b]	
before 1920	74%	(12)[c]	57 %	(18)[d]
1920 - 1929	11	(11)	12	(18)
1930 - 1939	10	(17)	12	(35)
1940 - 1949	3	(30)	12	(68)
1950 - 1959	1	(21)	3.2	(66)
1960 - 1969	.2	(13)	1.2	(30)
1970 - 1979	.5	(8)	2.2	(13)
1980 - 1986	.2	(5)	.2	(6)

[a] This column attributes all recoverable oil (as evaluated at end of 1986) of 117 fields to decade of discovery of first accumulation in field.

[b] This column attributes recoverable oil (as evaluated at end of 1986) of 254 indivisible fields, and new areas and pools of divisible fields, to decade of discovery. Forty-two minor oil fields, each with less than 1 MMbbls of recoverable oil and an aggregate of about 6 MMbbls, are omitted.

[c] Total number of fields discovered during decade.

[d] Total number of indivisible fields, field areas and pools discovered during decade.

Computed from published records of the California Division of Oil and Gas (1985, 1987) and the Conservation Committee of California Oil Producers (1987).

Petroleum play definition is a subjective process, and different workers may define, with equal validity, different plays based on different criteria. The criteria used here to define plays is given at the beginning of the PETROLEUM PLAYS section (p. 26). After play definition, the Nehring (1986) data base of estimated recoverable oil and gas from discovered oil and gas fields of the basin was divided into the plays. Play names and estimated recoverable oil and gas from known accumulations are given in Table 5. Later steps in the petroleum assessment procedures are beyond the purview of the authors, and the reader is referred to Houghton (1987), Crovelli (1988), and Mast (1988).

The seemingly insignificant area of the San Joaquin basin compared to other U.S. petroleum provinces belies the fact that it is one of the most important oil and gas regions of the country. If categorized as a state, the San Joaquin basin ranks behind only Texas, Alaska, Louisiana, and California in present oil production, behind only Texas, Louisiana, Oklahoma, and California in cumulative oil production through 1986, and behind only Alaska, Texas, and California in estimated reserves at the end of 1986 (Department of Energy, 1987; Oil and Gas Journal, 1987). From 1977 through 1986 the increase in estimated recoverable oil of the San Joaquin basin (due primarily to revisions, field extensions, new pools, and new field areas) is approximately equal to the <u>combined</u> increase in estimated recoverable oil over the same period of Wyoming, New Mexico, North Dakota, Montana, and Colorado (Department of Energy, 1978-1987). Among U.S. oil basins, the southern part of the San Joaquin basin ranks behind only the Los Angeles and Santa Maria basins in terms of total discovered oil-in-place per unit basin volume (T. H. McCulloh, pers. comm., 1975).

In spite of the impressive position of the San Joaquin basin among oil-producing states of the U.S., discovery of new oil fields in the basin has not been a primary contributor to increases in recoverable oil for many decades (Table 4). Callaway and Rennie (1988) have determined that 58, 28, and 14% of the cumulative oil and gas production of the basin comes from stratigraphic, anticlinal and fault types of traps, respectively. Diagenetic (Schneeflock, 1978; McCulloh, 1980), hydrodynamic (Foss, 1972; Chamberlain and Madrid, 1986), fractured rock (Hardoin, 1963; Wilson, 1979) and hybrid (Bruer, 1965; McGuire and others, 1983) traps also are present. This variety of trapping mechanisms, when coupled with the inherent stratigraphic and, in places, structural complexity of the basin, has long challenged explorationists.

Today much of the unexplored portion of the San Joaquin basin is at greater depth where few wells have been drilled (pl. 4). There are reasons to doubt that significant oil or gas resources lie at greater depths in the basin, but the potential can be investigated. Areas that require better understanding include

(a) thermal and pore-fluid pressure history of different parts of the basin
(b) distribution, richness, and maturity levels of pre-Monterey Formation source rocks in different parts of the basin
(c) chemistry and movement history of pore-fluids in different parts of the basin

Table 5. Estimated recoverable oil (including condensate) and natural gas by petroleum play expressed as percent of total estimated recoverable oil and natural gas of San Joaquin basin, based on cumulative production and estimated recoverables of discovered cumulations as of the end of 1984 (Nehring, 1986)

	Petroleum Play	Cumulative production plus estimated reserves expressed as a percent of basin total: oil and condensate	Cumulative production plus estimated reserves expressed as a percent of basin total: associated and nonassociated natural gas
I:	Uppermost Miocene to Pleistocene Marine and Nonmarine Sandstones, South-Central and Southwest Area	32%	20%
II:	Upper Miocene West- and Southwest-Sourced Channel and Turbidite Sands, Southwest Area	16	15
III:	Middle and Upper Miocene Fractured Shales and Diatomaceous Rocks	5	7
IV:	Upper Eocene to Recent Marine and Nonmarine Sandstones, Southeast Margin and Tejon Platform	20	3
V:	Upper Cretaceous(?) through Miocene East- and Southeast-Sourced Basinal Sandstones, South-Central and Southeast Area	6	14
VI:	Upper Cretaceous through Middle Miocene Marine Sandstones, Southwest Basinal Area and Areas Westward to San Andreas Fault, including Vallecitos Syncline	20	40
VII:	Upper Cretaceous through Miocene Marine and Nonmarine Sandstone, Northern and Northeast Areas	1	1

(d) types, timing and patterns of sandstone diagenesis that degrade or enhance reservoir porosity and permeability, especially at greater depths
(e) baseline profiles in several central basin boreholes of present-day bulk-density, porosity, permeability, pore water chemistry, equilibrium temperature, pore-fluid pressure and study of recovered cuttings and core

Continued improvements and refinements are needed in

(a) timing and nature of the tectonic history and structural deformation of the basin and its parts, particularly along the west and south margins
(b) depositional environments, patterns and provenances of sandstones
(c) stratigraphic and age correlations
(d) burial history (geohistory) constructions for different parts of the basin

These kinds of information will allow the explorationist to estimate (1) the probability of an adequate source of hydrocarbons and (2) the timing of source rock maturation, migration route development and primary or secondary trap formation in deep parts of the basin. Continued improvements in geophysical exploration technology, especially the use of 3-D, full-wave form, full amplitude seismic reflection studies, eventually will find any deep reservoir targets that may be present.

Significant increases in recoverable oil over the next several decades should occur, as estimated reserves of large, known fields are revised upward in response to production increases generated by pool extension and improved and expanded recovery techniques. Elk Hills, Coalinga, Cymric, and most other large fields should show significant increases. Longer term increases in recoverable oil, more than several decades into the future, will require futuristic technologies, as well as favorable economic and environmental conditions, to extract the estimated billions of barrels of (1) untapped oil residing in low permeability sandstone and shale and (2) residual oil remaining in de-energized, conventionally depleted permeable sandstone reservoirs. The likelihood of such future oil recovery can only be imagined at this time. However, San Joaquin basin may be among the most responsive to such futuristic efforts because of its impressive oil-richness and the relatively high porosity of its oil-bearing rocks.

REFERENCES CITED

Addicott, W.O., 1968, Mid-Tertiary zoogeographic and paleogeographic discontinuities across the San Andreas fault, in Dickinson, W.R., and Grantz, Arthur, eds., Proceedings of conference on geologic problems of the San Andreas fault system: Stanford University Publications, Geological Sciences, v. 11, p. 144-165.

----- 1970, Tertiary paleoclimatic trends in the San Joaquin basin, California: U.S. Geological Survey Professional Paper 644-D, 19 p.

----- 1973, Oligocene molluscan biostratigraphy and paleontology of the lower part of the type Temblor Formation, California: U.S. Geological Survey Professional Paper 791, 48 p.

Adegoke, O.S., 1969, Stratigraphy and paleontology of the marine Neogene formations of the Coalinga region, California: University of California Publication in Geological Sciences, v. 80, 241 p.

Almgren, A.A., 1978, Timing of Tertiary submarine canyons and marine cycles of deposition in the southern Sacramento Valley, California (Chap. 19), in Stanley, D.J., and Kelling, G., eds., Sedimentation in submarine canyons, fans, and trenches: Stroudsburg, Penn., Dowden, Hutchinson & Ross, p. 276-291.

American Association of Petroleum Geologists, 1975, Geothermal gradient maps: American Association of Petroleum Geologists and U.S. Geological Survey, Portfolio map areas nos. 22, 23, and 24, 3 pls.

American Association of Petroleum Geologists, 1984, Central California Region: Correlation of stratigraphic units of North America (COSUNA) project: American Association of Petroleum Geologists, Tulsa, Oklahoma.

Anderson, D.N., and Land, P.E., 1969, Cymric oil field: Summary of operations, California Oil Fields, Division of Oil and Gas, v. 55, no. 1, p. 5-21.

Anderson, J.Q., and Ellison, B.R., 1952, Coalinga oil fields, in Guidebook Field Trip Routes, Geology Oil Fields: American Association of Petroleum Geologists, Society of Economic Paleontologists and Mineralogists, Society of Exploration Geophysicists, Joint Annual Meeting, Los Angeles, March 1952, p. 176-188.

Anderson, L.W., Anders, M.H., and Ostenaa, D.A., 1982, Late Quaternary faulting and seismic hazard potential, eastern Diablo Range, California, in Hart, E.W., Hirschfeld, S.E., and Schulz, S.S., eds., Proceedings of Conference on earthquake hazards in the eastern San Francisco Bay region: California Division of Mines and Geology Special Publication 62, p. 197-206.

Arnold, R., and Anderson, R., 1910, Geology and oil resources of the Coalinga District, California: U.S. Geological Survey Bulletin 398, 354 p.

Atwater, Tanya, 1970, Implications of plate tectonics for the Cenozoic tectonic evolution of western North America: Geological Society of America Bulletin, v. 81, p. 3513-3536.

Atwater, Tanya and Molnar, Peter, 1973, Relative motion of the Pacific and North American plates deduced from sea-floor spreading in the Atlantic, Indian, and South Pacific oceans, in Kovach, R.L., and Nur, Amos, eds., Proceedings of conference on the tectonic problems of San Andreas fault system: Stanford University Publications, Geological Sciences, v. 13, p. 136-148.

Bailey, E.H., Irwin, W.P., and Jones, D.L., 1964, Franciscan and related rocks, and their significance in the geology of western California: California Division of Mines and Geology Bulletin 183, 177 p.

Bandy, O.L., and Arnal, R.E., 1969, Middle Tertiary basin development, San Joaquin Valley, California: Geological Society of America Bulletin, v. 80, p. 783-819.

Barker, C., 1972, Aquathermal pressuring--role of temperature in development of abnormal-pressure zones: American Association of Petroleum Geologists Bulletin, v. 56, no. 10, p. 2068-2071.

Barron, J.A., 1986, Paleoceanographic and tectonic controls on deposition of the Monterey Formation and related siliceous rocks in California: Palaeogeography, Palaeoclimatogy, Palaeoecology, v. 53, p. 27-45.

Bartow, J.A., 1980, Constraints on the latest movements on the Melones fault zone, Sierra Nevada foothills, California: U.S. Geological Survey Professional Paper 1126-J, p. J1-J4.

----- 1983, Map showing configuration of the basement surface, northern San Joaquin Valley, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1430, scale 1:250,000.

----- 1984, Geologic map and cross sections of the southeastern margin of the San Joaquin Valley, California: U.S. Geological Survey Miscellaneous Investigations Series Map I-1496, scale 1:125,000.

----- 1985, Map and cross sections showing Tertiary stratigraphy and structure of the northern San Joaquin Valley, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1761, scale 1:250,000.

----- 1987a, Cenozoic nonmarine sedimentation in the San Joaquin Basin, central California, in Ingersoll, R.V., and Ernst, W.G., eds., Cenozoic basin development of coastal California: Rubey Volume VI, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, p. 146-171.

----- 1987b, The Cenozoic evolution of the San Joaquin Valley, California: U.S. Geological Survey Open-File Report 87-581, 74 p., 3 pls.

Bartow, J.A., and McDougall, Kristin, 1984, Tertiary stratigraphy of the southeastern San Joaquin Valley, California: U.S. Geological Survey Bulletin 1529-J, 41 p.

Bartow, J.A., Lettis, W.R., Sonneman, H.S., and Switzer, J.R., Jr., 1985, Geologic map of the east flank of the Diablo Range from Hospital Creek to Poverty Flat, San Joaquin, Stanislaus and Merced Counties, California: U.S. Geological Survey Miscellaneous Investigations Series Map I-1656, scale 1:62,500.

Bate, M.A., 1984, Sedimentary facies and depositional environments of the Big Blue Formation between Anticline Ridge and the Domengine Ranch, in Carlson, Christine, ed., Depositional facies of sedimentary serpentinite: selected examples from the Coast Ranges, California: Society of Economic Paleontologists and Mineralogists Field Trip Guidebook no. 3, 1984 Midyear Meeting, San Jose, Calif., p. 81-85.

----- 1985, Depositional sequence of Temblor and Big Blue Formations, Coalinga anticline, California, in Graham, S.A., ed., Geology of the Temblor Formation, Western San Joaquin Basin, California: Pacific Section, Society of Economic Paleontologists and Mineralogists, Book 44, p. 69-86.

Bateman, P.C., and Wahrhaftig, Clyde, 1966, Geology of the Sierra Nevada, in Bailey, E.H., ed., Geology of northern California: California Division of Mines and Geology Bulletin 190, p. 107-172.

Benfield, A.E., 1947, A heat flow value for a well in California: American Journal of Science, v. 245, no. 1, p. 1-18.

Bent, J.V., 1985, Provenance of upper Oligocene-middle Miocene sandstones of the San Joaquin basin, California, in Graham, S.A., ed., Geology of the Temblor Formation, western San Joaquin basin, California: Society of Economic Paleontologists and Mineralogists, Pacific Section, Field Trip Guidebook, p. 97-120.

Berg, R.R., 1986, Reservoir Sandstones: Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 481 p.

Berggren, W.A., and Aubert, Jane, 1983, Paleogene benthic foraminiferal biostratigraphy and paleobathymetry of the central ranges of California, in Brabb, E.E., ed., Studies in Tertiary stratigraphy of the California Coast Ranges: U.S. Geological Survey Professional Paper 1213, p. 4-21.

Berggren, W.A., Kent, D.V., Flynn, J.J., and Van Couvering, J.A., 1985, Cenozoic geochronology: Geological Society of America Bulletin, v. 96, p. 1407-1418.

Berry, F.A.F., 1973, High fluid potentials in California Coast Ranges and their tectonic significance: American Association of Petroleum Geologists Bulletin, v. 57, no. 7, p. 1219-1249.

----- 1980, Preliminary investigation of geopressure/geothermal resources in California: Study made under contract to U.S. Geological Survey, Yousif K. Kharaka, project officer, 72 p.

Beyer, L.A., 1987, Porosity of unconsolidated sand, diatomite and fractured shale reservoirs, South Belridge and West Cat Canyon oil fields, California, in Meyer, R. F., ed., Exploration for Heavy Crude Oil and Natural Bitumen, AAPG Studies in Geology No. 25, p. 395-413.

Bilodeau, B.J., Haug, G.A., and Thurston, S. P., 1986, Oil and gas developments in west coast in 1985: American Association of Petroleum Geologists Bulletin, v. 70, no. 10, p. 1303-1314.

Blake, M.C., Jr., Campbell, R.H., Dibblee, T.W., Jr., Howell, D.G., Nilsen, T.H., Normark, W.R., Vedder, J.C., and Silver, E.A., 1978, Neogene basin formation in relation to plate-tectonic evolution of San Andreas fault system, California: American Association of Petroleum Geologists Bulletin, v. 62, p. 344-372.

Bloch, R.B., 1986, Ramp style deposition of the Oligocene marine Vedder Formation, San Joaquin Valley, California (abs.): American Association of Petroleum Geologists Bulletin, v. 70, no. 4, p. 463.

Blueford, J.R., ed., 1984, Kreyenhagen Formation and related rocks: Society of Economic Paleontologists and Mineralogists, Pacific Section, 78 p.

Bohannon, R.G., and Howell, D.G., 1982, Kinematic evolution of the junction of the San Andreas, Garlock, and Big Pine faults, California: Geology, v. 10, p. 358-363.

Boles, J.R., 1984, Secondary porosity reactions in the Stevens sandstone, San Joaquin Valley, California, in McDonald, D.A., and Surdam, R.C., eds., Clastic diagenesis: American Association of Petroleum Geologists Bulletin, Memoir 37, p. 217-224.

Boles, J.R., and Ramseyer, K., 1987, Diagenetic carbonate in Miocene sandstone reservoir, San Joaquin basin, California: American Association of Petroleum Geologists Bulletin, v. 71, no. 12, p. 1475-1487.

Brasher, J.E., Pike, J.D., Tieh, T.T., and Berg, R.R., 1982, Effects of arkosic sandstone diagenesis on reservoir rock properties (abs.): American Association of Petroleum Geologists Bulletin, v. 66, no. 5, p. 552-553.

Briggs, L.I., Jr., 1953, Geology of the Ortigalita Peak quadrangle, California: California Division of Mines and Geology Bulletin 167, 61 p.

Bruer, W.G., 1965, Edison oil field (abs.), in Pierce, R.L., ed., Geology of southern San Joaquin Valley, California, Kern River to Grapevine Canyon: American Association of Petroleum Geologists Guidebook, Pacific Section, p. 17-19.

Burford, R.O., 1965, Strain analysis across the San Andreas fault and Coast Ranges of California: Proceedings 2nd International Symposium on Recent Crustal Movements, Aulanko, Finland, p. 100-110.

Burruss, R.C., 1985, Paleo-temperatures from fluid inclusions--Advances in theory and technique (abs): American Association of Petroleum Geologists Bulletin, v. 69, no. 2, p. 241-242.

Cady, J.W., 1975, Magnetic and gravity anomalies in the Great Valley and western Sierra Nevada metamorphic belt, California: Geological Society of America Special Paper 168, 56 p.

California Division of Oil and Gas, 1985, California oil and gas fields, central California: California Department of Conservation, Division of Oil and Gas, v. 1, TR 11, 490 p.

----- 1987, 72nd Annual Report of the State Oil and Gas Supervisor, 1986: California Department of Conservation, Division of Oil and Gas, Publication No. PR06, 167 p.

Callaway, D.C., 1964, Distribution of uppermost Cretaceous sands in the Sacramento-Northern San Joaquin basin of California: San Joaquin Geological Society Selected Papers, v. 2, p. 5-18.

----- 1971, Petroleum potential of San Joaquin basin, California, in Cram, I.H., ed., Future petroleum provinces of the United States--their geology and potential: American Association of Petroleum Geologists Memoir 15, p. 239-253.

Callaway, D.C., and Rennie, E.W., Jr., 1988, San Joaquin Basin of California, in Gluskoter, H.J., Rice, D.D., Taylor, R.B. eds., Economic geology, U.S., Decade of North American Geology: Geol. Soc. America, v. P-2 (in press).

Carlson, A.J., 1931, Geothermal variations in Coalinga area, Fresno County, California: American Association of Petroleum Geologists Bulletin, v. 15, no. , p. 829-836.

Carter, J.B., 1985, Depositional environments of the type Temblor Formation, Chico Martinez Creek, Kern County, California, in Graham, S.A., ed., Geology of the Temblor Formation, western San Joaquin basin, California: Society of Economic Paleontologists and Mineralogists, Pacific Section, Field Trip Guidebook, p. 5-18.

Castle, R.O., Church, J.P., Yerkes, R.F., and Manning, J.C., 1983, Historical surface deformation near Oildale, California: U.S. Geological Survey Professional Paper 1245, 42 p.

Chamberlain, E.R., and Madrid, V.M., 1986, Influence of uplift on oil migration: Tulare heavy oil accumulations, west side San Joaquin Valley, California: American Association of Petroleum Geologists Pacific Section Convention Abstracts with Addendum, p. 45-46.

Cherven, V.B., 1983, A delta-slope-submarine fan model for Maestrichtian part of Great Valley sequence, Sacramento and San Joaquin basins, California: American Association of Petroleum Geologists Bulletin, v. 67, p. 772-816.

Christensen, M.N., 1966, Late Cenozoic crustal movements in Sierra Nevada: Geological Society of America Bulletin, v. 77, p. 163-182.

Church, H.V., Jr., and Krammes, Kenneth, co-chairmen, 1957, Correlation section across central San Joaquin Valley from San Andreas fault to Sierra Nevada foothills: American Association of Petroleum Geologists, Pacific Section.

----- 1958, Correlation sections longitudinally north-south thru (sic) central San Joaquin Valley from Rio Vista thru (sic) Riverdale (10 North) and Riverdale thru (sic) Tejon Ranch area (10 South), California: American Association of Petroleum Geologists, Pacific Section.

----- 1959, Correlation section longitudinally north-south thru (sic) westside San Joaquin Valley from Coalinga to Midway Sunset and across San Andreas fault into southeast Cuyama Valley: American Association of Petroleum Geologists, Pacific Section.

Clark, J.C., Brabb, E.E., Greene, H.G., and Ross, D.C., 1984, Geology of Point Reyes Peninsula and implications for San Gregorio fault history, in Crouch, J.K., and Bachman, S.B., eds., Tectonics and sedimentation along the California margin: Los Angeles, Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 67-86.

Clark, J.L., and Clark, M.N., 1982, Vitrinite reflectance and kerogen analysis of Miocene Monterey Formation rocks of the San Joaquin Valley, in Williams, L.A., and Graham, S.A., eds., Monterey Formation and associated coarse clastic rocks: Pacific Section Society of Economic Paleontologists and Mineralogists Guidebook, no. 25, p. 43-54.

Clarke, S.H., Jr., 1973, The Eocene Point of Rocks Sandstone--Provenance, mode of deposition, and implications for the history of offset along the San Andreas fault in central California: Berkeley, Calif., University of California, Ph.D. thesis, 302 p.

Clarke, S.H., Jr., Howell, D.G., and Nilsen, T.H., 1975, Paleogene geography of California, in Weaver, D.W., Hornaday, G.R., and Tipton, Ann, eds., Paleogene symposium and selected technical papers: Long Beach, Calif., American Association of Petroleum Geologists-Society of Economic Paleontologists and Mineralogists-Society of Exploration Geophysicists, Pacific Sections, p. 121-154.

Clarke, S.H., Jr., and Nilsen, T.H., 1973, Displacement of Eocene strata and implications for the history of offset along the San Andreas fault, central and northern California, in Kovach, R.L., and Nur, Amos, eds., Proceedings of the conference on tectonic problems of the San Andreas fault: Stanford University Publications, Geological Sciences, v. 13, p. 358-367.

Cole, M.R., and Armentrout, J.M., 1979, Neogene paleogeography of the western United States, in Armentrout, J.M., Cole, M.R., and Terbest, H., Jr., eds., Cenozoic paleogeography of the western United States: Los Angeles, Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 297-323.

Condon, M.W., 1986, Review of Vedder pool development, Kern River field, Kern County, California (abs.): American Association Petroleum Geologists Bulletin, v. 70, no. 7, p. 940.

Conservation Committee of California Oil Producers, 1987, Annual review of California oil and gas production 1986: Conservation Committee of California Oil Producers, Los Angeles, p. A-1 to M-24.

Cooley, S.A., 1985, Depositional environments of the lower and middle Miocene Temblor Formation of Reef Ridge, Fresno and Kings Counties, California, in Williams, L.A., and Graham, S.A. eds., Monterey Formation and associated coarse clastic rocks, central San Joaquin basin, California: Society of Economic Paleontologists and Mineralogists, Pacific Section, Annual Meeting, 1982, Field Trip Guidebook, p. 55-72.

Cox, Allan, and Engebretson, David, 1985, Change in motion of Pacific plate at 5 Myr BP: Nature, v. 313, p. 472-474.

Croft, M.G., 1972, Subsurface geology of the late Tertiary and Quaternary water-bearing deposits of the southern part of the San Joaquin Valley, California: U.S. Geological Survey Water-Supply Paper 1999-H, 29 p., 16 plates.

Croft, M.G., and Gordon, G.V., 1968, Geology, hydrology, and quality of water in the Hanford-Visalia area, San Joaquin Valley, California: U.S. Geological Survey Open-File Report, 63 p.

Crossey, L.J., Frost, B.R., and Surdam, R.C., 1984, Secondary porosity in laumontite-bearing sandstones, in McDonald, D.A., and Surdam, R.C., eds., Clastic diagenesis: American Association Petroleum Geologists Memoir 37, p. 225-237.

Crough, S.T., and Thompson, G.A., 1977, Upper mantle origin of the Sierra Nevada uplift: Geology, v. 5, no. 7, p. 396-399.

Crovelli, R.A., 1988, U.S. Geological Survey assessment methodology for estimation of undiscovered petroleum resources in play analysis of the United States (in preparation).

Crowell, J.C., 1987, Late Cenozoic basins of onshore southern California: complexity is the hallmark of their tectonic history, in Ernst, W.G., and Ingersoll, R.V., eds., Cenozoic basin development of coastal California (Rubey vol. 6): Englewood Cliffs, N.J., Prentice-Hall, p. 207-241.

Dalrymple, G.B., 1964, Cenozoic chronology of the Sierra Nevada, California: University of California, Publications in Geological Sciences, v. 47, 41 p.

----- 1979, Critical tables for conversion of K-Ar ages from old to new constants: Geology, v. 7, p. 558-560.

Davis, G.A., and Burchfiel, B.C., 1973, Garlock fault: An intracontinental transform structure, southern California: Geological Society of America Bulletin, v. 84, p. 1407-1422.

Davis, T.L., 1983, Late Cenozoic structure and tectonic history of the western "Big Bend" of the San Andreas fault and adjacent San Emigdio Mountains: Santa Barbara, University of California, Ph.D. thesis, 580 p.

----- 1986, A structural outline of the San Emigdio Mountains, in Davis, T.L., and Namson, J.S., eds., Geologic transect across the western Transverse Ranges: Society of Economic Paleontologists and Mineralogists, Pacific Section, Field Trip Guidebook, p. 23-32.

Davis, T.L., and Namson, J.S., eds., 1986, Geologic transect across the western Transverse Ranges: Pacific Section, Society of Economic Paleontologists and Mineralogists, Book 48, 74 p.

----- 1987, Structural Evolution of the Western Transverse Ranges: Pacific Section, Society of Economic Paleontologists and Mineralogists, Book 48A, 156 p.

Dean, J.S., 1986, Depositional model for submarine fan deposits of Vedder sandstone, eastern San Joaquin Basin (abs.): American Association of Petroleum Geologists Bulletin, v. 70, no. 4, p. 466.

DeCelles, P.G., 1986, Middle Tertiary depositional systems of the San Emidgio Range, southern California: Society of Economic Paleontologists and Mineralogists, Pacific Section, Field Trip Guidebook, 32 p.

DeLise, K.C., 1967, Biostratigraphy of the San Emigdio Formation, Kern County, California: California University Publications in Geological Sciences, v. 68, 66 p.

Department of Energy, 1978-1987, U.S. crude oil, natural gas and natural gas liquids reserves, 1977-1986 annual reports, Energy Information Administration, Office of Oil and Gas, U.S. Department of Energy, Washington, D.C., DOE/EIA-0216.

Dibblee, T.W., Jr., 1973a, Regional geologic map of San Andreas and related faults in Carrizo Plain, Temblor, Caliente, and La Panza Ranges and vicinity, California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-757, scale 1:125,000.

----- 1973b, Stratigraphy of the southern Coast Ranges near the San Andreas fault from Cholame to Maricopa, California: U.S. Geological Survey Professional Paper 764, 45 p.

----- 1979a, Geologic map of the central Diablo Range between Hollister and New Idria, San Benito, Merced, and Fresno Counties, California: U.S. Geological Survey Open-File Report 79-358, scale 1:62,500.

----- 1979b, Middle and late Cenozoic deposition and tectonics of the central Diablo Range between Hollister and New Idria, in Nilsen, T.H., and Dibblee, T.W., Jr., eds., Geology of the central Diablo Range between Hollister and New Idria, California: Geological Society of America, Cordilleran Section, Field Trip Guidebook, April 9-11, 1979, p. 56-65.

Dibblee, T.W., Jr., and Chesterman, C.W., 1953, Geology of the Breckenridge Mountain quadrangle: California Division of Mines and Geology Bulletin 168, 56 p.

Dibblee, T.W., Jr., and Nilsen, T.R., 1973, Geologic map of San Emigdio and western Tehachapi Mountains, Kern County, California: American Association of Petroleum Geologists Field Trip Guidebook, scale 1:62,500.

Dickinson, W.R., Armin, R.A., Bechvar, Nancy, Goodlin, T.C., Janecke, S.U., Mark, R.A., Norris, R.D., Radel, Gregg, and Wortman,. A.A., 1987, Geohistory analysis of rates of sediment accumulation and subsidence for selected California basins, in Ernst, W.G., and Ingersoll, R.V., eds., Cenozoic basin development of coastal California (Rubey vol. 6): Englewood Cliffs, N.J., Prentice-Hall, p. 1-23

Dickinson, W.R., Ingersoll, R.V., and Graham, S.A., 1979, Paleogene sediment dispersal and paleotectonics in northern California: Geological Society of America Bulletin, Pt. II, v. 90, p. 1458-1528.

Dickinson, W.R., and Seely, D.R., 1979, Structure and stratigraphy of forearc regions: American Association of Petroleum Geologists Bulletin, v. 63, p. 2-31.

Dickinson, W.R., and Snyder, W.S., 1979, Geometry of triple junctions related to San Andreas transform: Journal of Geophysical Research, v. 84, no. B2, p. 561-572.

Dixon, S.A., and Kirkland, D.W., 1985, Relationships of temperature to reservoir quality for feldspathic sandstones of southern California (abs.): American Association of Petroleum Geologists Bulletin Abstracts, v. 69, no. 2, p. 250.

Dunwoody, J.A., 1969, Correlation section 17, San Joaquin Valley, Kingsburg to Tejon Hills: American Association of Petroleum Geologists, Pacific Section, 1 sheet.

----- chm., 1986, Correlation section 8 (revised), south San Joaquin Valley from San Andreas fault to Sierra Nevada foothills: American Association of Petroleum Geologists, Pacific Section, 1 sheet.

Eaton, G.P., 1979, Regional geophysics, Cenozoic tectonics, and geologic resources of the Basin and Range Province and adjoining regions, in Newman, G.W., and Goode, H.D., eds., Basin and Range Symposium and Great Basin Field Conference: Rocky Mountain Association of Geologists and Utah Geological Association, p. 11-39.

Eaton, J.P., 1985a, Regional seismic background of the May 2, 1983 Coalinga earthquake, in Rymer, M.J., and Ellsworth, W.L., eds., Mechanics of the May 2, 1983 Coalinga earthquake: U.S. Geological Survey Open-File Report 85-44, p. 44-60.

----- 1985b, The May 2, 1983 Coalinga earthquake and its aftershocks: a detailed study of the hypocenter distribution and of the focal mechanisms of the larger aftershocks, in Rymer, M.J., and Ellsworth, W.L., eds., Mechanics of the May 2, 1983 Coalinga earthquake: U.S. Geological Survey Open-File Report 85-44, p. 132-201.

Edwards, E.C., 1943, Kern Front area of the Kern River oil field, in Geologic formations and economic development of the oil and gas fields of California: California Division of Mines and Geology Bulletin 118, p. 571-574.

Emery, W.B., II, 1956, The Ohio Oil Company's deep test well, Paloma oil field, Kern County, California: Drilling and Production Practice, 1955, American Petroleum Institute, p. 336-358.

Engebretson, D.C., Cox, Allan, and Gordon, R.G., 1985, Relative motions between oceanic and continental plates in the Pacific basin: Geological Society of America Special Paper 206, 59 p.

Eslinger, E., and Ranganathan, V., 1983, Diagenesis in Stevens sandstone, a Miocene deep-water turbidite in San Joaquin Valley, California, and probable interactions with surrounding siliceous shales (abs.): American Association of Petroleum Geologists Bulletin, v. 67, no. 3, p. 456-457.

Estill, W.D., 1980, Kettleman City "When you core enough, you get the very best": Selected Papers, San Joaquin Geological Society, v. 5, p. 58-66.

Fischer, P.J., 1984, An early Paleogene submarine canyon and fan system: The Meganos Formation, southern Sacramento basin, California, in Cherven, Victor, and Fischer, P.J., eds., Latest Cretaceous and early Tertiary depositional systems of the northern Diablo Range, California: Society of Economic Paleontologists and Mineralogists Field Trip Guidebook No. 3, 1984 Midyear Meeting, San Jose, Calif., p. 53-64.

Foss, C.D., 1972a, A note on the fluid level traps in the San Joaquin Valley, in Rennie, E.W., Jr., ed., Geology and oil fields, west side central San Joaquin Valley: Pacific Sections, American Association of Petroleum Geologists, Society of Exploration Geophysicists, Society of Economic Paleontologists and Mineralogists, 47th Annual Meeting, 1972 Guidebook, p. 15.

-----, 1972b, Lower Eocene to Upper Cretaceous stratigraphy, central San Joaquin Valley, in Rennie, E.W., Jr., ed., Geology and oil fields, west side central San Joaquin Valley: Pacific Sections, American Association of Petroleum Geologists, Society of Exploration Geophysicists, Society of Economic Paleontologists and Mineralogists, 47th Annual Meeting, 1972 Guidebook, p. 59-63.

-----, 1972c, A preliminary sketch of the San Joaquin Valley stratigraphic framework, in Rennie, E.W., Jr., ed., Geology and oil fields, west side central San Joaquin Valley: Pacific Sections, American Association of Petroleum Geologists, Society of Exploration Geophysicists, Society of Economic Paleontologist and Mineralogists, 47th Annual Meeting, 1972 Guidebook, p. 40-50.

Foss, C.D., and Blaisdell, R., 1968, Stratigraphy of the west side southern San Joaquin Valley, in Karp, S.A., ed., Geology and Oilfieds (sic), west side southern San Joaquin Valley, 1968 guidebook: American Association of Petroleum Geologists, Society of Exploration Geophysicists, Society of Economic Paleontologists and Mineralogists, Pacific Sections, p. 33-43.

Fox, K.E. Jr., Fleck, R.J., Curtis, G.H., and Meyer, C.H., 1985, Implications of the northwestwardly younger age of the volcanic rocks of west-central California: Geological Society of America Bulletin, v. 96, p. 647-654.

Franks, K. A., and Lambert, P. L., 1985, Early California oil, a photographic history, 1865-1940: Texas A&M University Press, College Station, 243 p.

French, R.W., 1939, Geothermal gradients in California oil wells: Drilling and Production Practice, 1939, American Petroleum Institute, p. 653-658.

Frink, J.W., and Kues, H.A., 1954, Corcoran clay--a Pleistocene lacustrine deposit in San Joaquin Valley, California: American Association of Petroleum Geologists Bulletin, v. 38, p. 2357-2371.

Fritsche, A.E., 1977, Miocene paleogeography of California, in Late Mesozoic and Cenozoic sedimentation and tectonics in California: San Joaquin Geological Society, Short Course, Bakersfield, Feb. 1977, p. 109-119.

Gale, H.S., Piper, A.M., and Thomas, H.E., 1939, Geology (of the Mokelumne area), in Piper, A.M., Gale, H.S., Thomas, H.E., and Robinson, T.W., Geology and ground-water hydrology of the Mokelumne area, California: U.S. Geological Survey Water-Supply Paper 780, p. 14-101.

Galehouse, J.S., 1967, Provenance and paleocurrents of the Paso Robles Formation, California: Geological Society of America Bulletin, v. 78, p. 951-978.

Garfunkel, Zvi, 1973, History of the San Andreas fault as a plate boundary: Geological Society of America Bulletin, v. 84, p. 2035-2042.

Gillespie, B.W., 1986, The Temblor Formation: Maricopa to the Eastern San Emigdio Mountains, Kern County, California: Stanford University Masters Thesis, 161 p.

----- 1988, Miocene Temblor Formation and related basin evolution, southwestern San Joaquin basin, California (abs.): American Association of Petroleum Geologists Bulletin, v. 72, no. 2, p. 189.

Golomkek, M.P., and Brown, L.L., 1988, Clockwise rotation of the western Mojave Desert: Geology, v. 16, no. 2, p. 126-130.

Goudkoff, P.P., 1934, Subsurface stratigraphy of Kettleman Hills oil field, California: American Association of Petroleum Geologists Bulletin, v. 18, no. 4, p. 435-475.

-----, 1945, Stratigraphic relations of Upper Cretaceous in Great Valley, California: American Association of Petroleum Geologists Bulletin, v. 29, no. 7, p. 956-1007.

Graham, S.A., 1978, Role of Salinian block in evolution of San Andreas fault system: American Association of Petroleum Geologists Bulletin, v. 62, p. 2214-2231.

-----, ed., 1985, Geology of the Temblor Formation, Western San Joaquin Basin, California: Society of Economic Paleontologists and Mineralogists, Pacific Section, 44, 202 p.

-----, 1987, Tectonic controls on petroleum occurrence in central California, in Ingersoll, R.V., and Ernst, W.G., eds., Cenozoic basin development of coastal California: Rubey Volume VI, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, p. 47-63.

Graham, S.A., and Berry, K.D., 1979, Early Eocene paleogeography of the central San Joaquin Valley: Origin of the Cantua Sandstone, in Armentrout, J.M., Cole, M.R., and TerBest, Harry, Jr., eds., Cenozoic paleogeography of the western United States: Los Angeles, Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 119-127.

Graham, S.A., Stanley, R.G., Bent, J.V., and Carter, J.B., 1986, Record of initial tectonism and total right-slip along the San Andreas fault from Oligo-Miocene strata, Santa Cruz Mountains and Temblor Range (abs.): Geological Society of America, Cordilleran Section, Abstracts with Programs, v. 18, no. 2, p. 110.

Graham, S.A., and Williams, L.A., 1985, Tectonic, depositional and diagenetic history of Monterey Formation (Miocene), central San Joaquin Basin, California: American Association of Petroleum Geologists Bulletin, v. 69, no. 3, p. 385-411.

Graham, S.A., Williams, L.A., Bate, M., and Weber, L.S., 1982, Stratigraphic and depositional framework of the Monterey Formation and associated coarse clastics of the central San Joaquin basin, in Williams, L.A., and Graham, S.A., eds., Monterey Formation and associated coarse clastic rocks, central San Joaquin basin, California: Society of Economic Paleontologists and Mineralogists, Pacific Section, Annual Meeting, 1982, Field Trip Guidebook, p. 3-16.

Grant, T.A., McCleary, J.R., and Blum, R.L., 1977, Correlation and dating of geomorphic and bedding surfaces on the east side of the San Joaquin Valley using dip, in Singer, M.J., ed., Soil development, geomorphology and Cenozoic history of the northeastern San Joaquin Valley and adjacent areas, California: American Society of Agronomy, Geological Society of America, Soil Science Society of America, Joint field section, guidebook, Davis, Univ. of Calif. Press, p. 312-218.

Greene, H.G., and Clarke, J.C., 1979, Neogene paleogeography of the Monterey Bay area, California, in Armentrout, J.M., Cole, M.R., and TerBest, H., Jr., eds., Cenozoic paleogeography of the western United States: Los Angeles, Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 277-296.

Hackel, Otto, 1966, Summary of the geology of the Great Valley, in Bailey, E.H., ed., Geology of North California: California Division of Mines and Geology Bulletin 190, p. 217-238.

Harding, T.P., 1976, Tectonic significance and hydrocarbon trapping consequences of sequential folding synchronous with San Andreas faulting, San Joaquin Valley, California: American Association of Petroleum Geologists Bulletin, v. 60, p. 356-378.

Hardoin, J.L., 1963, Cahn pool of Lost Hills field: California Division of Oil and Gas, Summary of Operations, v. 49, no. 2, p. 39-44.

Harrison, T.M., and Be, K., 1983, $^{40}Ar/^{39}Ar$ age spectrum analysis of detrital microclines from the southern San Joaquin Basin, California: An approach to determining the thermal evolution of sedimentary basins: Earth and Planetary Science Letters, v. 64, p. 244-256.

Haug, G.A., and Bilodeau, B.J., 1985, Oil and gas developments in west coast in 1984: American Association of Petroleum Geologists Bulletin, v. 69, no. 10, p. 1567-1575.

Hay, E.A., 1976, Cenozoic uplifting of the Sierra Nevada in isostatic response to the North American and Pacific plate interactions: Geology, v. 4, p. 763-766.

Heikkila, H.H., and MacLeod, G.M., 1951, Geology of Bitterwater Creek area, Kern County, California: California Division of Mines and Geology Special Report 6, 21 p.

Herd, D.G., 1979a, Neotectonics of the San Francisco Bay region, California <u>in</u> Summaries of technical reports, vol. VIII, prepared by participants in National earthquake hazards reduction program: Menlo Park, U.S. Geological Survey, p. 29-31.

----- 1979b, The San Joaquin fault zone--evidence for late Quaternary faulting along the west side of the northern San Joaquin Valley, California (abs.): Geological Society of America, Cordilleran Section, Abstracts with Programs, v. 11, no.3, p. 83.

Hill, D.P., 1982, Contemporary block tectonics: California and Nevada: Journal of Geophysical Research, v. 87, no. B7, p. 5433-5450.

Hirst, Brian, 1986, Tectonic development of the Tejon and adjacent areas, Kern County, California, <u>in</u> Structure and stratigraphy of the east side San Joaquin Valley: American Association of Petroleum Geologists, Pacific Section, Field Trip Guidebook, April 18-19, 1986, p. 2-8.

Hluza, A.G., 1960, Northeast area of Wheeler Ridge oil field: California Division of Oil and Gas, Summary of Operations--California Oil Fields, v. 46, no. 2, p. 61-67.

Hoffman, R.D., 1964, Geology of the northern San Joaquin: San Joaquin Geological Society Selected Papers, v. 2, p. 30-45.

Holzer, T.L., 1980, Faulting caused by groundwater declines, San Joaquin Valley, California: Water Resources Research, v. 16, no. 6, p. 1065-1070.

Hood, A., and Castano, J. R., 1974, Organic metamorphism: Its relationship to petroleum generation and application to studies of authigenic minerals: United Nations ESCAP, CCOP Technical Bulletin, v. 8, p. 85-118.

Hoots, H.W., Bear, T.L., and Kleinpell, W.D., 1954, Geological summary of the San Joaquin Valley, California, in Jahns, R.H., ed., Geology of southern California, Chapter 2, pt. 8: California Division of Mines and Geology Bulletin 170, p. 113-129.

Houghton, J.C., 1987, Use of field size distributions in the U.S. Geological Survey's estimates of undiscovered domestic petroleum resources (abs.): American Association of Petroleum Geologists Bulletin, v. 71, no. 5, p. 568.

Howell, D.G., Crouch, J.K., Greene, H.G., McCulloch, D.S., and Vedder, J.G., 1980, Basin development along the late Mesozoic and Cainozoic California margin: a plate tectonic margin of subduction, oblique subduction and transform tectonics, in Ballance, P.F., and Reading, H.G., eds., Sedimentation in oblique-slip mobile zones: International Association of Sedimentologists Special Publication 4, p. 43-62.

Howell, D.G., Champion, D.E., and Vedder, J.G., 1987, Terrane accretion, crustal kinematics, and basin evolution, southern California, in Ingersoll, R.V., and Ernst, W.G., eds., Cenozoic basin development of coastal California (Rubey vol. 6): Englewood Cliffs, N.J., Prentice Hall, p. 242-258.

Huber, N.K., 1981, Amount and timing of late Cenozoic uplift and tilt of the central Sierra Nevada, California--evidence from the upper San Joaquin basin: U.S. Geological Survey Professional Paper 1197, 28 p.

Huffman, O.F., 1972, Lateral displacement of upper Miocene rocks and the Neogene history of offset along the San Andreas fault in central California: Geological Society of America Bulletin, v. 83, p. 2913-2946.

Ingersoll, R.V., 1978, Paleogeography and paleotectonics of the late Mesozoic forearc basin of northern and central California, in Howell, D.G., and McDougall, K., eds., Mesozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 2, p. 471-482.

----- 1979, Evolution of the Late Cretaceous forearc basin, northern and central California: Geological Society of America Bulletin, pt. 1, v. 90, p. 813-826.

----- 1982, Triple-junction instability as cause for late Cenozoic extension and fragmentation of the western United States: Geology, v. 10, p. 621-624.

Ingle, J.C., 1981, Origin of Neogene diatomites around the north Pacific rim, in Garrison, R.E., and Douglas, R.G., eds., The Monterey Formation and related siliceous rocks of California: Los Angeles, Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 159-179.

Isaacs, C.M., 1980, Diagenesis in the Monterey Formation examined laterally along the coast near Santa Barbara, California: Stanford University unpublished Ph.D. thesis, 329 p.

----- 1981, Porosity reduction during diagenesis of the Monterey Formation, Santa Barbara coastal area, California, in Garrison, R.E. and others, eds., The Monterey Formation and related siliceous rocks of California: Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 257-271.

----- 1982, Influence of rock composition on kinetics of sillica phase changes in the Monterey Formation, Santa Barbara area, California: Geology, v. 10, p. 304-308.

----- 1985, Bulk density, grain density, and porosity determinations, chemical analyses, and X-ray diffraction evaluations of cores spanning the silica phase boundary from opal-A to opal-CT in the McLure Shale member of the Miocene Monterey Formation, Chevron APC-65 well, Thirty-five anticline area, Midway-Sunset Oil Field, Kern County, California: U.S. Geological Survey Open-File Report, 14 p.

Isaacson, K.A., and Blueford, J.R., 1984, Kreyenhagen Formation and related rocks--a history, in Blueford, J.R., ed., Kreyenhagen Formation and related rocks: Society of Economic Paleontologists and Mineralogists, Pacific Section, 1-7 p.

Jennings, C.W., 1977, Geologic map of California: California Division of Mines and Geology, scale 1:750,000.

Johnson, C.M., and O'Neil, J.R., 1984, Triple junction magmatism: a geochemical study of Neogene volcanic rocks in western California: Earth and Planetary Science Letters, v. 71, p. 241-262.

Kanter, L.R., and McWilliams, M.O., 1982, Rotation of the southernmost Sierra Nevada, California: Journal of Geophysical Research, v. 87, no. B5, p. 3819-3830.

Kappeler, K.A., Squires, R.L., and Fritsche, A.E., 1984, Transgressive marginal-marine deposits of the Avenal sandstone, Reef Ridge, central California, in Blueford, J.R., Kreyenhagen Formation and Related Rocks: Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 9-27.

Keith, S.B., 1978, Paleosubduction geometries inferred from Crateceous and Tertiary magmatic patterns in southwestern North America: Geology, v. 6, p. 516-521.

Kharaka, Y.K., and Berry, F.A.F., 1974, The influence of geological membranes on the geochemistry of subsurface waters from Miocene sediments at Kettleman North Dome, California: Water Resources Research, v. 10, no. 2, p. 313-327.

Kiser, S.C., chm., 1987, Correlation Section 25, San Joaquin Valley, California: Pacific Section, American Association of Petroleum Geologists, 1 sheet.

Kron, A., and Stix, J., 1982, Geothermal gradient map of the United States: National Geophysical Data Center, National Oceanic and Atmospheric Administration, 1:2,500,000, 2 sheets.

Kruge, M.A., 1983, Diagenesis of Miocene biogenic sediments in Lost Hills oil field, San Joaquin basin, California, in Isaacs, C.M., and Garrison, R.E., eds., Petroleum generation and occurrence in the Miocene Monterey Formation, California: Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 39-51.

Kruge, M.A., and Williams, L.A., 1982, Silica diagenesis in the Monterey Formation (Miocene) in the Lost Hills oil field, San Joaquin Valley, California, in Williams, L.A., and Graham, S.A., eds., Monterey Formation and associated coarse clastic rocks: Society of Economic Paleontologists and Mineralogists, Pacific Section, Guidebook, no. 25, p. 37-42.

Krystinik, L.F., 1980, Pore-filling cements--products of shale dewatering in upper Miocene Stevens sandstone, Elk Hills field, Kern County, California (abs.): American Association of Petroleum Geologists Bulletin, v. 64, no. 3, p. 445.

Kuespert, J.G., 1983, The depositional environment of the Miocene Temblor Formation and associated Oligo-Miocene units in the vicinity of Kettleman North Dome, San Joaquin Valley, California: Stanford, Calif., Stanford University, M.S. thesis, 105 p.

----- 1985, Depositional environments and sedimentary history of the Miocene Temblor Formation and associated Oligo-Miocene units in the vicinity of Kettleman North Dome, San Joaquin Valley, California, in Graham, S.A., ed., Geology of the Temblor Formation, western San Joaquin basin, California: Society of Economic Paleontologists and Mineralogists, Pacific Section, Field Trip Guidebook, p. 53-67.

Lachenbruch, A.H., and Sass, J.H., 1980, Heat flow and energetics of the San Andreas fault zone: Journal of Geophysical Research, v. 85, no. B11, p. 6185-6222.

LaForge, R., and Lee, W.H.K., 1982, Seismicity and tectonics of the Ortigalita fault and southeast Diablo Range, California, in Hart, E.W., Hirschfeld, S.E., and Schulz, S.S., eds., Proceedings of Conference on earthquake hazards in the eastern San Francisco Bay region: California Division of Mines and Geology Special Publication 62, p. 93-101.

Lagoe, M.B., 1986, Stratigraphic nomenclature and time-rock relationships in the Paleogene rocks of the San Emigdio Mountains, in Davis, T.L., and Namson, J.S., eds., Geologic transect across the western Transverse Ranges: Society of Economic Paleontologists and Mineralogists, Pacific Section, Field Trip Guidebook, p. 11-21.

----- 1987, Cenozoic stratigraphic framework for the San Emigdio Mountains, California, in Davis, T.L., and Namson, J.S., eds., Structural evolution of the western Transverse Ranges: Society of Economic Paleontologists and Mineralogists, Pacific Section, v. 48A, p. 85-98.

Lampley, B.E., 1986, Kerogen types and potential of source rocks of Cretaceous, Paleogene and Neogene ages from western San Joaquin Valley, California (abs.): American Association of Petroleum Geologists Bulletin, v. 70, no. 4, p. 471.

Land, P.E., and Bright, L., 1978, Yowlumne oil field: California Division of Oil and Gas Publication No. TR23, 10 p.

Larue, D.K., and Underwood, M.B., 1986, Some rock potential of Franciscan complex: The galloping gourmet and the hydrocarbon kitchen (abs.): American Association of Petroleum Geologists Bulletin, v. 70, no. 4, p. 471.

Lettis, W.R., 1982, Late Cenozoic stratigraphy and structure of the western margin of the central San Joaquin Valley, California: U.S. Geological Survey Open-File Report 82-526, 26 plates, scale 1:24,000.

----- 1985, Late Cenozoic stratigraphy and structure of the west margin of the central San Joaquin Valley, California, in Weide, D.L. ed., Soils and Quaternary geology of the southwestern United States: Geological Society of America Special Paper 203, p. 97-114.

Lipman, P.W., Prostka, H.J., and Christiansen, R.L., 1972, Cenozoic volcanism and plate-tectonic evolution of the western United States. I. Early and middle Cenozoic: Philosophical Transactions of the Royal Society of London, Series A, v. 271, p. 217-248.

Loomis, D.P., and Glazner, A.F., 1986, Middle Miocene tectonic uplift of southern San Joaquin basin, California: American Association of Petroleum Geologists Bulletin, v. 70, p. 1003-1007.

Los Angeles (City) Department of Water and Power, 1975, San Joaquin Nuclear Project, Early Site Review Report: Los Angeles, Department of Water and Power, report submitted to the U.S. Nuclear Regulatory Commission, 5 vols.

MacGowan, D.B., and Surdam, R.C., 1987, The role of carboxylic acid anions in formation waters, sandstone diagenesis and petroleum reservoir modeling (abs.): Geological Society of America, Abstracts with Program, v. 19, p. 753.

MacPherson, B.A., 1978, Sedimentation and trapping mechanism in upper Miocene Stevens and older turbidite fans of southeastern San Joaquin Valley, California: American Association of Petroleum Geologists Bulletin, v. 62, no. 11, p. 2243-2274.

Maher, J.C., Carter, R.D., and Lantz, R.J., 1975, Petroleum geology of Naval Petroleum Reserve No. 1, Elk Hills, Kern County, California: U.S. Geological Survey Professional Paper 912, 109 p.

Malloy, V.S., 1959, Lower Tertiary biostratigraphy of the California Coast Ranges: American Association of Petroleum Geologists, Tulsa, Oklahoma, 416 p.

Marchand, D.E., 1977, The Ceonzoic history of the San Joaquin Valley and adjacent Sierra Nevada as inferred from the geology and soils of the eastern San Joaquin Valley, in Singer, M.J., ed., Soil development, geomorphology and Cenozoic history of the northeastern San Joaquin Valley and adjacent areas, California: American Society of Agronomy, Geological Society of America, Soil Sciences Society of America, Joint field section, guidebook, Davis, Univ. of Calif. Press, p. 39-50.

Marchand, D.E., and Allwardt, Alan, 1978, Preliminary geologic map showing Quaternary deposits of the northeastern San Joaquin in parts of Stanislaus, Merced, Madera, Fresno, and Mariposa Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-945, scale 1:125,000.

----- 1981, Late Cenozoic stratigraphic units, northeastern San Joaquin Valley, California: U.S. Geological Survey Bulletin 1470, 70 p.

Marsh, O.T., 1960, Geology of the Orchard Peak area, California: California Division of Mines, Special Report 62, 42 p.

Mast, R.F., Dolton, G.L., Crovelli, R.A., Powers, R.B., Charpentier, R.R., Root, D.H., and Attanosi, E.D., 1988, Estimates of undiscovered recoverable oil and gas resources for the onshore and state offshore areas of the United States (abs.): American Association of Petroleum Geologists Bulletin, v. 72, no. 2, p. 218.

Mavko, B.B., and Thompson, G.A., 1983, Crustal and upper mantle structure of the northern and central Sierra Nevada: Journal of Geophysical Research, v. 88, no. B7, p. 5874-5892.

May, J.A., Yeo, R.K., and Warme, J.E., 1984, Eustatic control on synchronous stratigraphic development: Cretaceous and Eocene coastal basins along an active margin: Sedimentary Geology, v. 40, p. 131-149.

McCulloh, T.H., 1967, Mass properties of sedimentary rocks and gravimetric effects of petroleum and natural-gas reservoirs: U.S. Geological Survey Professional Paper 528-A, p. A1-A50.

McCulloh, T.H., and Cashman, S.M., and Stewart, R.J., 1978, Diagenetic baselines for interpretive reconstructions of maximum burial depths and paleotemperatures in clastic sedimentary rocks, in Oltz, D.F., ed., Low Temperature Metamorphism of Kerogen and Clay Minerals, Symposium in Geochemistry: Pacific Section, Society of Economic Mineralogists and Paleontologists, Los Angeles, p. 18-46.

McCulloh, T.H., and Fan, J. J., 1985, Burial thermal histories, vitrinite reflectance and laumontite isograd (abs.): American Association of Petroleum Geologists Bulletin, v. 69, no. 2, p. 285.

McCulloh, T.H., and Stewart, R.J., 1979, Subsurface laumontite crystallization and porosity destruction in Neogene sedimentary basins (abs.): Geological Society of America, Abstracts with Programs, v. 11, p. 475.

----- 1980, Subsurface interface between zeolitized and overlying less-altered rocks, southern San Joaquin Valley, California--configuration and implications for petroleum entrapment (abs.): American Association of Petroleum Geologists Bulletin, v. 64, no. 3, p. 446.

McElwee, C.D., 1986, Thermal basin modeling including compaction and fluid flow (abs.): EOS Transactions, American Geophysical Union, v. 67, no. 44, p. 959.

McGuire, D.J., 1986, Source rock potential of Upper Cretaceous-lower Tertiary (Maestrichtian-Danian) Moreno Formation, west-central San Joaquin Valley, California (abs.): American Association of Petroleum Geologists Bulletin, v. 70, no. 4, p. 472.

----- 1988, Stratigraphy, depositional history and petroleum source rocks of the Moreno Formation, central San Joaquin Valley, California: Stanford University, Ph.D. thesis, Stanford, California, 341 p.

McGuire, M.D., Bowersox, J.R., and Earnest, L.J., 1983, Diagenetically enhanced entrapment of hydrocarbons--Southeastern Lost Hills fractured shale pool, Kern County, California, in Isaacs, C.M., and Garrison, R.E., eds., Petroleum generation and occurrence in the Miocene Monterey Formation, California: Society of Economic Paleontologists and Mineralogists Special Publication, Pacific Section, p. 171-183.

McWilliams, Michael, and Li, Yianping, 1985, Oroclinal bending of the southern Sierra Nevada batholith: Science, v. 230, p. 172-175.

Medwedeff, D.A., and Suppe, John, 1986, Growth fault-bend folding--precise determination of kinematics, timing, and rates of folding and faulting from syntectonic sediments (abs.): Geological Society of America Abstracts with Programs, v. 18, no. 6, p. 692.

Menzie, R.J., Jr., and Horton, R.A., Jr., 1987, Diagenetic trends, secondary porosity and hydrocarbon migration in Miocene Temblor Formation arkosic sandstones, Coalinga oil field, California (abs.): Geological Society of America, Abstracts with Program, v. 19, p. 771.

Merino, E., 1975a, Diagenesis in Tertiary sandstones from Kettleman North Dome, California. I. Diagenetic mineralogy: Journal of Sedimentary Petrology, v. 45, no. 1, p. 320-336.

----- 1975b, Diagenesis in Tertiary sandstones from Kettleman North Dome, California. II. Interstitial solutions: distribution of aqueous species at 100^{o} C and chemical relation to the diagenetic mineralogy: Geochimica et Cosmochimica Acta, v. 39, no. 12, p. 1629-1645.

Milam, R.W., 1985, Biostratigraphy and sedimentation of the Eocene and Oligocene Kreyenhagen Formation, central California: Stanford, Calif., Stanford University, Ph.D. thesis, 240 p.

Miller, R.E., Green, J.H., and Davis, G.H., 1971, Geology of the compacting deposits in the Los Banos-Kettleman City subsidence area, California: U.S. Geological Survey Professional Paper 497-E, 46 p.

Miller, R.H., and Bloom, C.V., 1937, Mountain View oil field: California Division of Oil and Gas, Summary of Operations--California Oil Fields, v. 22, no. 4, p. 5-36.

Minster, J.B., and Jordan, T.H., 1984, Vector constraints on Quaternary deformation of the western United States east and west of the San Andreas fault, in Crouch, J.K., and Bachman, S.B., eds., Tectonics and sedimentation along the California margin: Los Angeles, Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 1-16.

Moore, J.G., and Dodge, F.C.W., 1980, Late Cenozoic volcanic rocks of the southern Sierra Nevada, California: I. Geology and petrology: Summary: Geological Society of America Bulletin, Pt. 1, v. 91, p. 515-518.

Moxon, I.W., 1986, Subsidence history of the San Joaquin-Sacramento Valleys: Forearc evolution coupled to convergent margin tectonics (abs.): 12th International Sedimentological Congress, 24th-30th August, 1986, Canberra, Australia, Abstracts, p. 220.

Moxon, I.W., and Graham, S.A., 1987, History and controls of subsidence in the Late-Cretaceous-Tertiary Great Valley forearc basin, California: Geology, v. 15, no. 7, p. 626-629.

Mulhern, M.E., Eacman, Jr., J.C., and Lester, G.K., 1983, Geology and oil occurrence of displaced diatomite member, Monterey Formation-McKittrick oil field, in Isaacs, C.M., and Garrison, R.E., eds., Petroleum generation and occurrence in the Miocene Monterey Formation, California: Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 17-37.

Munger, A.H., 1986, Discoveries in 1985: Pacific Oil World, v. 78, no. 1, p. 38-43.

----- 1987, Discoveries in 1986: Pacific Oil World, v. 79, no. 1, p. 40-47.

Musser, J.A., Martinez, D.R., and Ligon, J.H., 1988, Three-dimensional seismic program detailing structures in an operating oil field: American Association of Petroleum Geologists, v. 72, no. 2, p. 227.

Naeser, N.D., Naeser, C.W., and McCulloh, T.H., 1988, The application of fission track dating to the depositional and thermal history of rocks in sedimentary basins, in Naeser, N.D., and McCulloh, T.H., eds., Thermal History of Sedimentary Basins--Methods and Case Histories: Springer Verlag, New York, in press.

Namson, J.S., and Davis, T.L., 1984, Deformational history, thrust-belt structural styles and plate tectonic origin of Coast Range structures along the San Joaquin Valley, California (abs.): Geological Society of America Absracts with Programs, v. 16, no. 6, p. 607.

----- 1988, Seismically active fold and thrust belt in the San Joaquin Valley, central California: Geological Society of America Bulletin, v. 100, no. 2, p. 257-273.

Nehring, R., 1986, Significant oil and gas fields in the United States, 1986 Version: NRG Associates.

Nilsen, T.H., 1979, Early Cenozoic stratigraphy, tectonics and sedimentation of the central Diablo Range between Hollister and New Idria, in Nilsen, T.H., and Dibblee, J.W., Jr., eds., Geology of the central Diablo Range between Hollister and New Idria, California: Geological Society of America, Cordilleran Section, Field Trip Guidebook, April 9-11, 1979, p. 31-55.

----- 1984, Oligocene tectonics and sedimentation, California: Sedimentary Geology, v. 37, p. 305-336.

----- 1987a, Paleocene tectonics and sedimentation of coastal California, in Ingersoll, R.V., and Ernst, W.G., eds., Cenozoic basin development of coastal California: Rubey Volume VI, Englewood Cliffs, N.J., Prentice Hall, p. 81-123.

----- 1987b, Stratigraphy and sedimentology of the Eocene Tejon Formation, western Tehachapi and San Emigdio Mountains, California: U.S. Geological Survey Professional Paper 1268, 110 p.

Nilsen, T.H., and Clarke, S.H., Jr., 1975, Sedimentation and tectonics in the early Tertiary continental borderland of central California: U.S. Geological Survey Professional Paper 925, 64 p.

Nilsen, T.H., Dibblee, T.W., Jr., and Addicott, W.O., 1973, Lower and middle Tertiary stratigraphic units of the San Emidgio and western Tehachapi Mountains, California: U.S. Geological Survey Bulletin 1372-H, 23 p.

Nilsen, T.H., Dibblee, T.W., Jr., and Simoni, T.R., Jr., 1974, Stratigraphy and sedimentation of the Cantua Sandstone Member of the Lodo Formation, Vallecitos area, California, in Payne, M.B., chm., The Paleogene of the Panoche Creek-Cantua Creek area, central California: Pacific Section, Society of Economic Paleontologists and Mineralogists, fall field trip guidebook, p. 38-68.

Nilsen, T.H., and McKee, E.H., 1979, Paleogene paleogeography of the western United States, in U.S. Armentrout, J.M., Cole, M.R., and TerBest, H., Jr., eds., Cenozoic paleogeography of the western United States: Los Angeles, Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 257-276.

Oakeshott, G.B., 1955, The Kern County earthquakes in California's geologic history, in Oakeshott, G.B., ed., Earthquakes in Kern County, California during 1952: California Division of Mines and Geology Bulletin 171, p. 15-22.

Obradovich, J.D., and Naeser, C.W., 1981, Geochronology bearing on the age of the Monterey Formation and siliceous rocks in California, in Garrison, R.E., and Douglas, R.G., eds., The Monterey Formation and related siliceous rocks in California: Los Angeles, Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 87-95.

Oil and Gas Journal, 1987, Statistics: Oil and Gas Journal, v. 85, no. 52, p. 124.

Olson, H.C., Miller, G.E., and Bartow, J.A., 1986, Stratigraphy, paleoenvironment and depositional setting of Tertiary sediments, southeastern San Joaquin basin, in Structure and stratigraphy of the east side San Joaquin Valley: American Association of Petroleum Geologists Bulletin, Pacific Section, Field Trip Guidebook, April 18-19, 1986, p. 18-56.

Page, B.M., 1981, The southern Coast Ranges, in Ernst, W.G., ed., The geotectonic development of California (Rubey Volume 1): Englewood Cliffs, N.J., Prentice Hall, p. 329-417.

Page, B.M., and Engebretson, D.C., 1984, Correlation between the geologic record and computed plate motions for central California: Tectonics, v. 3, p. 133-155.

Page, R.W., 1986, Geology of the fresh ground-water basin of the Central Valley, California: U.S. Geological Survey Professional Paper 1401-C, 54 p.

Page, R.W., and LeBlanc, R.A., 1969, Geology, hydrology, and water quality in the Fresno area, California: U.S. Geological Survey Open-File Report, 193 p.

Palmer, C.M., and Merrill, R.D., 1982, Braided-stream and alluvial-fan depositional environments in the lower to middle Eocene Ione Formation, Madera County, California, in Ingersoll, R.V., and Woodburne, M.O., eds., Cenozoic nonmarine deposits of California and Arizona: Los Angeles, Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 1-10.

Payne, M.B., 1960, Type Panoche, Panoche Hills area, Fresno County, California, 1960 spring field trip, guidebook: Society of Economic Paleontologists and Mineralogists, Pacific Section, 18 p.

----- 1964, San Andreas fault cross section parallel along the east and west sides of the fault from Soda Lake to Santiago Creek, California: American Association of Petroleum Geologists, Pacific Section, cross section no. 7 east, 1 sheet.

Pence, J.J., 1985, Sedimentology of the Temblor Formation in the northern Temblor Range, California, in Graham, S.A., ed., Geology of the Temblor Formation, western San Joaquin basin, California: Society of Economic Paleontologists and Mineralogists, Pacific Section, Field Trip Guidebook, p. 19-34.

Perkins, J.A., 1987, Provenance of the upper Miocene and Pliocene Etchegoin Formation: Implications for paleogeography of the late Miocene of central California: U.S. Geological Survey Open-File Report 87-167, 86 p.

Phillips, F.J., Tipton, Ann, and Watkins, Rodney, 1974, Outcrop studies of the Eo-Oligocene Tumey Formation, Monocline Ridge, Fresno County, California, in The Paleogene of the Panoche Creek-Cantua Creek area: Society of Economic Paleontologists and Mineralogists, Pacific Section, Field Trip Guidebook, p. 38-68.

Phillips, R.L., 1981, Depositional environments of the Santa Margarita Formation in the Santa Cruz Mountains, California: Santa Cruz, University of California, Ph.D. thesis, 358 p.

Plescia, J.B., and Calderone, G.J., 1986, Paleomagnetic constraints on the timing and extent of rotation of the Tehachapi Mountains, California (abs.): Geological Society of America, Cordilleran Section, Abstracts with Programs, v. 18, no. 2, p. 171.

Poland, J.F., and Evenson, R.H., 1966, Hydrogeology and land subsidence, Great Central Valley, California, in Bailey, E.H., ed., Geology of northern California: California Division of Mines and Geology Bulletion 190, p. 239-247.

Poore, R.Z., 1980, Age and correlation of California Paleogene benthic foraminiferal stages: U.S. Geological Survey Professional Paper 1162-C, p. C1-C8.

Poore, R.Z., Barron, J.A., and Addicott, W.O., 1981, Biochronology of the northern Pacific Miocene: Proceedings of IGCP 114 International Workshop on Pacific Neogene Biostratigraphy, 6th International Working Group Meeting, November 25-29, 1981, Osaka Museum of Natural History, Osaka, p. 91-98.

Price, L.C., and Barker, C.E., 1985, Surpression of vitrinite reflectance in amorphous rich kerogen--A major unrecognized problem: Journal of Petroleum Geology, v. 8, no. 1, p. 59-85.

Procter, R.M., Lee, P.J., and Taylor, G.C., 1982, Methodology of resource evaluation--Petroleum Resource Assessment Workshop and Symposium, Third Circum Pacific Energy and Minerals Resource Conference, Honolulu, Hawaii (unpublished manual): Geological Society of Canada, 60 p.

Ramseyer, K., and Boles, J.R., 1986, Mixed-layer illite/smecctite minerals in Tertiary sandstones and shales, San Joaquin basin, California: Clays and Clay Minerals, v. 34, no. 2, p. 115-124.

Raymond, L.A., 1969, The stratigraphic and structural geology of the northern Lone Tree Creek and southern Tracy quadrangles: San Jose, Calif., San Jose State College (Univ.), M.S. thesis, 143 p.

Reed, R.D., 1933, Geology of California: Tulsa, Oklahoma, American Association of Petroleum Geologists, 355 p.

Reed, R.D., and Hollister, J.S., 1936, Structural evolution of southern California: Tulsa, Oklahoma, American Association of Petroleum Geologists, 157 p.

Rennie, E.W., Jr., 1972, ed., Geology and Oilfields, West Side Central San Joaquin Valley: Pacific Sections, American Association of Petroleum Geologists, Society of Exploration Geophysicists, Society of Economic Paleontologists and Mineralogists, 47th Annual Meeting, 1972, Guidebook, 102 p.

Rentschler, M.S., 1985, Structurally controlled Neogene sedimentation in the Vallecitos syncline, in Graham, S.A. ed., Geology of the Temblor Formation, western San Joaquin basin, California: Society of Economic Paleontologists and Mineralogists, Pacific Section, Field Trip Guidebook, p. 87-96.

Repenning, C.A., 1960, Geologic summary of the Central Valley of California with reference to the disposal of liquid radioactive waste: U.S. Geological Survey Trace Elements Investigation Report 769, 69 p.

Ryall, P., 1974, Upper Cantua Formation, Cantua Creek area: Gatchell or Cantua facies?: American Association of Petroleum Geologists, Society of Economic Paleontologists and Mineralogists, Pacific Section, Field Trip Guidebook, p. 85-90.

Sarna-Wojcicki, A.M., Meyer, C.E., Bowman, H.R., Hall, N.T., Russell, P.C. Woodward, M.J., and Slate, J.L., 1985, Correlation of the Rockland ash bed, a 400,000-year-old stratigraphic marker in northern California and western Nevada, and implications for middle Pleistocene paleogeography of central California: Quaternary Research, v. 23, p. 236-257.

Sass, J.H., Galanis, S.P., Jr., and Munroe, R.J., 1982, Measurement of heat flow by a downhole probe technique in the San Joaquin Valley California: U.S. Geological Survey Open-File Report 82-819, 27 p.

Sass, J.H., Lachenbruch, A.H., Munroe, R.J., Greene, G.W., and Moses, T.H., Jr., 1971, Heat flow in the western United States: Journal of Geophysical Research, v. 76, no. 26, p. 6376-6413.

Sass, J.H., and Munroe, R.J., 1974, Basic heat-flow data from the United States: U.S. Geological Survey Open-File Report 74-9, p. 3-21 - 3-67.

Schneeflock, T.R., 1978, Permeability traps in Gatchell (Eocene) sand of California: American Association of Petroleum Geologists Bulletin, v. 62, no. 5, p. 848-853.

Schwartz, D.E., Hottman, W.E., and Sears, S.O., 1981, Geology and diagenesis of Belridge diatomite and brown shale, San Joaquin Valley, California (abs.): American Association of Petroleum Geologists Bulletin, v. 65, no. 5, p. 988-989.

Scott, E.W., 1983, Petroleum potential of wilderness land in California, in Miller, B.M., ed., Petroleum Potential of Wilderness Lands in the Western United States: U.S. Geological Survey Circular 902-A-P, p. D1-D12.

Seiden, H., 1964, Kettleman Hills area, California: San Joaquin Geological Society, Selected Papers, v. 2, p. 46-53.

Slagle, L.P., 1979, Depositional systems and structures of the middle Eocene Domengine-Yokut Sandstone, Vallecitos, California: Stanford, Calif., Stanford University, M.S. thesis, 59 p.

Slemmons, D.B., 1966, Cenozoic volcanism of the central Sierra Nevada, California, in Bailey, E.H., ed., Geology of Northern California: California Division of Mines and Geology Bulletin 190, p. 199-208.

Snyder, W.S., Dickinson, W.R., and Silberman, M.L., 1976, Tectonic implications of space-time patterns of Cenozoic magmatism in the western United States: Earth and Planetary Science Letters, v. 32, p. 91-106.

Stanley, R.G., 1985, Middle Tertiary sedimentation and tectonics of the La Honda basin, central California: U.S. Geological Survey Open-File Report 85-596, 263 p.

Stein, R.S., 1985, Evidence for surface folding and subsurface fault slip from geodetic elevation changes associated with the 1983 Coalinga, California, earthquake, in Rymer, M.J., and Ellsworth, W.L., eds., Mechanics of the May 2, 1983 Coalinga earthquake: U.S. Geological Survey Open-File Report 85-44, p. 225-253.

Stein, R.S., and Thatcher, Wayne, 1981, Seismic and aseismic deformation associated with the 1952 Kern County, California earthquake and relationship to the Quaternary history of the White Wolf fault: Journal of Geophysical Research, v. 86, no. B6, p. 4913-4928.

Stosur, J.J., and David, A., 1976, Petrophysical evaluation of the diatomite formation of the Lost Hills field, California: Journal of Petroleum Technology, v. 28, p. 1138-1144.

Strubhar, M.K., Medlin, W.L., Nabi, S.M., and Andreani, F.S., 1984, Fracturing results in diatomaceous earth formations, South Belridge field, California: Journal of Petroleum Technology, v. 36, p. 495-502.

Sullivan, J.C., 1966, Kettleman North Dome oil field: California Division of Oil and Gas, Summary of Operations--California Oil Fields, v. 52, no. 1, p. 5-21.

Sullivan, J.C., and Weddle, J.R., 1960, Rio Bravo oil field: California Division of Oil and Gas, Summary of Operations--California Oil Fields, v. 46, no. 1, p. 27-39.

Teitsworth, R.A., 1964, Geology and development of the Lathrop gas field, San Joaquin County, California: San Joaquin Geological Society Selected Papers, v. 2, p. 19-29.

Thurston, S.P., Mason, T.D., and James, E.D., 1987, Oil and gas development in West Coast in 1986: American Association of Petroleum Geologists Bulletin, v. 71, no. 10B, p. 145-156.

Tieh, T.T., Berg, R.R., Popp, R.K., Brasher, J.E., and Pike, J.D., 1986, Deposition and diagenesis of upper Miocene arkoses, Yowlumne and Rio Viejo fields, Kern County, California: American Association of Petroleum Geologists Bulletin, v. 70, no. 8, p. 953-969.

Tipton, A., 1971, Oligocene faunas and biochronology in the subsurface southwest San Joaquin Valley, California: University of California, Berkeley, M.A. Thesis, 120 p.

Tipton, A., and Kleinpell, R.M., and Weaver, D.W., 1973, Oligocene biostratigraphy, San Joaquin Valley, California: California University Publications in Geological Sciences, v. 105, 81 p.

Tissot, B.P., and Welte, D.H., 1978, Petroleum Formation and Occurrence: Springer-Verlag, Berlin, 538 p.

Turner, D.L., 1970, Potassium-argon dating of Pacific Coast Miocene foraminiferal stages, in Bandy, O.L., ed., Radiometric dating and paleontologic zonation: Geological Society of America Special Paper 124, p. 91-129.

Varnes, K.L., and Dalton, G.L., 1982, Estimated areas and volumes of sedimentary rock in the United States by province--statistical background data for U.S. Geological Survey Circular 860: U.S. Geological Survey Open-File Report 82-666C, 11 p.

Vedder, J.G., 1970, Geologic map of the Wells Ranch and Elkhorn Hills quadrangles, San Luis Obispo and Kern Counties, California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-585, scale 1:24,000.

-----, 1975, Juxaposed Tertiary strata along the San Andreas fault in the Temblor and Caliente Ranges, California, in Crowell, J.C., ed., San Andreas fault in southern California, A guide to San Andreas fault from Mexico to Carrizo Plain: California Division of Mines and Geology Special Report 118, p. 234-240.

Wagner, H.M., 1981, Geochronology of the Mehrten Formation in Stanislaus County, California: Riverside, University of California, Ph.D. thesis, 385 p.

Wahrhaftig, Clyde, and Birman, J.H., 1965, The Quaternary of the Pacific mountain system in California, in Wright, H.E., Jr., and Frey, D.G., eds., The Quaternary of the United States, 7th INQUA Congress Review Volume: Princeton, Princeton University Press, p. 299-340.

Wang, J., and Munroe, R.J., 1982, Heat flow and sub-surface temperatures in the Great Valley, California: U.S. Geological Survey Open-File Report 82-844, 102 p.

Waples, D.W., 1980, Time and temperature in petroleum formation: application of Lopatin's method to petroleum exploration: American Association of Petroleum Geologists Bulletin, v. 64, no. 6, p. 916-926.

Warne, A.H., 1955, Ground fracture patterns in the southern San Joaquin Valley resulting from the Arvin-Tehachapi earthquake, in Oakeshott, D.B., ed., Earthquakes in Kern County, California during 1952: California Division of Mines and Geology Bulletin, p. 57-66.

Warren, A.D., 1983, Lower Tertiary nannoplankton biostratigraphy in the central Coast Ranges, California, in Brabb, E.E., ed., Studies in Tertiary Stratigraphy of the California Coast Ranges: U.S. Geological Survey Professional Paper 1213, p. 22-38.

Webb, G.W., 1981, Stevens and earlier Miocene turbidite sandstones, southern San Joaquin Valley, California: American Association of Petroleum Geologists Bulletin, v. 65, no. 3, p. 438-465.

Weber, G.E., 1973, Subsurface facies variations in the Metralla Sandstone Member of the Tejon Formation in the Wheeler Ridge and North Tejon oil fields, Kern County, California, in Vedder, J.G., chm., Sedimentary facies changes in Tertiary rocks--California Transverse and southern Coast Ranges: Society of Economic Paleontologists and Mineralogists Guidebook to Field Trip 2, Anaheim, Calif., p. 34-38.

Webster, C.B., and Ryall, P.L., 1972, East Coalinga Extension, Pleasant Valley and Guijarral Hills fields, in Rennie, E.W., Jr., ed., Geology and Oil-fields, West Side Central San Joaquin Valley: Pacific Sections, American Association of Petroleum Geologists, Society of Exploration Geophysicists, Society of Economic Paleontologists and Mineralogists, 47th Annual Meeting, 1972 Guidebook, p. 36-39.

Wentworth, C.M., 1985, Central California deep crustal study: U.S. Geological Survey Open-File Report 86-31, p. 98-102.

Wentworth, C.M., Blake, M.C., Jr., Jones, D.L., Walter, A.W., and Zoback, M.D., 1984, Tectonic wedging associated with emplacement of the Franciscan assemblage, California Coast Ranges, in Blake, M.C., ed., Franciscan geology of northern California: Society of Economic Paleontologists and Mineralogists, Pacific Section, v. 43, p. 163-173.

Wentworth, C.M., Walter, A.W., Bartow, J.A., and Zoback, M.D., 1983, Evidence on the tectonic setting of the 1983 Coalinga earthquakes from deep reflection and refraction profiles across the southeastern end of Kettleman Hills, in Bennett, J.H., and Sherburne, R.W., eds., The 1983 Coalinga, California earthquakes, California Division of Mines and Geology Special Paper 66, p. 113-126.

Wentworth, C.M., and Zoback, M.D., 1986, An integrated faulting model for the Coalinga earthquake: A guide to thrust deformation along the Coast Range-Great Valley boundary (abs.): EOS, v. 67, no. 44, p. 1222.

White, R.T., 1940, Eocene Yokut Sandstone north of Coalinga, California: American Association of Petroleum Geologists Bulletin, v. 24, p. 1722-1751.

Williams, L.A., 1984, Subtidal stromatolites in Monterey Formation and other organic-rich rocks as suggested source contributors to petroleum formation: American Association of Petroleum Geologists Bulletin, v. 68, no. 12, p. 1879-1893.

Williams, L.A., and Graham, S.A. eds., 1982, Monterey Formation and associated coarse clastic rocks, central San Joaquin Basin, California: Society of Economic Paleontologists and Mineralogists, Pacific Section, 95 p.

Williams, L.A., and Reimers, C., 1983, The role of bacterial mats in oxygen-deficient marine basins and coastal upwelling regimes: a preliminary report: Geology, v. 11, no. 5, p. 267-269.

Wilson, M.J., 1979, The Santos: a case history of fractured shale development: Proceedings of the California regional meeting of the Society of Petroleum Engineers, Contribution SPE 7978, 8 p.

Wood, J.R., and Hewett, T.A., 1982, Fluid convection and mass transfer in porous sandstones--a theoretical model: Geochimica et Cosmochimica Acta, v. 46, no. 10, p. 1707-1713.

Wong, I.G., and Ely, R.W., 1983, Historical seismicity and tectonics of the Coast Ranges-Sierran block boundary: implications to the 1983 Coalinga, California earthquake, in Bennett, J.H., and Sherburne, R.W., eds., The 1983 Coalinga, California earthuakes: California Division of Mines and Geology Special Publication 66, p. 89-104.

Wong, I.G., and Savage, W.U., 1983, Deep intraplate seismicity in the western Sierra Nevada, central California: Bulletin of Seismological Society of America, v. 73, p. 797-812.

Woodring, W.P., Stewart, Ralph, and Richards, R.W., 1940, Geology of the Kettleman Hills oil field, California: U.S. Geological Survey Professional Paper 195, 170 p.

Yerkes, R.F., Levine, P., and Wentworth, C.M., 1985, Abnormally high fluid pressures in the region of the Coalinga earthquakes--A preliminary report, in Proceedings of Workshop XXVII, Mechanics of the May 2, 1983, Coalinga Earthquake, 13-15 June 1984: U.S. Geological Survey Open-File Report 85-44, p. 344-375.

Young, R.J., 1968, West side oil fields, in Karp, S.E., ed., Geology and oil fields, West Side Southern San Joaquin Valley: Pacific Sections, American Association of Petroleum Geologists, Society of Exploration Geophysicists, Society of Economic Paleontologists and Mineralogists, 43rd Annual Meeting, 1968 Guidebook, p. 56-85.

Ziegler, D.L., and Spotts, J.H., 1978, Reservoir and source-bed history of Great Valley, California: American Association of Petroleum Geologists Bulletin, v. 62, no. 5, p. 813-826.

Ziegler, J.L., Frei, L.S., Wentworth, C.M., and Bartow, J.A., 1987, Structure contour map of the top of the Oligocene to middle Miocene Temblor Formation in the Kettleman Hills and Lost Hills areas, Fresno, Kings, and Kern Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1896.

Zoback, M.L., Anderson, R.E., and Thompson, G.A., 1981, Cainozoic evolution of the state of stress and style of tectonism of the Basin and Range province of the western United States: Philosophical Transactions of the Royal Society of London, Series A, v. 300, no. 1454, p. 407-434.

Zoback, M.D., and Wentworth, C.M., 1986, Crustal studies in central California using an 800-channel seismic reflection recording system, in Barazangi, M., and Brown, L., eds., Reflection Seismology: A Global Perspective: American Geophysical Union, Geodynamics Series, v. 13, p. 183-196.

Zoback, M.D., Zoback, M.L., Mount, V.S., Suppe, J., Eaton, J.P., Healy, J.H., Oppenheimer, D., Reasenberg, P., Jones, L., Raleigh, C.B., Wong, I.G., Scotti, O., and Wentworth, C., 1987, New evidence on the state of stress of the San Andreas fault system: Science, v. 238, no. 4830, p. 1105-1111.